COVER SHEET

RESPONSIBLE AGENCY: U.S. Department of Energy (DOE)

TITLE: Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada

CONTACT: For more information on this Environmental Impact Statement (EIS), write or call:

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The EIS is also available on the Internet at the Yucca Mountain Project website at *http://www.ymp.gov* and on the DOE National Environmental Policy Act (NEPA) website at *http://tis.eh.doe.gov/nepa/*.

For general information on the DOE NEPA process, write or call:

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ABSTRACT: The Proposed Action addressed in this EIS is to construct, operate and monitor, and eventually close a geologic repository at Yucca Mountain in southern Nevada for the disposal of spent nuclear fuel and high-level radioactive waste currently in storage at 72 commercial and 5 DOE sites across the United States. The EIS evaluates (1) projected impacts on the Yucca Mountain environment of the construction, operation and monitoring, and eventual closure of the geologic repository; (2) the potential long-term impacts of repository disposal of spent nuclear fuel and high-level radioactive waste; (3) the potential impacts of transporting these materials nationally and in the State of Nevada; and (4) the potential impacts of not proceeding with the Proposed Action.

PUBLIC COMMENTS: A 180-day comment period on this Draft EIS begins with the publication of the Environmental Protection Agency Notice of Availability in the *Federal Register*. DOE will consider comments received after the end of the 180-day period to the extent practicable. DOE will hold public meetings to receive comments on the Draft EIS at the times and locations to be announced in local media and a DOE Notice of Availability in the *Federal Register*. Written comments can also be submitted by U.S. mail to Wendy R. Dixon at the above address, or via the Internet at *http://www.ymp.gov*.

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Summary

ACRONYMS AND ABBREVIATIONS

To ensure a more reader-friendly document, the U.S. Department of Energy (DOE) limited the use of acronyms and abbreviations in this environmental impact statement. In addition, acronyms and abbreviations are defined the first time they are used in each chapter or appendix. The acronyms and abbreviations used in the text of this document are listed below. Acronyms and abbreviations used in tables and figures because of space limitations are listed in footnotes to the tables and figures.

BWR	boiling-water reactor
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy (also called *the Department*)
EIS	environmental impact statement
EPF	energy partition factor
FR	*Federal Register*
LCF	latent cancer fatality
MTHM	metric tons of heavy metal
NWPA	Nuclear Waste Policy Act, as amended
OCRWM	Office of Civilian Radioactive Waste Management
PM_{10}	particulate matter with an aerodynamic diameter of 10 micrometers or less
$PM_{2.5}$	particulate matter with an aerodynamic diameter of 2.5 micrometers or less
PWR	pressurized-water reactor
UFSAR	Updated Final Safety Analysis Report
USC	United States Code

UNDERSTANDING SCIENTIFIC NOTATION

DOE has used scientific notation in this EIS to express numbers that are so large or so small that they can be difficult to read or write. Scientific notation is based on the use of positive and negative powers of 10. The number written in scientific notation is expressed as the product of a number between 1 and 10 and a positive or negative power of 10. Examples include the following:

Positive Powers of 10	**Negative Powers of 10**
$10^1 = \times 1 = 10$	$10^{-1} = 1/10 = 0.1$
$10^2 = 10 \times 10 = 100$	$10^{-2} = 1/100 = 0.01$
and so on, therefore,	and so on, therefore,
$10^6 = 1{,}000{,}000$ (or 1 million)	$10^{-6} = 0.000001$ (or 1 in 1 million)

Probability is expressed as a number between 0 and 1 (0 to 100 percent likelihood of the occurrence of an event). The notation 3×10^{-6} can be read 0.000003, which means that there are three chances in 1,000,000 that the associated result (for example, a fatal cancer) will occur in the period covered by the analysis.

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OVERVIEW

The purpose of this environmental impact statement (EIS) is to provide information on potential environmental impacts that could result from a Proposed Action to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at the Yucca Mountain site. The potential repository would be located in Nye County, Nevada. The EIS also provides information on the potential environmental impacts from an alternative referred to as the No-Action Alternative, under which there would be no development of a geologic repository at Yucca Mountain.

U.S. Department of Energy Actions

The Nuclear Waste Policy Act, enacted by Congress in 1982 and amended in 1987, establishes a process leading to a decision by the Secretary of Energy on whether to recommend that the President approve Yucca Mountain for development of a geologic repository. As part of this process, the Secretary of Energy is to:

- Undertake site characterization activities at Yucca Mountain to provide information and data required to evaluate the site.
- Prepare an EIS.
- Decide whether to recommend approval of the development of a geologic repository at Yucca Mountain to the President.

The Nuclear Waste Policy Act, as amended (the EIS refers to the amended Act as the NWPA), also requires the U.S. Department of Energy (DOE) to hold hearings to provide the public in the vicinity of Yucca Mountain with opportunities to comment on the Secretary's possible recommendation of the Yucca Mountain site to the President. These hearings would be separate from the public hearings on the Draft EIS required under the National Environmental Policy Act. If, after completing the hearings and site characterization activities, the Secretary decides to recommend that the President approve the site, the Secretary will notify the Governor and legislature of the State of Nevada accordingly. No sooner than 30 days after the notification, the Secretary may submit a recommendation to the President to approve the site for development of a repository.

If the Secretary recommends the Yucca Mountain site to the President, a comprehensive statement of the basis for the recommendation, including the Final EIS, will accompany the recommendation. This Draft EIS has been prepared now so that DOE can consider the Final EIS, including the public input on the Draft EIS, in making a decision on whether to recommend the site to the President.

Presidential Recommendation and Congressional Action

If, after a recommendation by the Secretary, the President considers the site qualified for application to the U.S. Nuclear Regulatory Commission for a construction authorization, the President will submit a recommendation of the site to Congress. The Governor or legislature of Nevada may object to the site by submitting a notice of disapproval to Congress within 60 days of the President's action. If neither the Governor nor the legislature submits a notice within the 60-day period, the site designation would become effective without further action by the President or Congress. If, however, the Governor or the legislature did submit such a notice, the site would be disapproved unless, during the first 90 days of continuous session of Congress after the notice of disapproval, Congress passed a joint resolution of repository siting approval and the President signed it into law.

Actions To Be Taken After Site Designation

Once a site designation became effective, the Secretary of Energy would submit to the Nuclear Regulatory Commission a License Application, based on a particular facility design, for a construction authorization within 90 days. The NWPA requires the Commission to adopt the Final EIS to the extent practicable as part of the Commission's decisionmaking on the License Application.

Decisions Related to Potential Environmental Impacts Considered in the EIS

This EIS analyzes a Proposed Action to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. The EIS also analyzes a No-Action Alternative, under which DOE would not build a repository at the Yucca Mountain site, and spent nuclear fuel and high-level radioactive waste would remain at 72 commercial and 5 DOE sites across the United States. The No-Action Alternative is included in the EIS to provide a baseline for comparison with the Proposed Action. DOE has developed the information about the potential environmental impacts that could result from either the Proposed Action or the No-Action Alternative to inform the Secretary of Energy's determination whether to recommend Yucca Mountain as the site of this Nation's first monitored geologic repository for spent nuclear fuel and high-level radioactive waste. In making that determination, the Secretary would consider not only the potential environmental impacts identified in this EIS, but also other factors as provided in the NWPA.

As part of the Proposed Action, the EIS analyzes the potential impacts of transporting spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site from 77 sites across the United States. This analysis includes information on such matters as the comparative impacts of truck and rail transportation, alternative intermodal (rail to truck) transfer station locations, associated heavy-haul truck routes, and alternative rail transport corridors in Nevada. Although it is uncertain at this time when DOE would make any transportation-related decisions, DOE believes that the EIS provides the information necessary to make decisions regarding the basic approaches (for example, mostly rail or mostly truck shipments), as well as the choice among alternative transportation corridors. However, follow-on implementing decisions, such as selection of a specific rail alignment within a corridor, or the specific location of an intermodal transfer station or the need to upgrade the associated heavy-haul routes, would require additional field surveys, state and local government consultations, environmental and engineering analyses, and National Environmental Policy Act reviews.

S.1 The National Environmental Policy Act Process

The Department of Energy will evaluate whether to recommend to the President an action to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. An essential element of the DOE evaluation is a thorough understanding of the potential environmental impacts that could occur as a result of a decision by the President to implement the Proposed Action. The National Environmental Policy Act provides Federal agency decisionmakers with a process to consider potential environmental consequences (beneficial and adverse) of proposed actions before agencies make decisions. In following this process, DOE has prepared this *Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* to provide the necessary background, data, and analyses to help decisionmakers and the public understand the potential environmental impacts of the proposed repository.

ENVIRONMENTAL CONSEQUENCES

In its regulations implementing the procedural provisions of the National Environmental Policy Act, the Council on Environmental Quality requires that an EIS include a discussion of the *environmental consequences* of the Proposed Action and alternatives. The discussion of environmental consequences includes:

- Environmental *impacts* or *effects* (impacts are synonymous with effects under the regulations)
- Any adverse environmental impacts that cannot be avoided
- The relationship between short-term uses of the environment and the maintenance and enhancement of long-term productivity
- Any irreversible or irretrievable commitment of resources.

The NWPA addresses very specifically how the National Environmental Policy Act requirements should be applied for the proposed Yucca Mountain repository. In particular, the NWPA specifies that it is not necessary to consider in the EIS the need for a repository, alternatives to geologic disposal, or alternative sites to Yucca Mountain. Although the Act does not require an evaluation of alternatives to a repository in this EIS, DOE evaluated the No-Action Alternative to provide a baseline for comparison with the Proposed Action.

DOE is distributing this Draft EIS to the general public, including stakeholders—the organizations and individuals who have indicated an interest—and to Federal, state, local, and Tribal governments. During the comment period, organizations and individuals will be able to comment on this Draft EIS in a variety of ways (public hearings, mail, facsimile, Internet). DOE will provide information on the locations, dates, and times of the public meetings in the

COMMENTS

DOE encourages comments on the Draft Yucca Mountain Repository EIS. Please submit your comments at a public hearing on the Draft EIS or

by mail to:
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by facsimile to: 1-800-967-0739
by the Internet at: *http://www.ymp.gov*

Federal Register; in local newspapers; on radio and television stations; and on the EIS web site (*http://www.ymp.gov*).

DOE will consider timely comments it receives on the Draft EIS during its preparation of the Final EIS, which it plans to issue in 2000, and will consider comments it receives after the close of the prescribed comment period to the extent practicable.

S.2 Purpose and Need for Action and Background

S.2.1 PURPOSE AND NEED

For many years civilian and defense-related activities have produced spent nuclear fuel and high-level radioactive waste. These materials have accumulated—and continue to accumulate—at 72 commercial and 5 DOE sites across the United States. Figure S-1 shows the locations of these sites and Yucca Mountain.

In passing the Nuclear Waste Policy Act in 1982, Congress affirmed that the Federal Government is responsible for the permanent disposal of spent nuclear fuel and high-level radioactive waste. To that end, Congress has directed the Secretary of Energy to determine whether to recommend that the President approve the Yucca Mountain site for development of a repository for the permanent disposal of these materials.

S.2.2 BACKGROUND

DOE is responsible for implementing a permanent solution for the management of spent nuclear fuel and high-level radioactive waste. *Spent nuclear fuel* is fuel that has been withdrawn from a nuclear reactor following irradiation; it consists mostly of uranium, and is usually intensely radioactive because it also contains a high level of radioactive nuclear fission products. Commercial spent nuclear fuel was used in civilian nuclear reactors to produce electricity. The majority of DOE spent nuclear fuel comes from defense production reactors, naval propulsion plant reactors, test and experimental reactors. In addition to conventional uranium fuel, DOE is responsible for the disposition of weapons-usable plutonium that is surplus to national security needs. This EIS has included surplus weapons-usable plutonium that has been converted to mixed-oxide (uranium and plutonium) fuel as part of the commercial spent nuclear fuel inventory and that has been immobilized and included as part of the high-level

MATERIALS EVALUATED IN THIS EIS

Spent nuclear fuel is fuel that has been withdrawn from a reactor following irradiation.

- **Commercial** – from civilian nuclear powerplants that generate electricity (including mixed-oxide fuel)
- **DOE** – from DOE production reactors, naval reactors, test and experimental reactors, and research reactors (including some non-DOE reactors)

High-level radioactive waste is primarily waste that resulted from the chemical extraction of weapons-usable materials from the spent nuclear fuel. (Immobilized surplus weapons-usable plutonium is part of the high-level radioactive waste inventory.)

Greater-Than-Class-C waste is low level radioactive waste generated by commercial nuclear reactors that does not meet shallow land burial disposal limits.

Special-Performance-Assessment-Required waste is low-level radioactive wastes generated in DOE, production reactions, research reactions, reprocessing facilities, and research and development activities that exceed the Nuclear Regulatory Commission Class C shallow-land burial disposal limits.

Symbols do not reflect precise locations.

Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

Figure S-1. Locations of commercial and DOE sites and Yucca Mountain.

radioactive waste inventory. Mixed-oxide fuel is a mixture of uranium oxide and plutonium oxide fuel that could be used to power commercial nuclear reactors.

When the DOE production reactors were operating, they used a controlled fission process to irradiate nuclear fuel and produce materials for nuclear weapons. After the spent nuclear fuel was removed from the reactors, chemical processes extracted the weapons-usable materials from the spent nuclear fuel. This is called reprocessing. The byproduct remaining after reprocessing is *high-level radioactive waste*. High-level radioactive waste also resulted from the reprocessing of naval reactor fuels and some commercial reactor fuels, some DOE test reactor fuels, and some non-DOE research reactor fuels.

In addition to spent nuclear fuel and high-level radioactive waste, DOE is responsible for the disposal of other waste types, referred to as *Greater-Than-Class-C* and *Special-Performance-Assessment-Required* wastes. These waste types are low-level radioactive wastes that have high radionuclide concentrations. They could become eligible for disposal in a geologic repository in the future, so DOE has analyzed the cumulative environmental impacts associated with the potential disposal of these wastes in a repository at Yucca Mountain.

S.2.2.1 Legislative History

Methods to dispose of radioactive wastes have been studied since the late 1950s. In 1980, President Carter declared that the safe disposal of radioactive waste generated by both defense and civilian nuclear activities is a national responsibility. In the *Environmental Impact Statement, Management of Commercially Generated Radioactive Waste* (DOE/EIS-0046, 1980), DOE analyzed the environmental impacts that could occur if it implemented alternative strategies for the management and disposal of spent nuclear fuel. The disposal alternatives included mined geologic disposal, very deep hole waste disposal, disposal in a mined cavity that results in rock melting, island-based geologic disposal, subseabed disposal, ice sheet disposal, well injection disposal, transmutation, space disposal (for example, launching waste into orbit around the sun), and no action. The Record of Decision for that EIS, issued in 1981, announced the DOE decision to pursue the mined geologic disposal alternative.

In 1982, Congress enacted the Nuclear Waste Policy Act in recognition of the need to provide for the permanent disposal of spent nuclear fuel and high-level radioactive waste in the United States. This Act established the Federal Government's responsibility to provide permanent disposal of the Nation's spent nuclear fuel and high-level radioactive waste and set forth a process and schedule for the disposal of these materials in a geologic repository. In 1986, following the process outlined in the original Nuclear Waste Policy Act, DOE narrowed the number of potentially acceptable sites for a geologic repository to three: Deaf Smith County in Texas; the Hanford Site in Washington; and Yucca Mountain. President Reagan approved the DOE recommendation of these sites as suitable for site characterization. In 1987, Congress amended the Nuclear Waste Policy Act and directed the Secretary of Energy to characterize only Yucca Mountain as a potential location for a geologic repository, setting forth a process for the Federal Government to decide whether to designate Yucca Mountain as the site for a repository.

SITE CHARACTERIZATION OF YUCCA MOUNTAIN

DOE has an ongoing program of investigations and evaluations to assess the characteristics of Yucca Mountain as a potential monitored geologic repository and to provide information for this environmental impact statement. Data from site characterization activities have been used to describe the existing environment at the Yucca Mountain site and to assess the potential impacts of the proposed repository.

The site characterization program consists of scientific, engineering, and technical studies and activities. Site investigations and evaluations include the construction of the Exploratory Studies Facility, which is a large underground laboratory consisting of a long tunnel or *main drift* and side tunnels and rooms inside the mountain; investigations of the hydrology and geology of the site; studies of socioeconomics, cultural resources, and terrestrial ecosystems; and monitoring of air quality, meteorological, radiological, and water resource data.

S.2.2.2 Future Activities and Decisions

Decision Process for Site Recommendation. Under the NWPA, DOE is required to hold hearings in the vicinity of Yucca Mountain to provide the public with opportunities to comment on the Secretary's possible recommendation of the site to the President. If, after completing the hearings and site characterization activities, the Secretary decides to recommend that the President approve Yucca Mountain, the Secretary will notify the Governor and legislature of the State of Nevada accordingly. No sooner than 30 days after the notification, the Secretary may submit the recommendation to the President to approve the site for development of a repository. The NWPA further requires that the Secretary's recommendation to the President be based on the record of information developed through the site characterization program, as well as other sources, including the Final EIS.

DOE general guidelines (10 CFR Part 960) for assessing the suitability of multiple repository sites consider the location of valuable natural resources, hydrology, geophysics, seismic activity, atomic energy defense activities, and proximity to water supplies, populations, and public lands such as national parks and forests. In 1996, the Department proposed to amend the general guidelines to describe the process and criteria for evaluating the suitability of only the Yucca Mountain site, in accordance with the NWPA, but did not finalize that proposal. DOE has not yet made a decision whether to amend the current guidelines. As required by the NWPA, if the Secretary recommends the site, DOE will consider guidelines that are applicable at that time.

Decision Process for U.S. Nuclear Regulatory Commission Licensing. If the President and Congress approve the site, DOE will submit a License Application to the Nuclear Regulatory Commission for authorization to construct a geologic repository. The NWPA directs the Commission to adopt the Final EIS to the extent practicable in its decision on whether to issue a construction authorization and license for such a repository.

The Nuclear Regulatory Commission has issued requirements governing its licensing of DOE to construct a geologic repository and to receive and possess nuclear material at that repository (10 CFR Part 60). The Commission has stated its intention to amend these requirements as necessary to be consistent with standards that the U.S. Environmental Protection Agency is expected to promulgate for the storage and disposal of spent nuclear fuel and high-level radioactive waste at the Yucca Mountain site (40 CFR Part 197). Figure S-2 shows the sequence of past disposal decisions and projected activities.

REGULATORY STANDARDS

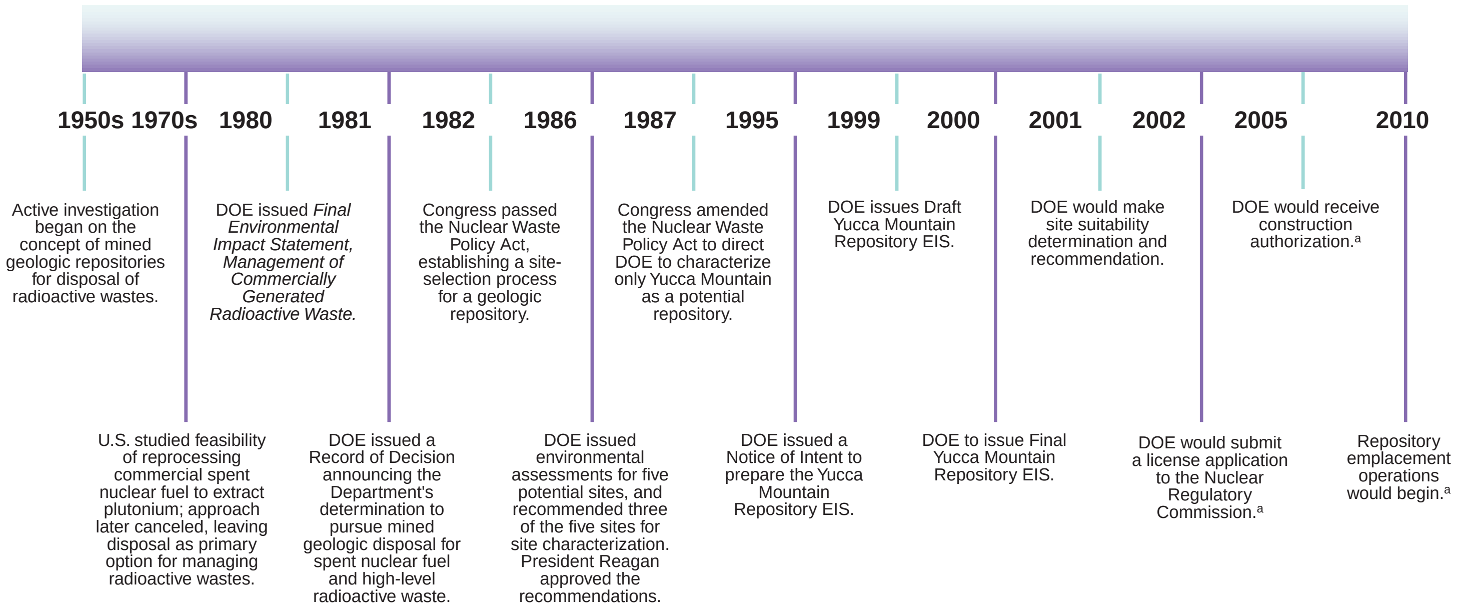
10 CFR Part 60: Nuclear Regulatory Commission regulations on the Disposal of High-Level Radioactive Waste in Geologic Repositories.

10 CFR Part 63 (Proposed February 22, 1999): Nuclear Regulatory Commission site-specific technical requirements are criteria to be used to approve or disapprove an application to construct a repository at Yucca Mountain, to receive and possess spent nuclear fuel and high-level radioactive waste at such a repository, and to close and decommission such a repository.

40 CFR Part 197 (in preparation): Environmental Protection Agency standards on the Storage and Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste.

S.2.2.3 Issues Raised in Public Scoping

DOE solicited written comments and held 15 public scoping meetings across the country between August 29 and October 24, 1995, to enable interested parties to present comments



1950s Active investigation began on the concept of mined geologic repositories for disposal of radioactive wastes.

1970s U.S. studied feasibility of reprocessing commercial spent nuclear fuel to extract plutonium; approach later canceled, leaving disposal as primary option for managing radioactive wastes.

1980 DOE issued *Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste.*

1981 DOE issued a Record of Decision announcing the Department's determination to pursue mined geologic disposal for spent nuclear fuel and high-level radioactive waste.

1982 Congress passed the Nuclear Waste Policy Act, establishing a site-selection process for a geologic repository.

1986 DOE issued environmental assessments for five potential sites, and recommended three of the five sites for site characterization. President Reagan approved the recommendations.

1987 Congress amended the Nuclear Waste Policy Act to direct DOE to characterize only Yucca Mountain as a potential repository.

1995 DOE issued a Notice of Intent to prepare the Yucca Mountain Repository EIS.

1999 DOE issues Draft Yucca Mountain Repository EIS.

2000 DOE to issue Final Yucca Mountain Repository EIS.

2001 DOE would make site suitability determination and recommendation.

2002 DOE would submit a license application to the Nuclear Regulatory Commission.[a]

2005 DOE would receive construction authorization.[a]

2010 Repository emplacement operations would begin.[a]

a. If Yucca Mountain is approved.

Figure S-2. Sequence of past disposal decisions and possible future repository activities.

on the scope of this EIS. During the public scoping process, a number of commenters asked that the EIS discuss the history of the Yucca Mountain site characterization program and requirements of the NWPA, address DOE's responsibility to begin accepting waste in 1998, describe the potential decisions that the EIS would support, and examine activities other than construction, operation and monitoring, and closure of a repository at Yucca Mountain. Other comments raised during public scoping addressed the consistency of the proposed repository with existing land uses, effects of earthquakes and volcanism, health and safety impacts, long-term impacts, and sabotage. In response to the public's input, DOE included discussions and analysis of these issues in the EIS.

DOE also received comments noting that the nation will have more than 70,000 metric tons of heavy metal (MTHM) of spent nuclear fuel and high-level radioactive waste, although the NWPA directs that the maximum amount allowed for repository disposal is 70,000 MTHM of these materials until a second repository is in operation. Commenters encouraged DOE to evaluate the disposal of the entire anticipated inventory of spent nuclear fuel and high-level radioactive waste and other waste types that might also require permanent isolation. For this reason, the EIS analyzes cumulative environmental impacts that could occur from the disposal at Yucca Mountain of the country's total projected inventory of spent nuclear fuel and high-level radioactive waste, as well as Greater-Than-Class C and Special Performance Assessment Required waste. In response to other public scoping comments, DOE added an additional transportation corridor and route in Nevada to the analysis.

DEFINITION OF
METRIC TONS OF HEAVY METAL

Quantities of spent nuclear fuel are traditionally expressed in terms of *metric tons of heavy metal* (typically uranium), without the inclusion of other materials such as cladding (the tubes containing the fuel) and structural materials. A metric ton is 1,000 kilograms (1.1 tons or 2,200 pounds). Uranium and other metals in spent nuclear fuel (such as thorium and plutonium) are called *heavy metals* because they are extremely dense; that is, they have high weights per unit volume. One metric ton of heavy metal disposed of as spent nuclear fuel would fill a space approximately the size of a typical household refrigerator.

Many other public scoping comments presented views and concerns not related to the scope or content of the Proposed Action. Examples of these comments include statements in general support of or opposition to a repository at Yucca Mountain, geologic repositories in general, and nuclear power; lack of public confidence in the Yucca Mountain program; perceived inequities and political aspects of the siting process by which Congress selected Yucca Mountain for further study; the constitutional basis for waste disposal in Nevada; perceived psychological costs or effects; risk perception and stigmatization; legal issues involving Native American land claims and treaty rights; and unrelated DOE activities. DOE considered and recorded these concerns, but has not included analyses of these issues in the EIS.

S.3 Proposed Action and No-Action Alternative

S.3.1 PROPOSED ACTION

Under the Proposed Action, DOE would construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. The Proposed Action would include the transportation of spent nuclear fuel and high-level radioactive waste from commercial and DOE sites to the Yucca Mountain site.

DOE would dispose of spent nuclear fuel and high-level radioactive waste in the repository using the natural geologic features of the mountain and engineered barriers as a total system to ensure the long-term isolation of the materials from the accessible environment. DOE would build the repository inside Yucca Mountain between 200 meters and 425 meters (660 and 1,400 feet) below the surface and between 175 and 365 meters (570 and 1,200 feet) above the water table. Figure S-3 shows the location of the proposed repository at Yucca Mountain.

In addition, the Proposed Action would include the use of active institutional controls (controlled access, inspection, and maintenance, etc.) through the end of the closure period, and the use of passive institutional controls (markers, engineered barriers, etc.) after the completion of closure. The purpose of the passive institutional controls would be to prevent inadvertent intrusion by and exposures to members of the public.

PREFERRED ALTERNATIVE

DOE's preferred alternative is to proceed with the Proposed Action to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. The analyses in this EIS did not identify any potential environmental impacts that would be a basis for not proceeding with the Proposed Action. DOE has not chosen any mode, corridor, or route as preferred at this time. It has, however, designated the Caliente-Chalk Mountain rail corridor and heavy-haul route as "nonpreferred alternatives."

S.3.1.1 Repository and Waste Package Design

The repository would be a large underground excavation with a number of interconnecting tunnels (called drifts) that DOE would use for waste emplacement. Figure S-4 shows the proposed repository concept.

DOE would receive materials at the repository in one of three configurations: uncanistered fuel (spent nuclear fuel placed directly in a shipping cask), dual-purpose canisters (containment vessel structures designed to store and transport commercial spent nuclear fuel), or disposable canisters (canisters for spent nuclear fuel or high-level radioactive waste with multiple specialized overpacks to enable their storage, transportation, and emplacement in a repository). DOE cannot establish the particular combination of uncanistered fuel, dual-purpose canisters, or disposable canisters it would receive at a repository because the commercial and DOE sites will determine the canister type they will use. For that reason, the Department analyzed two scenarios [uncanistered and canistered (including dual-purpose canisters and disposable canisters)] that cover the possible range of repository and transportation impacts to human health and the environment.

NATURAL AND ENGINEERED FEATURES

Water is the primary means by which radionuclides disposed of at Yucca Mountain could reach the accessible environment. The natural features of the very dry climate, large distance to the water table, and geology of the site would act to limit the amount of water that entered the repository. The engineered features, including waste packages made from corrosion-resistant material, would deter releases of radioactive material, even in the presence of any water that reached the emplacement area.

Material received at the repository would be unloaded from the shipping casks and placed in disposal containers that would then be sealed. The sealed disposal containers are called *waste packages*. Remote-controlled handling vehicles would place the waste packages in emplacement drifts.

According to the Viability Assessment reference design (that is, the repository design used for purposes of analysis in this EIS), the waste packages would have two layers: a structurally strong outer layer of carbon steel about 10 centimeters (4 inches) thick, and a corrosion-resistant inner layer of high-nickel alloy (Alloy-22) about 2 centimeters (0.8 inch) thick. These two layers would work together to help

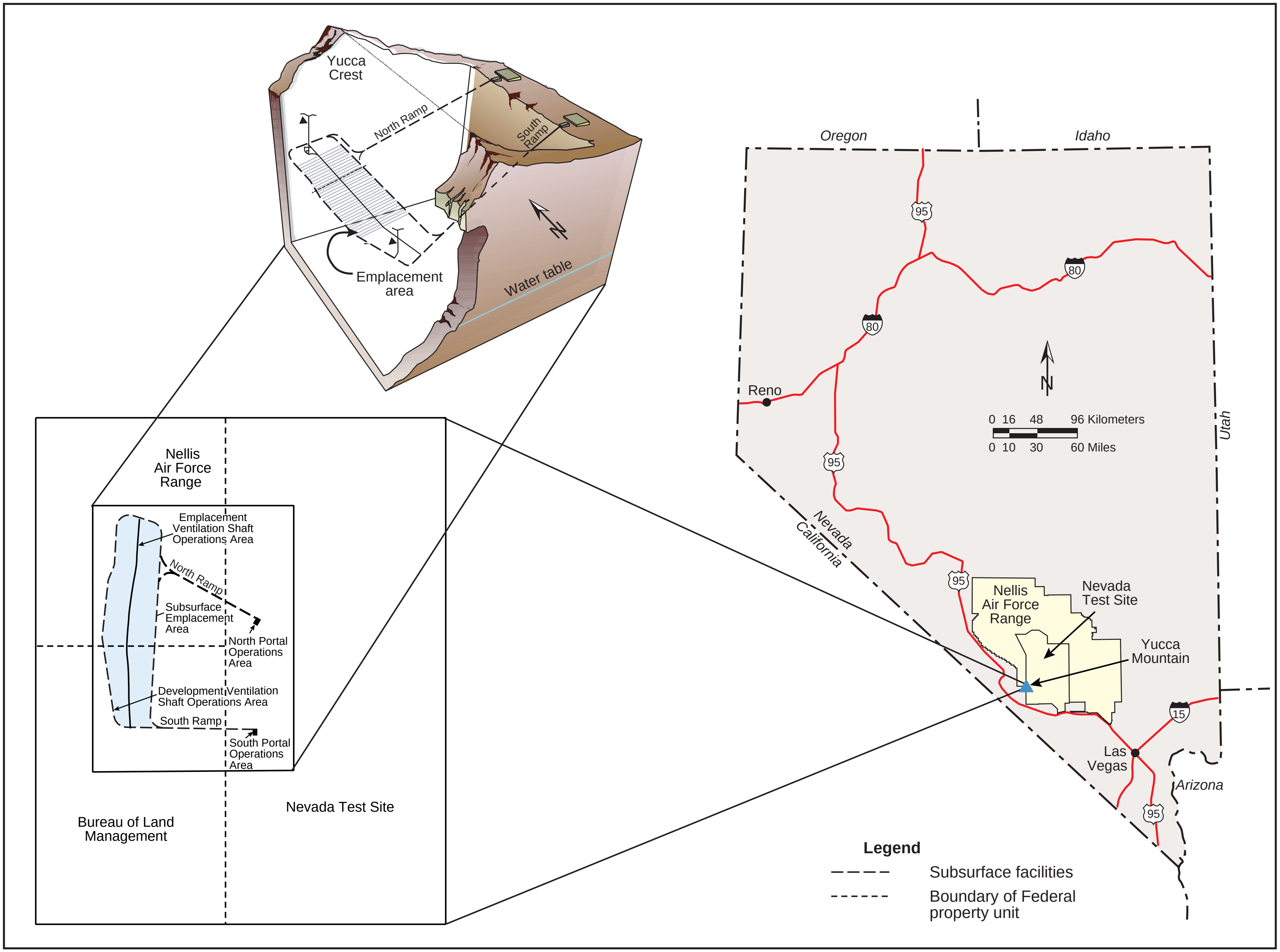


Figure S-3. Location of the proposed repository at Yucca Mountain.

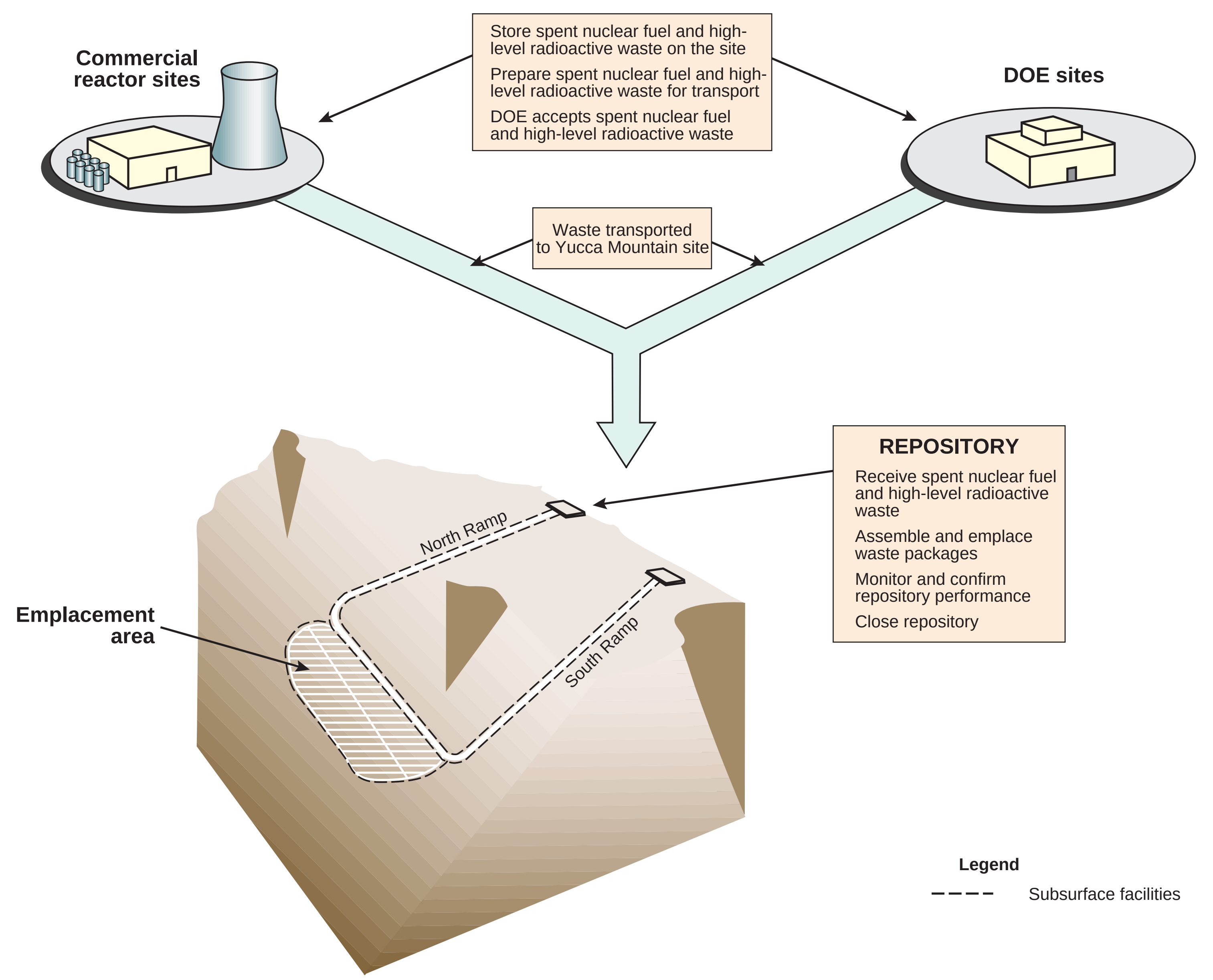


Figure S-4. Spent nuclear fuel and high-level radioactive waste handling, transportation, and disposal.

DEFINITIONS OF PACKAGING TERMS

Shipping cask: A thick-walled vessel that meets applicable regulatory requirements for shipping spent nuclear fuel or high-level radioactive waste.

Canister: A thin-walled metal vessel used to hold spent nuclear fuel assemblies or solidified high-level radioactive waste.

Dual-purpose canister: A canister suitable for storing (in a storage facility) and shipping (in a shipping cask) spent nuclear fuel assemblies. At the repository, dual-purpose canisters would be removed from the shipping cask and opened. The spent nuclear fuel assemblies would be removed from the canister and placed in a disposal container. The opened canister would be recycled or disposed of offsite as low-level radioactive waste.

Disposable canister: A canister for spent nuclear fuel assemblies or solidified high-level radioactive waste suitable for storage, shipping, and disposal. At the repository, the disposable canister would be removed from the shipping cask and placed directly in a disposal container.

Uncanistered spent nuclear fuel: Fuel placed directly into storage canisters or shipping casks without first being placed in a canister. At the repository, spent nuclear fuel assemblies would be removed from the shipping cask and placed in a disposal container.

Disposal container: A container for spent nuclear fuel and high-level radioactive waste consisting of the barrier materials and internal components. The filled, sealed, and tested disposal container is referred to as the *waste package*, which would be emplaced in the repository.

Waste package: The filled, sealed, and tested disposal container that would be emplaced in the repository.

preserve the integrity of the waste package for thousands of years. The waste packages would be the primary part of an engineered barrier system in the mountain. This system would, in combination with the natural features of the site, help retard the release of radioactive material to the accessible environment for long periods.

Under the Proposed Action, DOE would emplace 10,000 to 11,000 waste packages containing no more than 70,000 MTHM of spent nuclear fuel and high-level radioactive waste in the repository. Of that amount, 63,000 MTHM would be spent nuclear fuel assemblies that would be shipped from commercial sites to the repository. The remaining 7,000 MTHM would consist of about 2,333 MTHM of DOE spent nuclear fuel and high-level radioactive waste currently estimated to be approximately 8,315 canisters (the equivalent of 4,667 MTHM) that DOE would ship to the repository from DOE sites.

To determine the number of canisters of high-level radioactive waste included in the Proposed Action waste inventory, DOE used 0.5 MTHM per canister of defense high-level radioactive waste. DOE has used the 0.5-MTHM-per-canister approach since 1985. Using a different approach would change the number of canisters of high-level radioactive waste in the Proposed Action. Regardless of the number of canisters, the impacts of the analysis would not significantly change because long-term repository performance results are determined by the spent nuclear fuel inventory. In addition, the EIS analyzes the impacts from the entire inventory of high-level radioactive waste in the cumulative impacts analysis.

The inventory includes approximately 50 MTHM of surplus weapons-usable plutonium. At present, DOE expects that approximately 32 MTHM of the plutonium would be converted into mixed-oxide fuel, which is included as part of the commercial spent nuclear fuel inventory. DOE expects the remaining approximately 18 MTHM of plutonium to be immobilized and included in the high-level radioactive waste inventory.

Figure S-5 shows potential waste package designs for spent nuclear fuel and high-level radioactive waste. Figure S-6 shows waste packages in an emplacement drift.

S.3.1.2 Performance Confirmation, Construction, Operation and Monitoring, and Closure

DOE would construct and operate surface facilities at the repository site to receive, prepare, and package spent nuclear fuel and high-level radioactive waste for emplacement in underground drifts. The surface and subsurface facilities developed for site characterization activities at Yucca Mountain would be incorporated into the repository design to the extent practicable. Figures S-7 and S-8 show conceptual designs of the surface and subsurface facilities, respectively. Figure S-9 shows the sequence for repository development at Yucca Mountain.

THERMAL LOAD

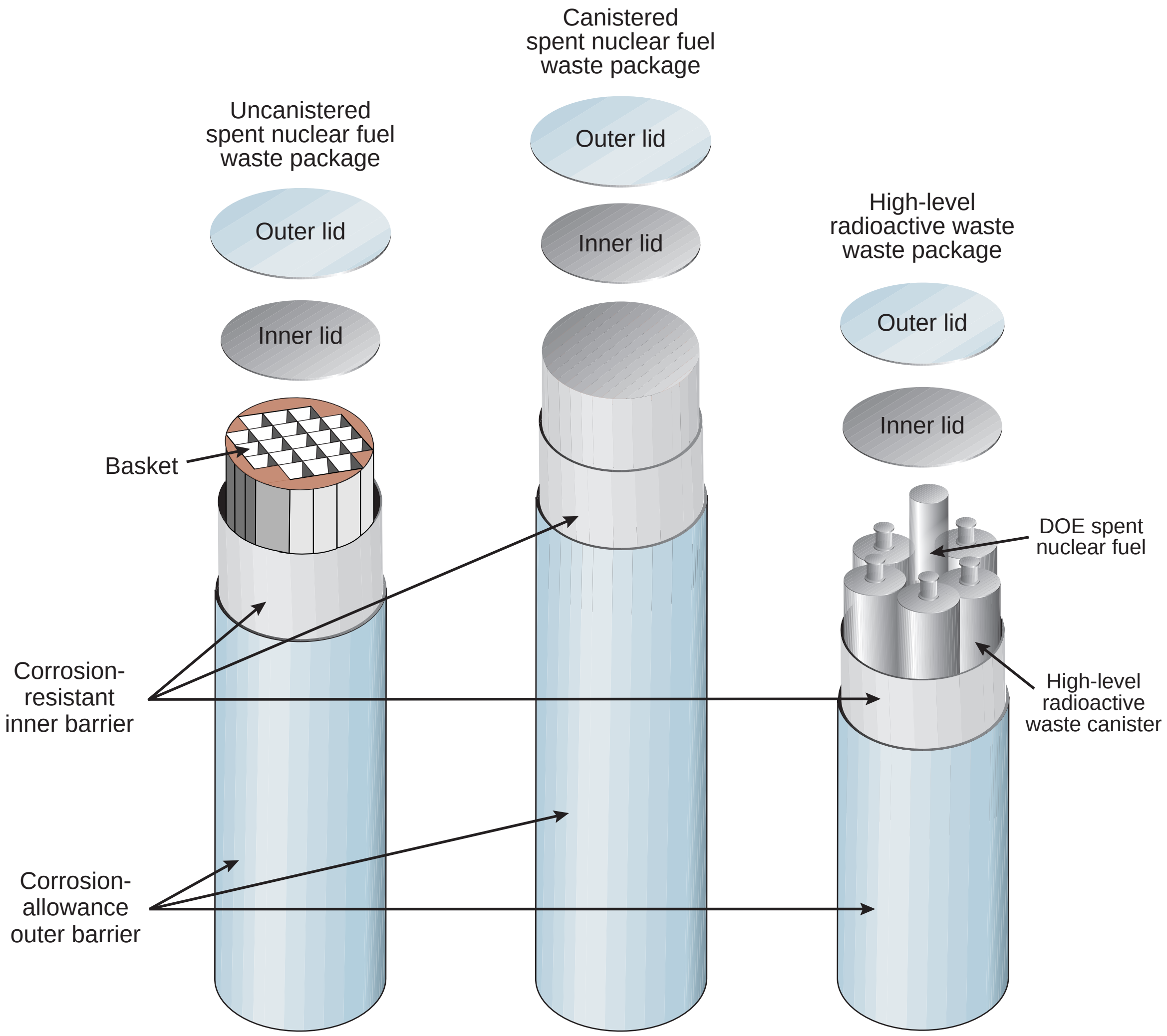
The heat generated by spent nuclear fuel and high-level radioactive waste in the waste packages creates a *thermal load*, which could affect the long-term performance of the repository (that is, the ability of the engineered and natural barrier systems to isolate the emplaced waste from the environment). Thermal load also could affect short-term repository attributes including the amount of surface area required for construction and operations, the number of workers, and utility consumption. Most of the thermal load is from commercial spent nuclear fuel.

DOE evaluated three thermal load scenarios to consider a range of the short- and long-term environmental impacts from repository construction, operation and monitoring, and closure. These scenarios include the *high thermal load*, a relatively high emplacement density of commercial spent nuclear fuel (85 MTHM per acre); the *low thermal load*, a relatively low density (25 MTHM per acre); and the *intermediate thermal load* between the high and low thermal loads (60 MTHM per acre). The spacing of the emplacement drifts and the spacing of the waste packages in the drifts are two examples of techniques that could control the thermal load. The additional spacing for the lower thermal loads would increase the subsurface area and the amount of excavation. In addition, the different thermal loads would affect the area requirements for the excavated rock pile on the surface.

Performance confirmation. Performance confirmation activities would be similar to the current site characterization activities and would include tests, experiments, and analyses that DOE would conduct to evaluate the long-term performance of the repository. Before the start of repository construction, the performance confirmation program would assume responsibility for activities now being performed as part of site characterization. Those activities would continue until after the closure of the repository.

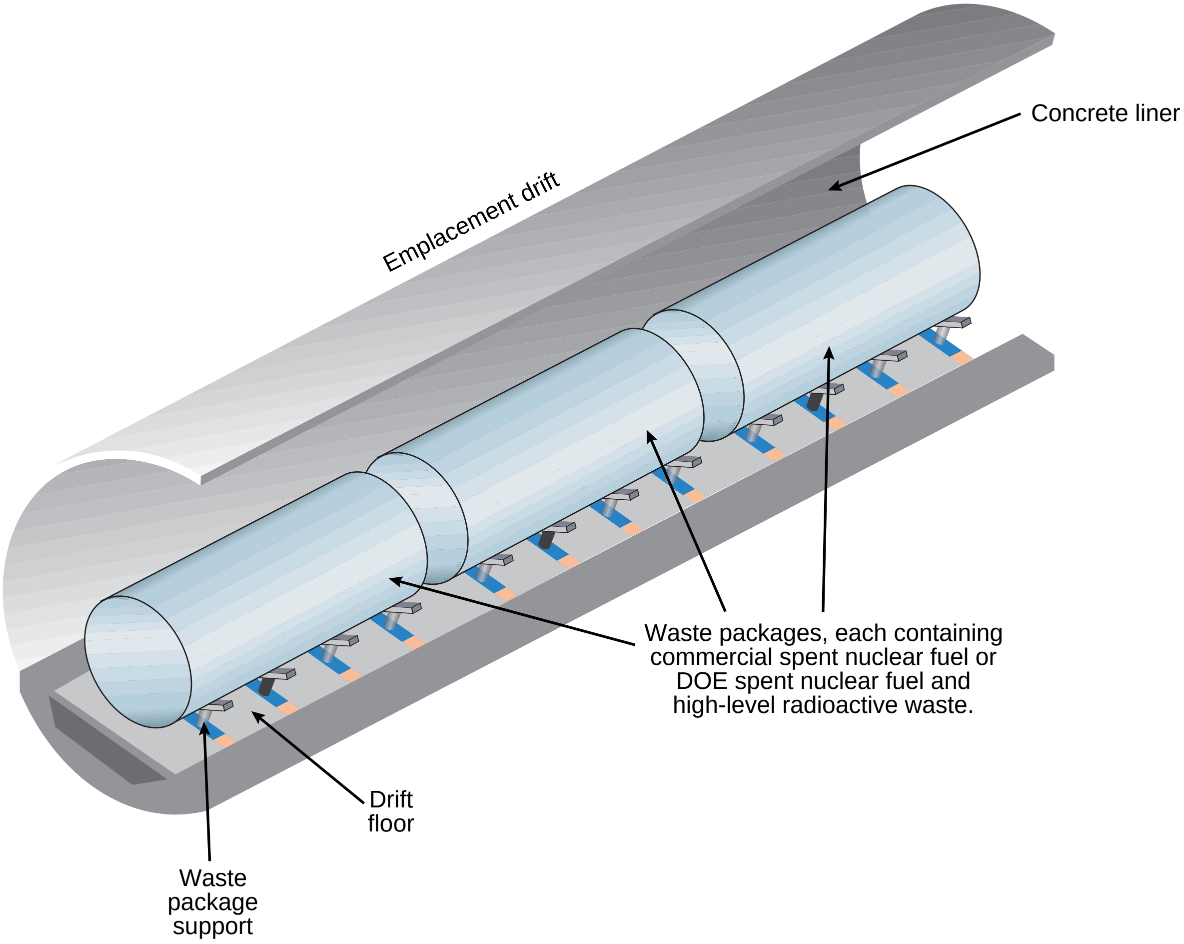
Construction. The construction of repository surface and subsurface facilities could begin after the receipt of construction authorization from the Nuclear Regulatory Commission. For analytical purposes, DOE assumed that construction would begin in 2005. The Department would build the repository surface facilities, main drifts, ventilation system, and initial emplacement drifts in about 5 years, from 2005 to 2010. Construction of the emplacement drifts would continue after emplacement began.

Surface facilities would receive, prepare, and package spent nuclear fuel and high-level radioactive waste for emplacement, and would support the construction of subsurface facilities. The primary surface facilities would be the *North Portal Operations Area* (including the *Waste Handling Building*), the *South Portal Operations Area* (supporting subsurface facility development), the *Emplacement Ventilation Shaft Surface Operations Area(s)*, and the *Development Ventilation Shaft Operations Area(s)*.



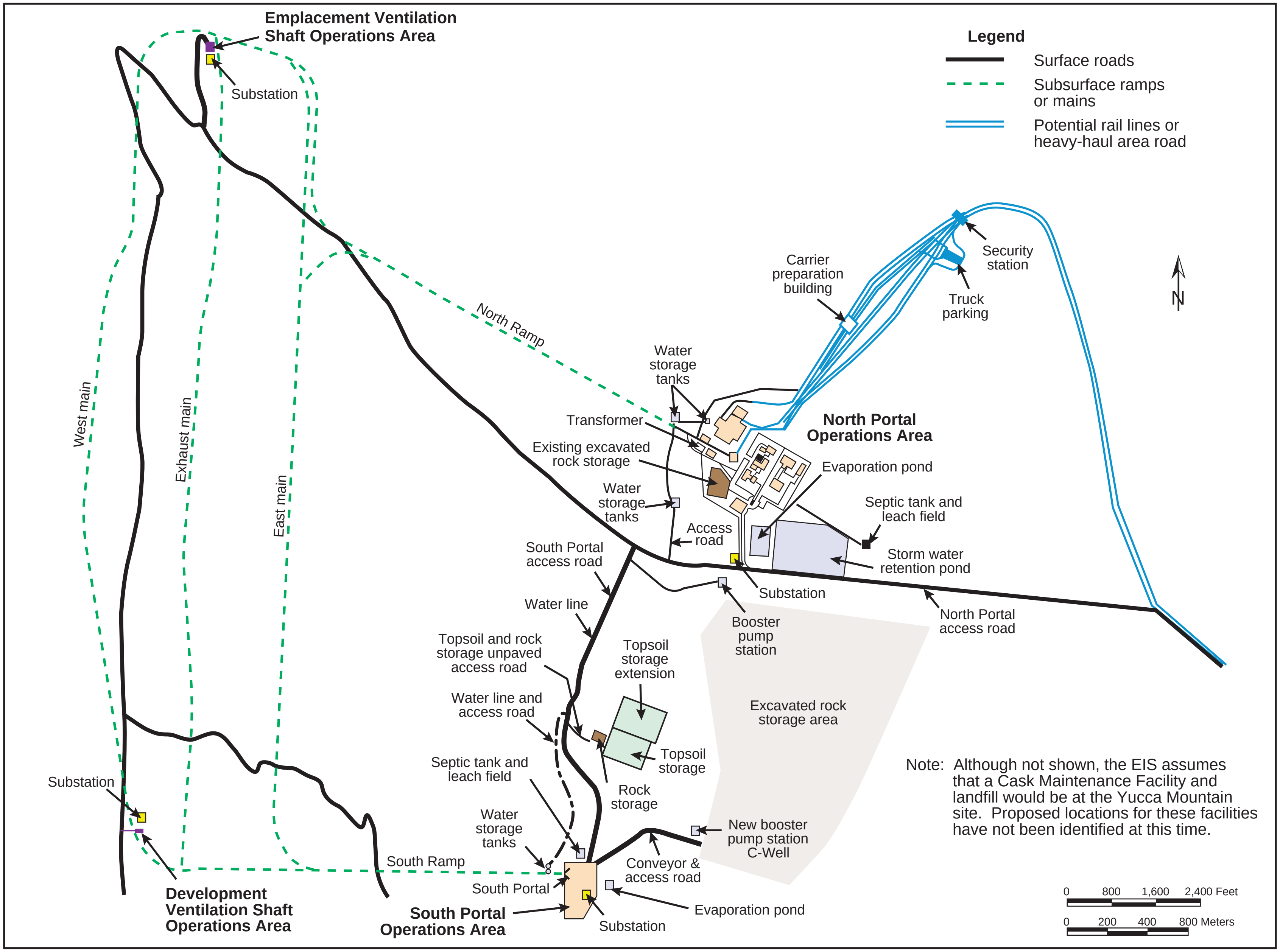
Note: Waste packages would range in size from 3.7 to 6.2 meters (12 to 20 feet) long and 1.25 to 2.0 meters (4.1 to 6.6 feet) in diameter. They would range in weight from 35,000 kilograms (77,000 pounds) to 83,000 kilograms (183,000 pounds).

Figure S-5. Potential waste package designs for spent nuclear fuel and high-level radioactive waste.



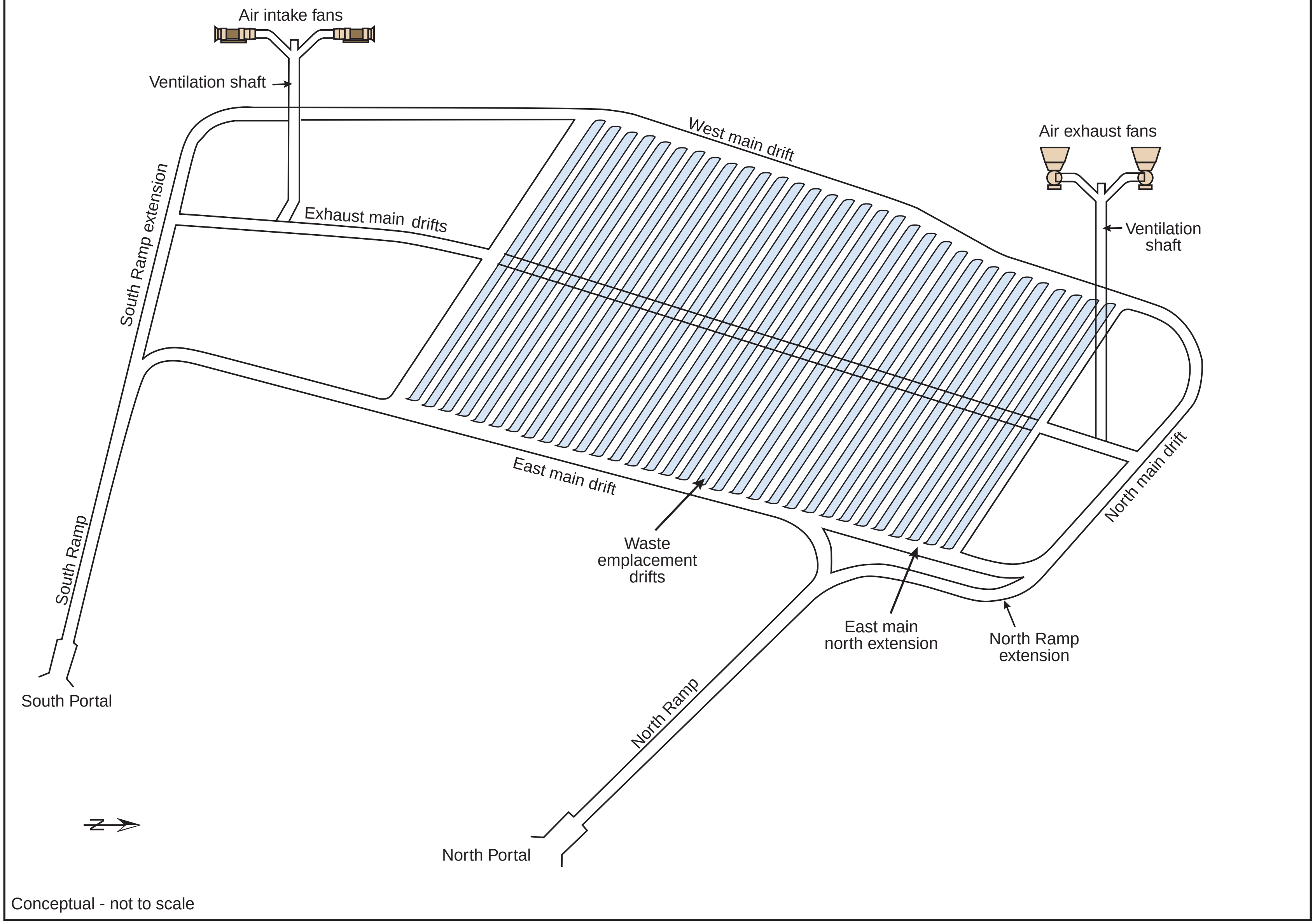
Note: Spacing between packages is for illustration only. The actual spacing would be determined as a function of the final repository thermal load design.

Figure S-6. Artist's conception of waste packages in emplacement drift.



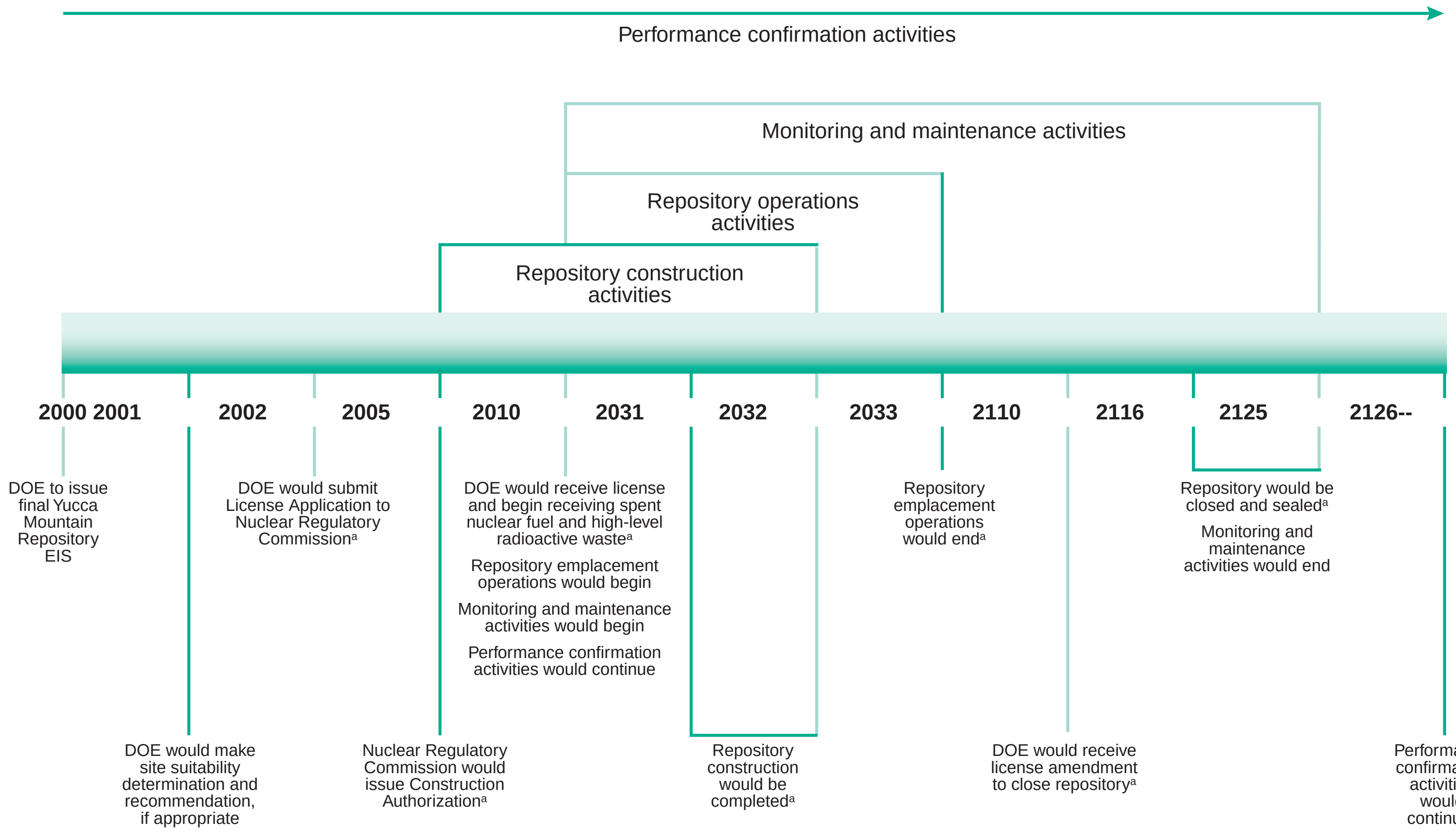
Note: Although not shown, the EIS assumes that a Cask Maintenance Facility and landfill would be at the Yucca Mountain site. Proposed locations for these facilities have not been identified at this time.

Figure S-7. Repository surface facilities plan.



Conceptual - not to scale

Figure S-8. Repository subsurface facilities plan.



a. If Yucca Mountain is approved.

Figure S-9. Expected sequence for proposed Yucca Mountain Repository development.

EVOLVING REPOSITORY DESIGN

The EIS analyzes thermal load and packaging scenarios to identify the range of potential short- and long-term impacts of a repository at Yucca Mountain. The analysis used conceptual designs, which is typical for an EIS. However, the current level of repository design is insufficient to meet information needs for a License Application to the Nuclear Regulatory Commission. The design will continue to evolve through the submittal of the License Application. The DOE License Application Design Selection process is evaluating various features and enhanced design alternatives. The purpose of the evaluation is to determine if these features and alternatives would reduce uncertainties in or improve the long-term performance of the repository, reduce costs, or improve operations.

The reference design discussed in the EIS, together with the thermal load and packaging scenarios, are representative of the design features and enhanced design alternatives under evaluation.

Subsurface facilities would include the drifts developed during site characterization activities. During construction, additional underground excavation would occur. Excavation in the subsurface facilities would include gently sloping *access ramps* for the movement of construction and waste package vehicles, *main drifts* for the movement of construction and waste package vehicles, *emplacement drifts* for the placement of waste packages, *exhaust mains* to transfer air in the subsurface area, and *ventilation shafts* to transfer air between the surface and the subsurface. *Performance confirmation drifts* would contain instrumentation to monitor emplaced waste packages.

Operation and Monitoring. Repository operations would begin after the Nuclear Regulatory Commission granted a license to “receive and possess” spent nuclear fuel and high-level radioactive waste. For planning purposes, DOE assumed that the receipt and emplacement of these materials would begin in 2010. Based on a total emplacement of 70,000 MTHM at approximately 3,000 MTHM each year, waste emplacement would end in about 2033.

The construction of emplacement drifts would continue during the waste emplacement period, and would end in about 2031 for the high or intermediate thermal load scenario or 2032 for the low thermal load scenario. The repository design would enable simultaneous construction and emplacement operations, but it would physically separate construction or development activities from emplacement activities. Ventilation barriers would create airlocks to separate the emplacement and development sides of the repository, and the ventilation system would be designed to maintain the emplacement side at a lower pressure than the development side. This would ensure that no air leakage would occur from the emplacement side to the development side.

Monitoring and maintenance activities would begin with the first emplacement of waste packages and would continue until repository closure. After the completion of emplacement, DOE would maintain the repository facilities, including the ventilation system and utilities (air, water, electric power) that would enable the continued monitoring and inspection of waste packages, continued investigations of long-term repository performance, and the retrieval of waste packages, if necessary. Immediately after the completion of emplacement, DOE would decontaminate and close the nuclear facilities on the surface to eliminate potential radioactive material

RETRIEVAL

Section 122 of the NWPA requires DOE to maintain the ability to retrieve emplaced materials. Because of this requirement, the EIS includes an analysis of the impacts of retrieval. Although the EIS analyzes it, DOE does not believe that retrieval would be necessary, and it is not part of the Proposed Action. DOE would maintain the ability to retrieve the spent nuclear fuel and high-level radioactive waste for at least 100 years and possibly for as long as 300 years in the event of a decision to retrieve the materials to protect public health and safety or the environment or to recover constituent parts of spent nuclear fuel.

hazards. However, the Department would maintain the Waste Handling Building for the possible retrieval of waste.

Closure. To ensure flexibility for future decisionmakers, DOE is designing the repository with a capability for closure in as few as 50 years or as many as 300 years after the start of waste emplacement. While the reference design assumes that closure would begin 100 years after emplacement began, this EIS assessed impacts for closure beginning 50 and 300 years after the start of emplacement.

Repository closure would occur after DOE received a license amendment from the Nuclear Regulatory Commission. The period to perform closure would range from 6 years to 15 years, depending on the thermal load (a longer period would be needed to close the larger number of drifts needed for the low thermal load). Closure activities would include closing the subsurface facilities, decommissioning the surface facilities, sealing openings into the mountain (access ramps, ventilation shafts, boreholes), performing reclamation activities at the site, and establishing institutional controls such as permanent monuments to mark and identify the area.

S.3.1.3 Transportation

DOE would transport spent nuclear fuel and high-level radioactive waste from commercial and DOE sites around the country to the Yucca Mountain site by rail and legal-weight truck. The Department is not proposing to use a particular combination of rail and legal-weight truck shipments, so it analyzed two transportation scenarios (*mostly legal-weight truck* and *mostly rail*) that cover the possible range of transportation impacts to human health and the environment.

DEFINITIONS FOR TRUCK TRANSPORTATION

Legal-weight trucks: trucks with a gross vehicle weight (both truck and cargo weight) of less than 36,300 kilograms (80,000 pounds), which is the loaded weight limit for commercial vehicles operated on public highways without special state-issued permits.

Heavy-haul trucks: overweight, overdimension vehicles that must have permits from state highway authorities to use public highways.

The mostly legal-weight truck scenario assumes that DOE would transport most of the spent nuclear fuel and high-level radioactive waste to the repository by legal-weight truck. The trucks would travel from the 77 sites to the Yucca Mountain site primarily on the U.S. Interstate Highway system, as shown in Figure S-10. An exception to this scenario would be the naval spent nuclear fuel, which the Navy would transport from the Idaho National Engineering and Environmental Laboratory to Nevada by rail.

The mostly rail scenario assumes that DOE and the Navy would transport most of the spent nuclear fuel and high-level radioactive waste to Nevada by rail, with the exception of material from commercial nuclear generating sites that do not have the capability to load large-capacity rail shipping casks. Those sites would use legal-weight trucks to ship material to the repository. Commercial sites with the capability to load the rail shipping casks but that did not have rail access could use heavy-haul trucks or barges to ship spent nuclear fuel to the nearest rail line. Figure S-11 shows the commercial and DOE sites and Yucca Mountain in relation to the U.S. railroad system over which the railcars would travel.

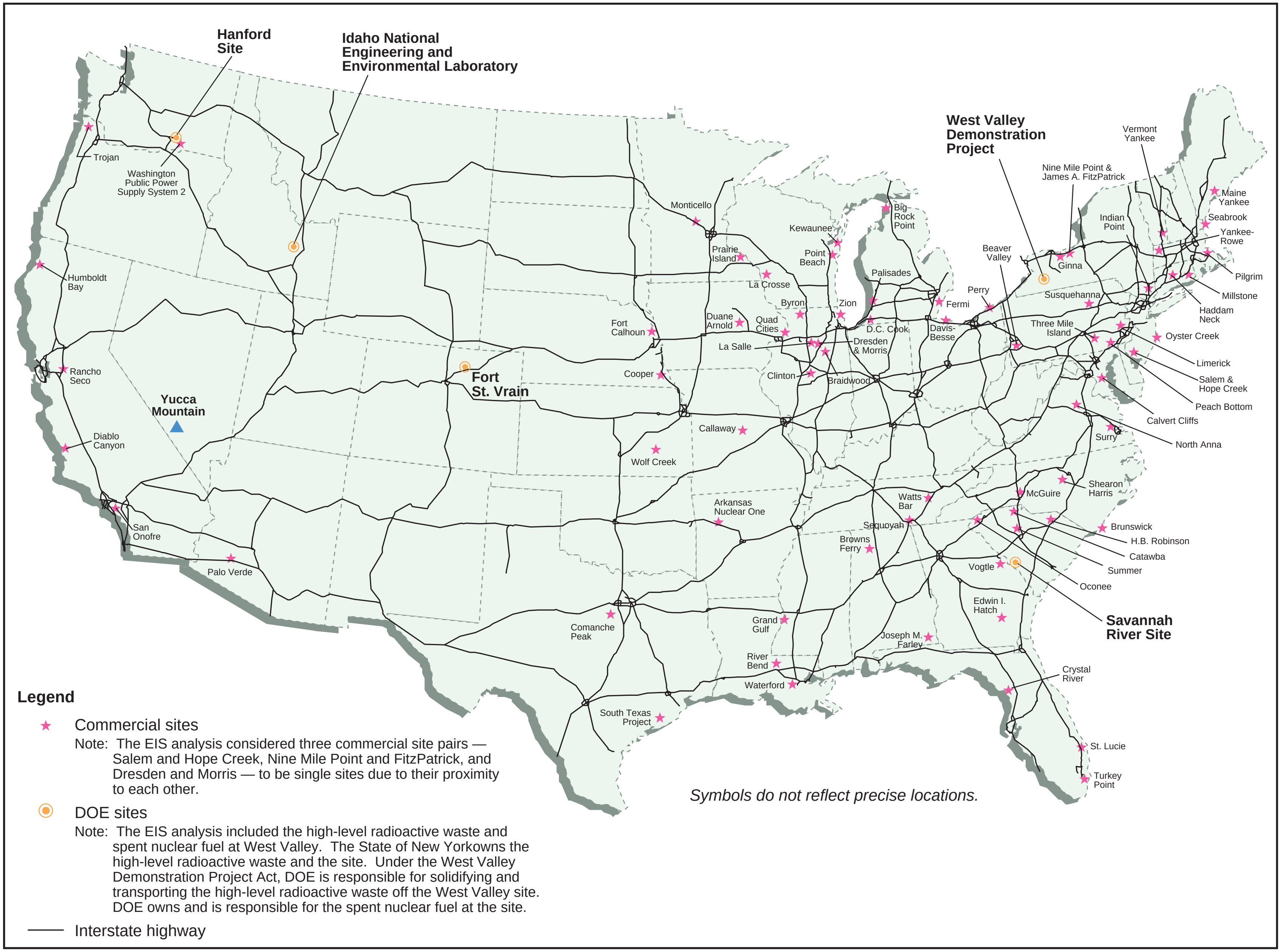
NEVADA TRANSPORTATION IMPLEMENTING ALTERNATIVES

Rail corridors

- Caliente
- Caliente-Chalk Mountain
- Carlin
- Jean
- Valley Modified

Intermodal transfer station locations and heavy-haul truck routes

- Apex-Dry Lake (one route)
- Caliente
  - Caliente route
  - Caliente-Chalk Mountain route
  - Caliente-Las Vegas route
- Sloan/Jean (one route)



Legend

★ Commercial sites

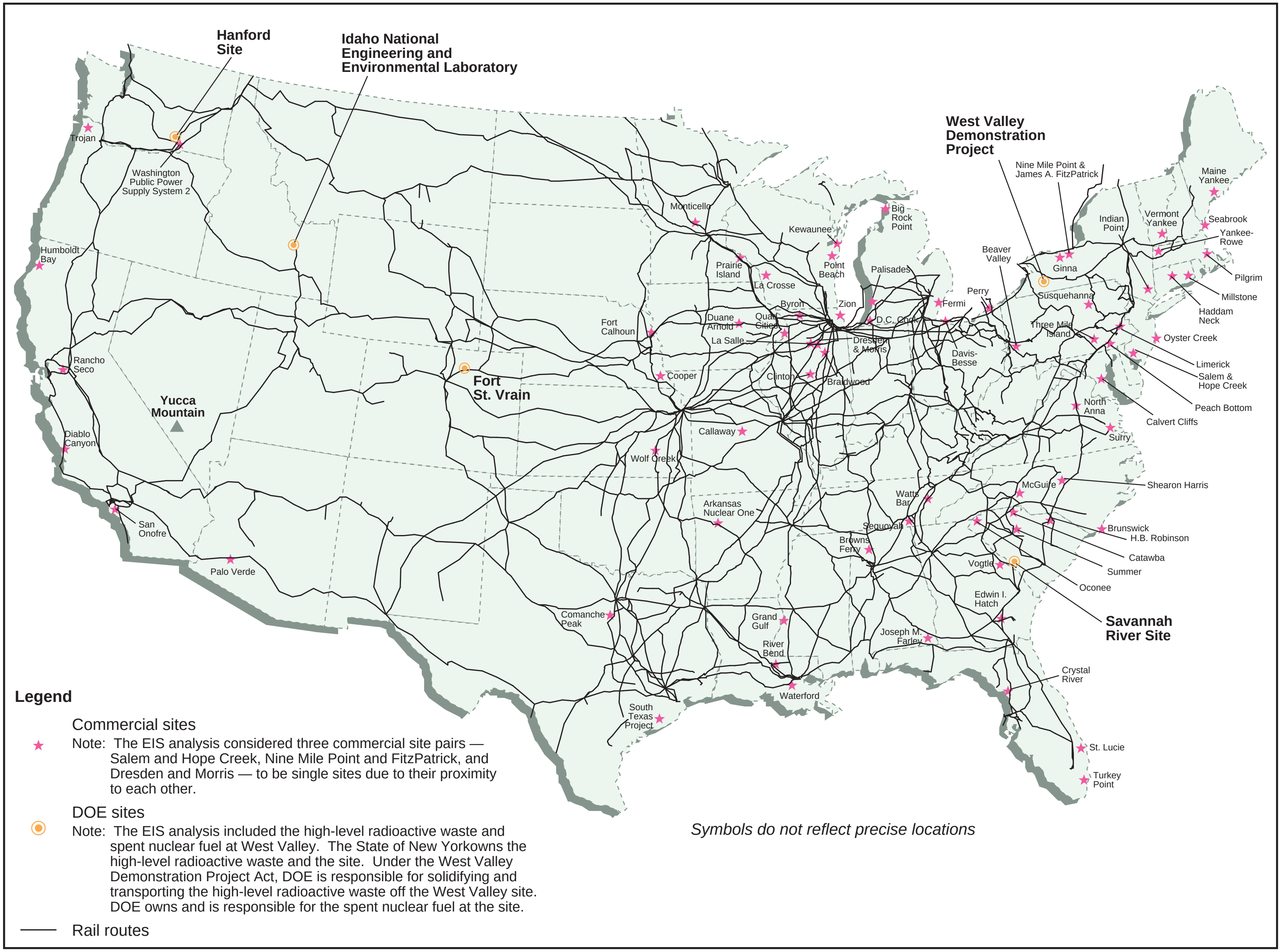
Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◎ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

— Interstate highway

Figure S-10. Commercial and DOE sites and Yucca Mountain in relation to the U.S. Interstate Highway System.



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★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

—— Rail routes

Figure S-11. Commercial and DOE sites and Yucca Mountain in relation tothe U.S. railroad system.

In the State of Nevada, waste that traveled from the commercial and DOE sites by legal-weight truck would continue to the repository in the same manner. Figure S-12 shows the southern Nevada highways over which the legal-weight trucks would travel. Potential routes for legal-weight truck shipments in Nevada comply with U.S. Department of Transportation regulations (49 CFR 397.101) for selecting "preferred routes" and "delivery routes" for motor carrier shipments of highway route-controlled quantities of radioactive materials. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

At this time there is no rail access to the Yucca Mountain site. This means that material traveling by rail would have to continue to the repository on a new branch rail line or transfer to heavy-haul trucks at an intermodal (that is, from rail to truck) transfer station in Nevada and then travel on existing highways that could need to be upgraded. DOE is considering implementing alternatives for the construction of either a new branch rail line or an intermodal transfer station with associated highway improvements. The Department has identified five alternatives for rail corridors, each of which has alignment variations (Figure S-13), and three alternative locations for an intermodal transfer station and five associated highway routes for heavy-haul trucks (Figure S-14). Figure S-15 shows how the national and Nevada transportation scenarios relate.

REPOSITORY ANALYSIS

Repository Facilities and Operations

Packaging scenarios
- Mostly uncanistered fuel
- Mostly canistered fuel

Thermal load scenarios
- High thermal load
- Intermediate thermal load
- Low thermal load

Transportation Activities

National transportation scenarios
- Mostly legal-weight truck
- Mostly rail

Nevada transportation scenarios
- Mostly legal-weight truck
- Mostly rail with a new branch rail line (five corridors)
- Mostly rail with heavy-haul truck from a new intermodal transfer station (five routes)

S.3.1.4 Costs

DOE estimates that the total cost of the Proposed Action (construct, operate and monitor for 100 years, and close a geologic repository at Yucca Mountain), including the transportation of spent nuclear fuel and high-level radioactive waste to the repository, would be about $28.8 billion (in 1998 dollars). This would vary, depending on the thermal load, packaging, other repository design features, and transportation scenarios, and on the Nevada transportation implementing alternative.

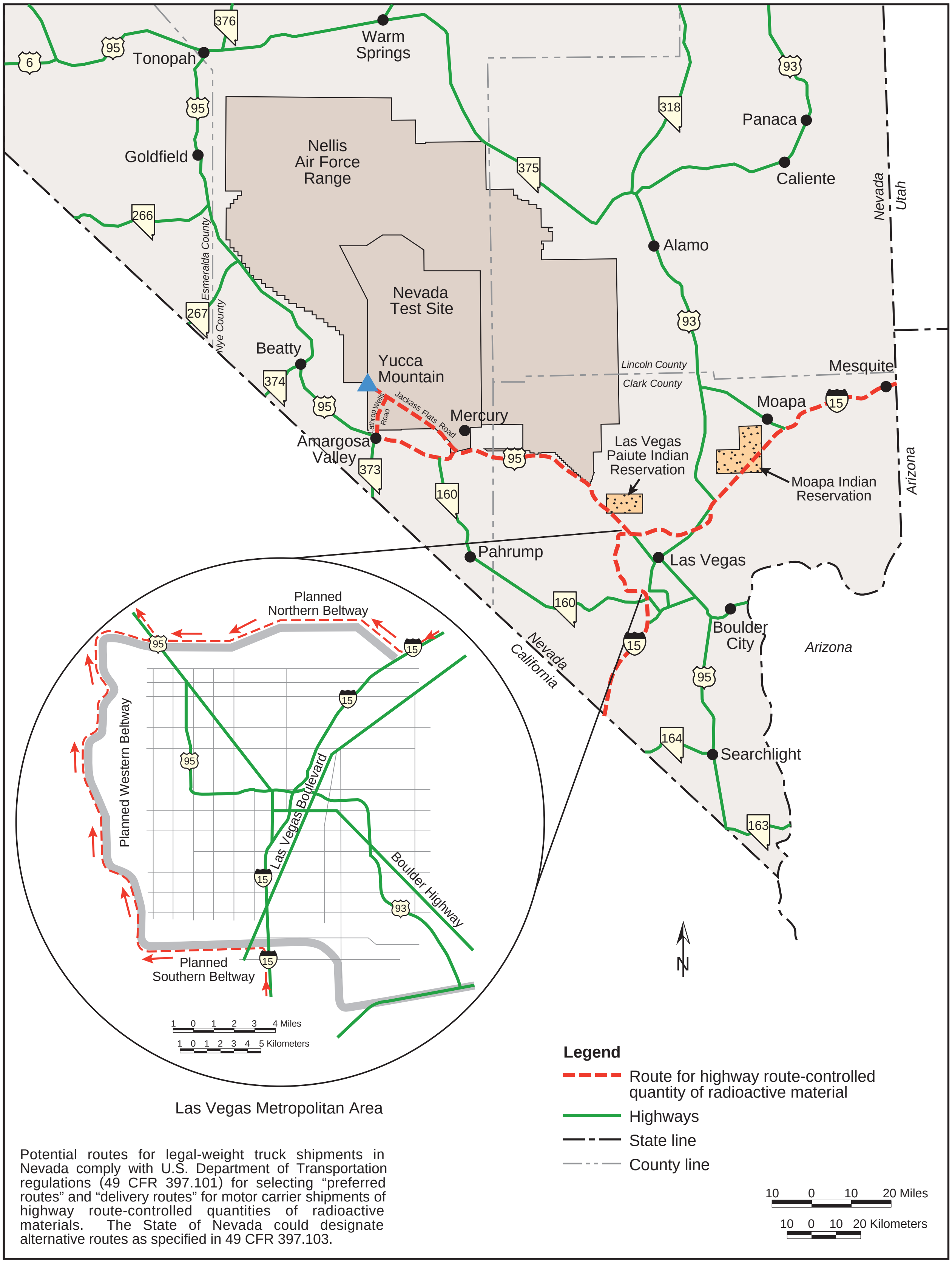
S.3.2 NO-ACTION ALTERNATIVE

Under the No-Action Alternative, DOE would end site characterization activities at Yucca Mountain and begin site decommissioning and reclamation. The commercial nuclear power utilities and DOE would continue to store spent nuclear fuel and high-level radioactive waste. Because it would be highly speculative to attempt to predict future events, DOE decided to illustrate one set of possibilities by focusing its analysis of the No-Action Alternative on the potential impacts of two scenarios:

- Scenario 1 assumes that spent nuclear fuel and high-level radioactive waste would remain at the 72 commercial and 5 DOE sites under institutional control for at least 10,000 years.

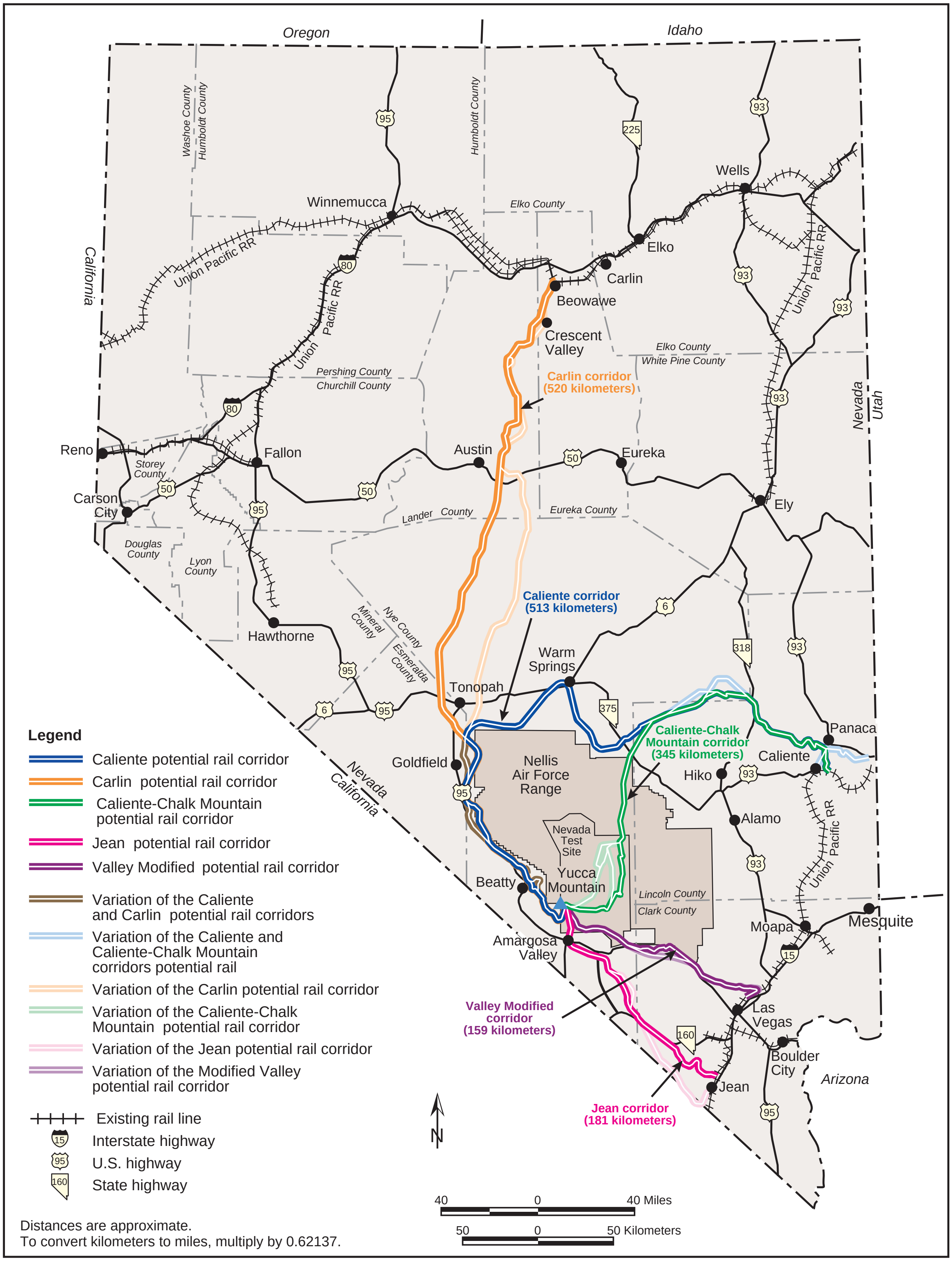
INSTITUTIONAL CONTROL

Monitoring and maintenance of storage facilities to ensure that radiological releases to the environment and radiation doses to workers and the public remain within Federal limits and DOE Order requirements.



Potential routes for legal-weight truck shipments in Nevada comply with U.S. Department of Transportation regulations (49 CFR 397.101) for selecting "preferred routes" and "delivery routes" for motor carrier shipments of highway route-controlled quantities of radioactive materials. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

Figure S-12. Potential Nevada routes for legal-weight truck shipments of spent nuclear fuel and high-level radioactive waste to Yucca Mountain.

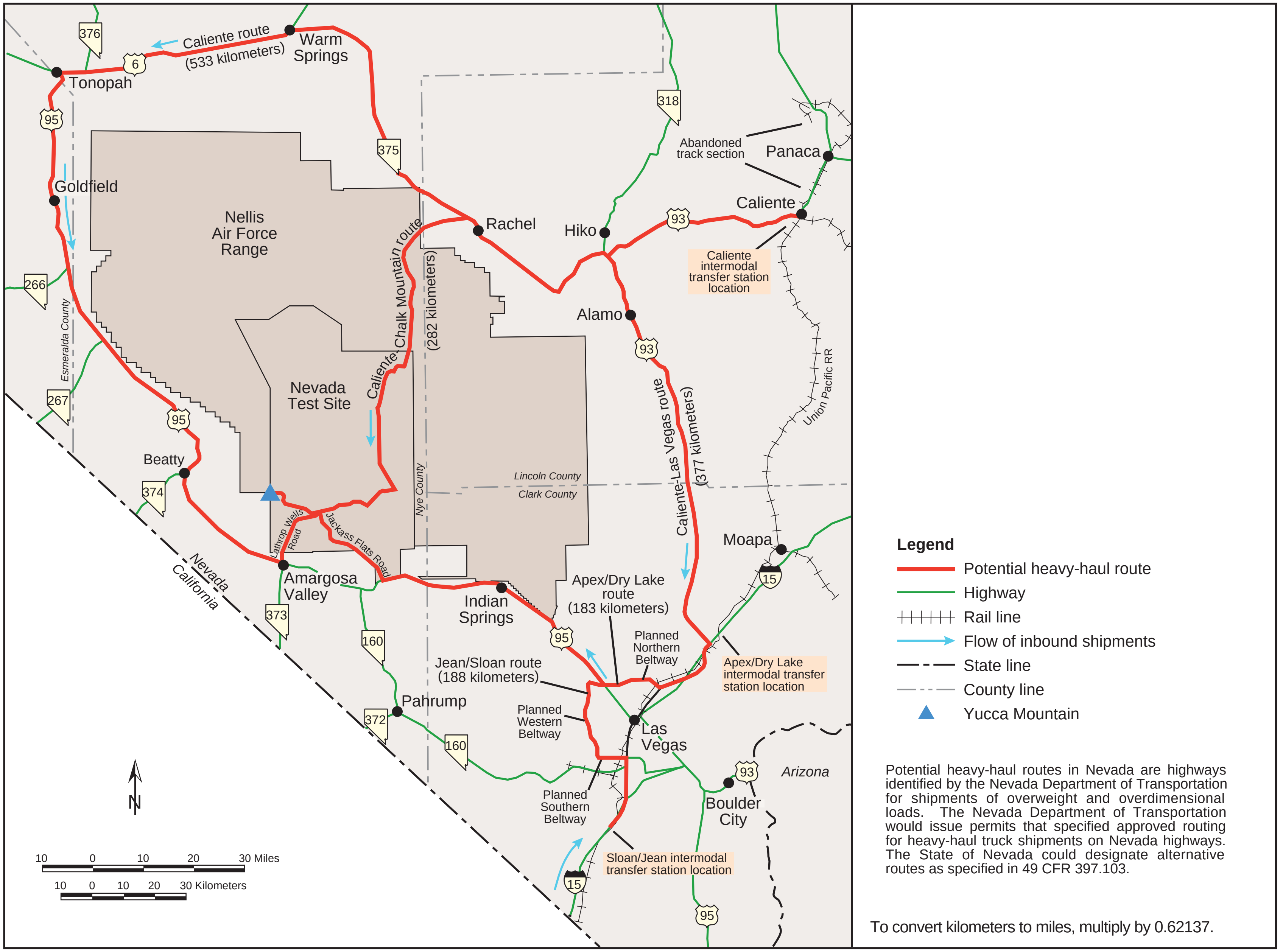


Legend

- Caliente potential rail corridor
- Carlin potential rail corridor
- Caliente-Chalk Mountain potential rail corridor
- Jean potential rail corridor
- Valley Modified potential rail corridor
- Variation of the Caliente and Carlin potential rail corridors
- Variation of the Caliente and Caliente-Chalk Mountain corridors potential rail
- Variation of the Carlin potential rail corridor
- Variation of the Caliente-Chalk Mountain potential rail corridor
- Variation of the Jean potential rail corridor
- Variation of the Modified Valley potential rail corridor
- Existing rail line
- 15 Interstate highway
- 95 U.S. highway
- 160 State highway

Distances are approximate.
To convert kilometers to miles, multiply by 0.62137.

Figure S-13. Potential Nevada rail routes to Yucca Mountain.



Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. The Nevada Department of Transportation would issue permits that specified approved routing for heavy-haul truck shipments on Nevada highways. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

To convert kilometers to miles, multiply by 0.62137.

Figure S-14. Potential intermodal transfer station locations and potential routes in Nevada for heavy-haul trucks.

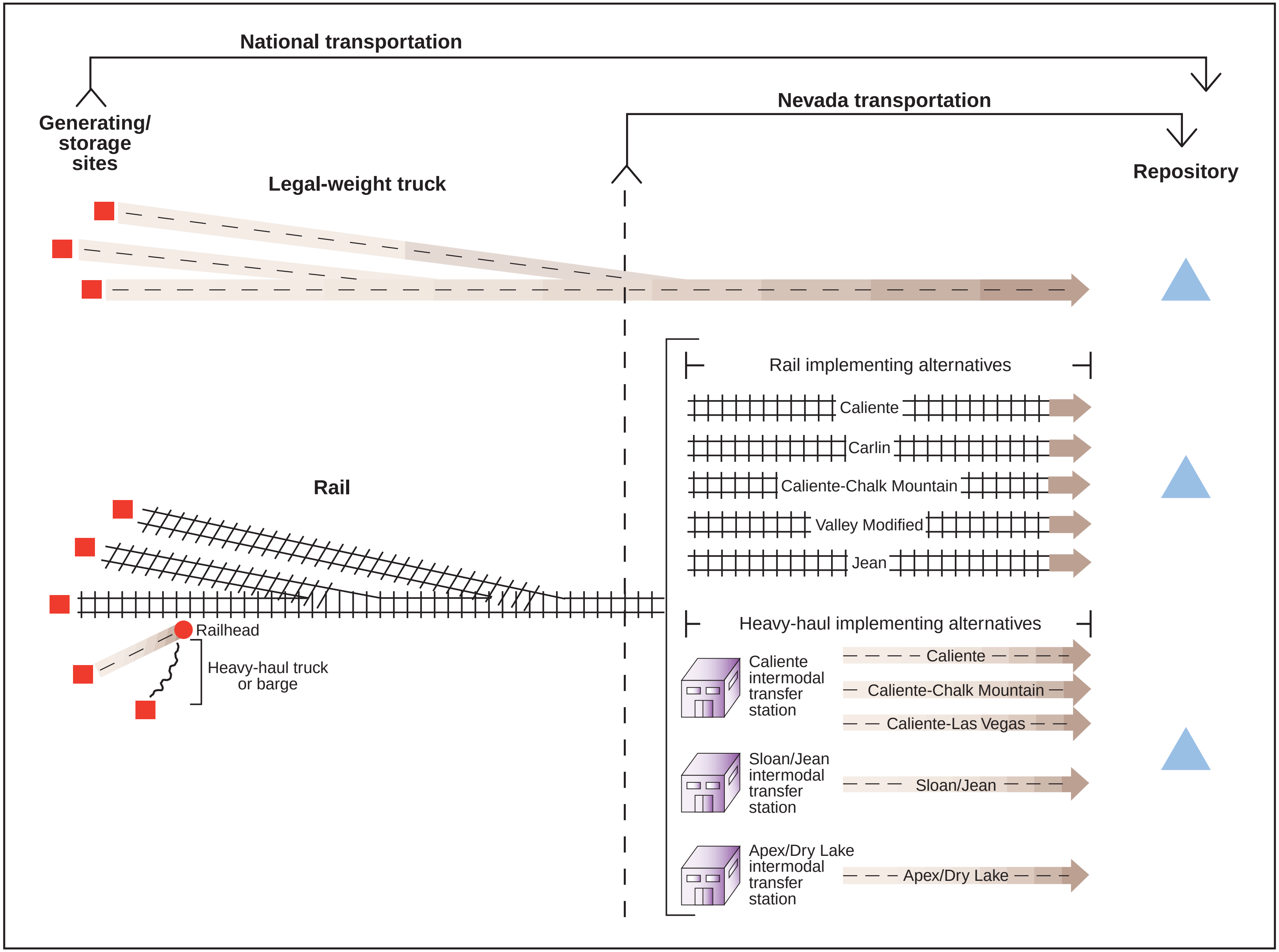


Figure S-15. Relationship of Nevada and national transportation.

- Scenario 2 assumes that spent nuclear fuel and high-level radioactive waste would remain at the 77 sites in perpetuity, but under institutional control for only about 100 years. This scenario assumes no effective institutional control of the stored spent nuclear fuel and high-level radioactive waste after 100 years.

DOE recognizes that neither scenario would be likely if there were a decision not to develop a repository at Yucca Mountain; however, they are part of the EIS analysis to provide a baseline for comparison to the Proposed Action. There are a number of possibilities that the Nation could pursue, including continued storage of the material at its current locations or at one or more centralized location(s); the study and selection of another location for a deep geologic repository; development of new technologies; or reconsideration of other disposal alternatives to deep geologic disposal. However, any of these potential actions are speculative, and DOE therefore did not evaluate them in the EIS. Under any future course that would include continued storage, both commercial and DOE sites have an obligation to continue managing the spent nuclear fuel and high-level radioactive waste in a manner that protects public health and safety and the environment.

S.3.2.1 Reclamation and Decommissioning at Yucca Mountain

Under the No-Action Alternative, site characterization activities would end at Yucca Mountain. DOE would start site decommissioning and reclamation. These activities would include the removal or shutdown of all surface and subsurface facilities, and the restoration of the lands disturbed during site characterization. DOE would fill and seal drill holes to meet Nevada requirements.

S.3.2.2 Continued Storage at Commercial and DOE Sites

Under the No-Action Alternative, the 72 commercial and 5 DOE sites would continue to store spent nuclear fuel and high-level radioactive waste. For purposes of analysis, the No-Action Alternative assumes that those sites would treat and package the materials, as necessary, for their safe onsite management. It also assumes that the amount of spent nuclear fuel and high-level radioactive waste stored would be the same as that shipped under the Proposed Action (70,000 MTHM).

The EIS analysis assumed that spent nuclear fuel and high-level radioactive waste would be placed in dry-storage canisters inside reinforced concrete storage modules. Both the canister and the concrete storage module would provide shielding against the radiation that the material would emit, although the concrete module would provide the primary shielding. The dry configuration would enable outside air to circulate and remove the heat of radioactive decay. As long as spent nuclear fuel, high-level radioactive waste, canisters, and storage modules were properly maintained, this would provide safe storage.

No-Action Scenario 1. Spent nuclear fuel and high-level radioactive waste would remain in dry storage at the commercial and DOE sites and would be under institutional control for at least 10,000 years. Institutional control at these facilities would ensure the protection of workers and the public in accordance with Federal regulations. For purposes of analysis, DOE assumed that the storage facilities would undergo one major repair during the first approximately 100 years, and complete replacement after the first 100 years every 100 years thereafter.

No-Action Scenario 2. Spent nuclear fuel and high-level radioactive waste would remain in dry storage at the commercial and DOE sites and would be under institutional control for approximately 100 years (as in Scenario 1). This scenario, however, assumes no effective institutional control after 100 years, and that the storage facilities at 72 commercial and 5 DOE sites would begin to deteriorate after 100 years. The facilities would eventually release radioactive materials to the environment, contaminating the atmosphere, soil, surface water, and groundwater for the 10,000-year period analyzed.

The assumption for Scenario 2 that there would be no effective institutional control after approximately 100 years is based on a review of generally applicable requirements that discount altogether the consideration of institutional control after 100 years for purposes of conducting performance assessments [U.S. Environmental Protection Agency regulations (40 CFR Part 191); U.S. Nuclear Regulatory Commission regulations for disposal of low-level radioactive material (10 CFR Part 61); and the National Research Council report on standards for the proposed Yucca Mountain Repository]. Thus, in addition to its inherent conservatism, the assumption that no institutional control would be in place after 100 years provides a consistent analytical basis for comparing the No-Action Alternative and the Proposed Action.

Figure S-16 shows conceptual timelines for activities at the commercial and DOE sites for Scenarios 1 and 2.

S.3.2.3 Costs

DOE estimates that the total cost of Scenario 1 or 2 for the first 100 years, including the decommissioning and reclamation of the Yucca Mountain site, would range from $51.5 billion to $56.7 billion, depending on the need to replace the dry-storage canisters in addition to replacing the storage facilities during that time. The estimated cost for the remaining 9,900 years of Scenario 1 would range from $480 million to $529 million per year. There would be no costs under Scenario 2 after the first 100 years because that scenario assumes no effective institutional control after that time.

S.4 Environmental Consequences of the Proposed Action

To analyze the potential environmental impacts associated with the Proposed Action, DOE compiled baseline information for various environmental resource areas and examined how the construction, operation and monitoring, and eventual closure of a repository at Yucca Mountain could affect each of those environmental resources, and resulting impacts on human health. In considering the impacts on human health, DOE analyzed both routine operations and accident scenarios.

ENVIRONMENTAL CONSEQUENCES AND PERIODS OF ANALYSIS

Short-term consequences are those that could occur in the period before the completion of repository closure, or approximately 100 years after the start of waste emplacement. DOE analyzed potential short-term impacts that could occur in resource areas as a result of performance confirmation, construction, operation and monitoring, closure, and transportation activities.

Long-term consequences are those that could occur after repository closure. DOE analyzed potential long-term impacts that could occur to human health and biological resources from radiological and chemical groundwater contamination for 10,000 years after repository closure. In addition, peak dose to 1 million years was estimated.

DOE conducted a broad range of studies to obtain or evaluate the information needed for the assessment of Yucca Mountain as a geologic repository. These studies have provided in-depth knowledge about the Yucca Mountain site and vicinity and provide sufficient information to aid in DOE decisionmaking. The Department used the information from these studies in the analyses described in this EIS. However, because some of these studies are ongoing, some of the information is incomplete. Further, the complexity and variability of the natural system at Yucca Mountain, the long period evaluated (10,000 years), and incomplete information or the unavailability of some information have resulted in uncertainty in the analyses and findings. Throughout the EIS, DOE notes both the use of incomplete information if complete information is unavailable, and the existence of uncertainty, to enable the reader to better understand EIS findings.

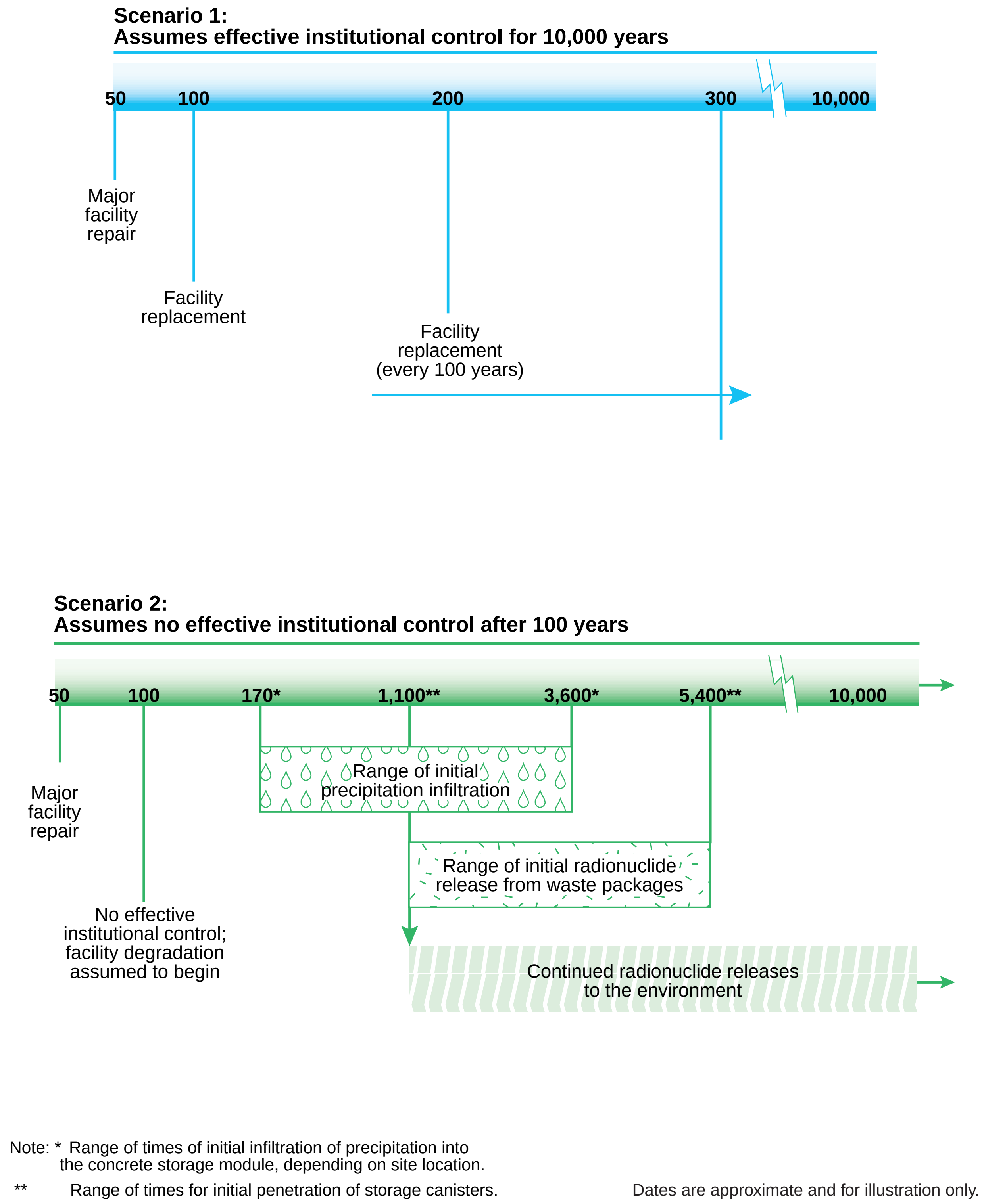


Figure S-16. Conceptual timelines for events at commercial and DOE sites for No-Action Scenarios 1 and 2.

The following paragraphs describe the potentially affected resources at the Yucca Mountain site and vicinity and a summary of the extent to which the Proposed Action could affect those resources.

S.4.1 YUCCA MOUNTAIN SITE AND VICINITY

The Yucca Mountain site is on Federal land in a remote area of the Mojave Desert in Nye County in southern Nevada, about 160 kilometers (100 miles) northwest of Las Vegas, Nevada. The Yucca Mountain region is sparsely populated and receives only about 10 to 25 centimeters (4 to 10 inches) of precipitation each year. The Yucca Mountain Repository land withdrawal area would occupy about 600 square kilometers (230 square miles or 150,000 acres) of land currently under the control of DOE, the U.S. Air Force, and the Bureau of Land Management.

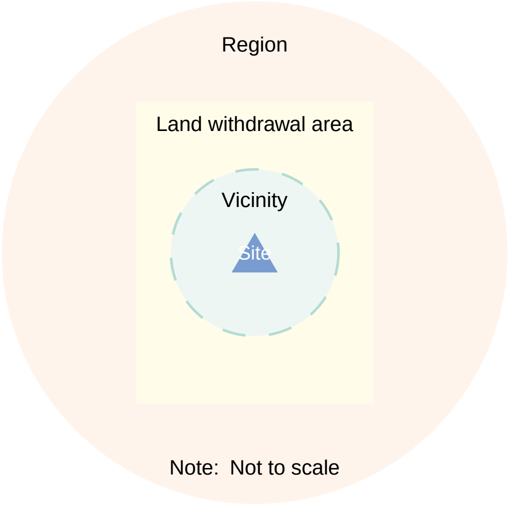
SITE-RELATED TERMS

Yucca Mountain site (the site): The area on which DOE has built or would build the majority of facilities or cause the majority of land disturbances related to the proposed repository.

Yucca Mountain vicinity: A general term used in nonspecific discussions about the area around the Yucca Mountain site. The EIS also uses terms such as area, proximity, etc., in a general context.

Land withdrawal area: An area of Federal property set aside for the exclusive use of a Federal agency. For the analyses in this EIS, DOE used an assumed land withdrawal area of 600 square kilometers, or 150,000 acres.

Region of influence (the region): A specialized term indicating a specific area of study for each of the resource areas that DOE assessed for the EIS analyses.



Surface repository facilities would occupy about 3.5 square kilometers (1.4 square miles or 870 acres) of the Yucca Mountain site. The remainder of the site would be used to locate support facilities, and for continued performance confirmation testing (for example, wells) and to separate repository facilities from other human activities. Performance confirmation activities would take place on and in the vicinity of the site. The existing environment at the site includes the structures and physical disturbances from DOE-sponsored activities that took place from 1977 to 1988 related to the selection of Yucca Mountain for site characterization, and continuing site characterization activities that began in 1989 to determine the suitability of the site for a repository.

S.4.1.1 Land Use and Ownership

The Yucca Mountain site is in the southwest corner of the DOE Nevada Test Site, adjacent to the Nellis Air Force Range. The lands in the region include Bureau of Land Management special-use areas excluded from development that would require terrain alterations, unless the alterations would benefit wildlife or public recreation. The Fish and Wildlife Service of the U.S. Department of the Interior manages the Desert National Wildlife Range and the Ash Meadows National Wildlife Refuge, which are about 48 kilometers (30 miles) east and 39 kilometers (24 miles) south of Yucca Mountain, respectively.

These areas provide habitat for a number of resident and migratory animal species in relatively undisturbed natural ecosystems. The National Park Service manages Death Valley National Park, which at its closest point is about 35 kilometers (22 miles) southwest of Yucca Mountain. The National Park Service also manages the small Devils Hole Protective Withdrawal in Nevada south of Ash Meadows.

State-owned lands are limited in the vicinity of the proposed repository. There are scattered tracts of private land in and near the towns of Beatty, Amargosa Valley, and Indian Springs in Nevada. There are larger private tracts in the agricultural areas of the Las Vegas Valley, near Pahrump, and in the Amargosa Desert south of the town of Amargosa Valley. The closest year-round housing is at Lathrop Wells, about 22 kilometers (14 miles) south of the site. There are farming operations about 30 kilometers (19 miles) south of the proposed repository in the town of Amargosa Valley. Figure S-17 shows the land use and ownership in the Yucca Mountain region.

Only Congress has the power to withdraw Federal lands permanently for the exclusive purposes of specific agencies. If the Yucca Mountain site were recommended for development as a repository, a permanent land withdrawal would be necessary to isolate the land designated for the site from public access to satisfy Nuclear Regulatory Commission licensing requirements. The EIS analysis assumed the use of an area of approximately 600 square kilometers (150,000 acres) on Bureau of Land Management, U.S. Air Force, and DOE lands in the vicinity of the proposed repository. Performance confirmation, repository construction, operation and monitoring, and closure activities would require the use of about 3.5 square kilometers (870 acres) of noncontiguous areas within the 600-square-kilometer (150,000-acre) area. These activities would not conflict with land uses on adjacent lands.

RUBY VALLEY TREATY ISSUE

The Western Shoshone people maintain that the Ruby Valley Treaty of 1863 gives them rights to certain lands, including the Yucca Mountain region. The Western Shoshone filed a claim in the early 1950s alleging that the Government had taken the tribe’s land. The Indian Claims Commission found that Western Shoshone title to the land had gradually been extinguished, and set a monetary award as payment for the land. In 1976, the Commission granted a final award to the Western Shoshone people. The Western Shoshone dispute these findings, and have not accepted the monetary award for the lands in question. The tribe maintains that no payment has been made and that Yucca Mountain is on Western Shoshone land. Although DOE recognizes the sensitivity of this issue, it must abide by rulings that have been made by the U.S. Supreme Court, which in 1985 held that payment had been made in accordance with the Indian Claims Commission Act of 1946. This constituted full and final settlement for the land. DOE is aware that among the Native American community there is significant disagreement with the Court rulings.

S.4.1.2 Air Quality

The evaluation of impacts to air quality considered potential releases of nonradiological and radiological pollutants associated with the Proposed Action and doses to maximally exposed individuals and populations of the public and noninvolved workers (workers who could be exposed to air emissions from repository activities but who would not be directly associated with those activities). Involved workers are discussed in Section S.4.1.8. The EIS also discusses potential long-term human health impacts from exposure to these releases.

Nonradiological Impacts. Sources of nonradiological air pollutants at the proposed repository site could include fugitive dust emissions from land disturbances, excavated rock handling, and concrete batch plant operations and emissions from fossil fuel consumption. Nonradiological air quality impacts could include those from criteria pollutants, including nitrogen dioxide, sulfur dioxide, carbon monoxide, and particulate matter with a diameter of less than 10 micrometers (PM_{10}), and from other potentially harmful material such as cristobalite, a form of silica dust that can cause a respiratory disease known as silicosis

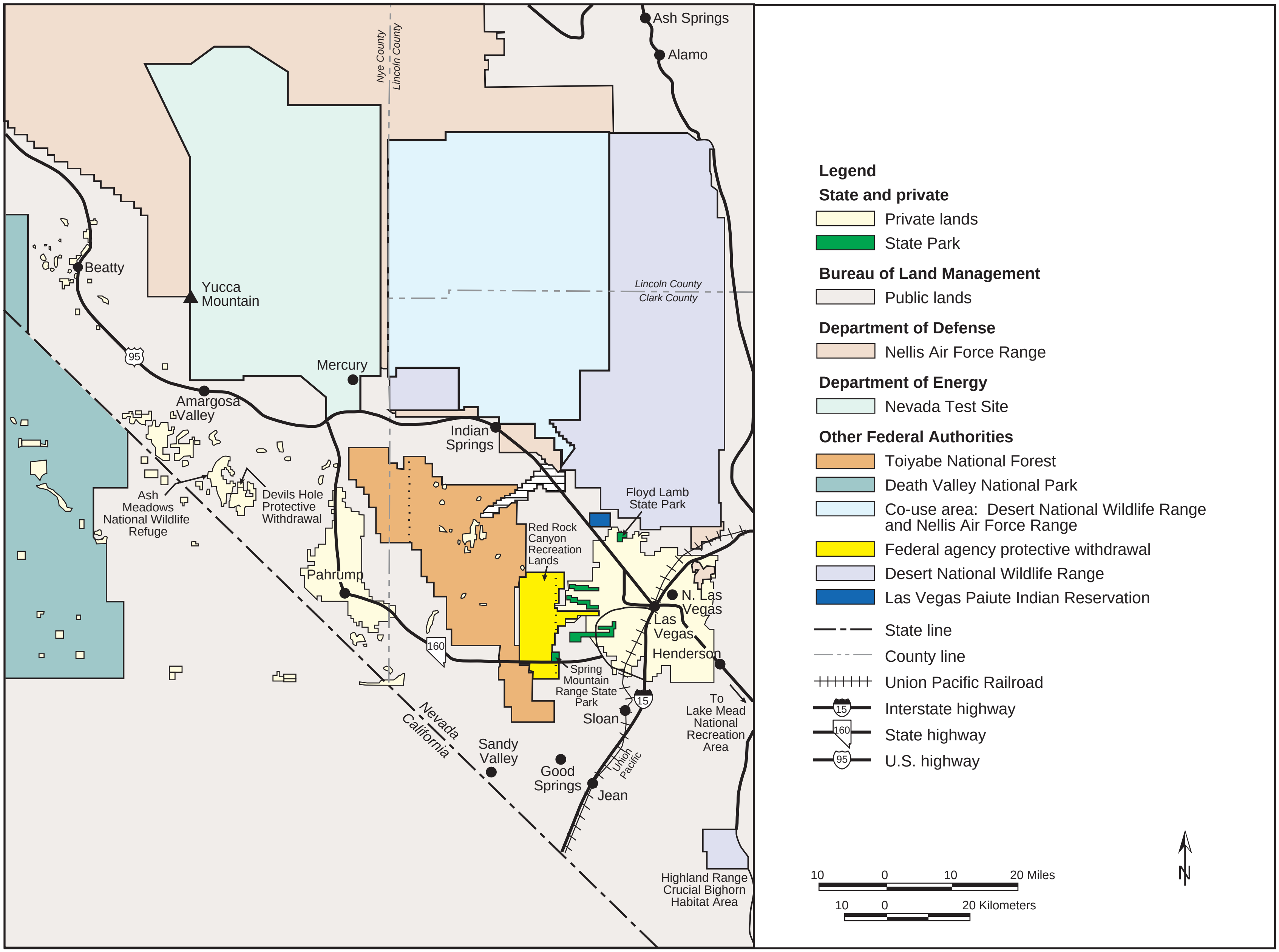


Figure S-17. Land use and ownership in the Yucca Mountain region.

and that might be a carcinogen. DOE compared the potential releases to the new U.S. Environmental Protection Agency National Ambient Air Quality Standard for particulate matter with a diameter of less than 2.5 micrometers. A Federal appeals court recently struck down these new standards. [See American Trucking Association, Inc. v. EPA, No. 97-1440 (D.C. Cir. May 14, 1999).] However, the EIS used these standards, among other standards that were not at issue in that case, in analyzing air quality impacts.

DOE analyzed nonradiological air quality impacts at the potential locations of maximally exposed members of the public. Exposures of maximally exposed individuals to airborne pollutants would be a small fraction of applicable regulatory limits established by the U.S. Environmental Protection Agency. There are slight differences in estimated concentrations for the different thermal loads and different packaging scenarios; however, these do not show meaningful distinctions among any of the scenarios.

Cristobalite would be emitted from the subsurface in exhaust ventilation air during excavation operations and would be released as fugitive dust from the excavated rock pile, so members of the public and noninvolved workers could be exposed. Fugitive dust from the excavated rock pile would be the largest potential source of cristobalite exposure to the public. The postulated annual average exposure of the hypothetical maximally exposed member of the public to cristobalite from construction activities would be small, ranging from 0.01 to 0.03 microgram per cubic meter for the different thermal load scenarios. DOE would use common dust suppression techniques (water spraying, etc.) to reduce releases of fugitive dust from the excavated rock pile.

Radiological Impacts. Radiological air quality impacts could occur from releases of radionuclides, primarily naturally occurring radon-222 and its radioactive decay products, which would be released from the rock into the subsurface facility and then into the ventilation air during all phases of the repository project.

No releases of manmade radionuclides would occur during the construction phase because such materials would not be present until repository operations began. However, there would be naturally occurring radon-222 and its radioactive decay products in the air exhausted from the subsurface. Exposure to naturally occurring radon-222 results in an annual average individual dose in the United States of about 200 millirem. In the subsurface, radon-222 would leave the rock and enter the drifts, from which it would be exhausted as part of repository ventilation. Total estimated radon releases during construction would increase as the thermal load decreased because the excavated volume of the repository would increase as the thermal load decreased. The dose to an offsite maximally exposed individual member of the public would be approximately 0.49 millirem per year; the dose to the maximally exposed noninvolved worker would be approximately 5.4 millirem per year.

During the early years of the operation and monitoring phase, the handling of spent nuclear fuel and continued subsurface ventilation would result in radionuclide releases. Radionuclides, primarily krypton-85 and small amounts of carbon-14, would be released during the transfer of fuel assemblies from transportation casks to disposal containers in the Waste Handling Building. Releases would vary from 90 to 2,600 curies annually depending on the packaging scenario.

A continuing source of doses to members of the public and noninvolved (surface) workers during the operation and monitoring phase would be releases of naturally occurring radon-222 from the subsurface. Estimated radon emissions during this phase would be greater than those during the construction phase because of the larger excavated volume, with more radon emanations from the repository walls and greater quantities exhausted by ventilation. Doses to an offsite maximally exposed individual member of the public and to the maximally exposed noninvolved worker would be highest under the low thermal load scenario (about 1.8 and 3.4 millirem per year, respectively, during the handling, emplacement, and development activities of the operation and monitoring phase).

RADIATION

In the United States, people are inevitably exposed to three sources of ionizing radiation: natural sources unaffected by human activities, such as cosmic radiation from space and natural radiation in the ground (for example, that from radon); sources of natural origin but affected by human activities, such as air travel and tunneling through rocks as at Yucca Mountain; and manmade sources, such as medical X-rays and consumer products. In the Yucca Mountain region, individuals are typically exposed to a 340- to 390-millirem radiation dose from natural and manmade sources each year, compared to about 300 millirem for the average person living in other areas of the United States.

When a person is exposed to radioactive material, the amount of ionizing radiation absorbed by the body is called the radiation *dose*. Dose is often described in measurement units of *rem*, which take into account how different types of radiation affect the body (the biological effectiveness). Small doses are described in *millirem*, each of which is one one-thousandth of a rem.

To analyze the impact of exposure to radiation, DOE used a hypothetical *maximally exposed individual* (member of the public, involved worker, or noninvolved worker), defined as the individual whose location and habits result in the highest potential total radiation dose from a particular source for all exposure routes (inhalation, ingestion, direct exposure).

The dose to members of the public from repository operations would vary by thermal load scenario but not by packaging scenario because naturally occurring radon-222 released from the subsurface would be the dominant dose contributor. Releases from surface facilities during spent nuclear fuel handling would make small differences in the dose received.

During the closure phase, repository subsurface facilities would continue to be ventilated for a period of time. The only doses from releases of radionuclides to the atmosphere would be from naturally occurring radon-222 and its radioactive decay products released from the continued ventilation of subsurface facilities. Doses to an offsite maximally exposed individual member of the public and to the maximally exposed noninvolved worker would be highest under the low thermal load scenario (about 1.2 and 0.12 millirem per year, respectively). The hypothetical maximally exposed individual member of the public would receive a higher dose than the noninvolved worker maximally exposed individual because air would be removed from the repository through exhaust shafts, which would result in more radon being carried to the exposure point for the offsite individual than to that for the noninvolved worker.

S.4.1.3 Geology

Yucca Mountain is a product of volcanic activity that occurred 11.4 million to 14 million years ago and subsequent seismic faulting. The mountain is bordered on the north by Pinnacles Ridge and Beatty Wash, on the west by Crater Flat, on the south by the Amargosa Valley, and on the east by Jackass Flats, which contains Fortymile Wash. Beatty Wash is one of the largest tributaries of the Amargosa River and drains the region north and west of Pinnacles Ridge, a part of Yucca Mountain that is north of the proposed repository. Fortymile Wash is the most prominent drainage through Jackass Flats to the Amargosa River. The river is dry along most of its length most of the time. Figure S-18 shows the physiographic subdivisions and characteristic land forms in the region of influence for geology.

DOE would build the proposed repository and emplace the waste packages in a mass of volcanic rock (welded tuff) known as the Topopah Springs Formation. This formation was formed by a volcanic ash-flow from the calderas north of Yucca Mountain 12.8 million years ago and has not been disturbed by volcanic activity since then. The volcanic activity that produced these rocks is complete and, based on the geology of similar volcanic systems in the region, additional silicic activity would be unlikely. (Younger, small-volume basaltic volcanoes to the north and west of Yucca Mountain have been the focus

VOLCANISM

Differing views on the likelihood of volcanism near Yucca Mountain result from uncertainty in the volcanic hazard assessment. To address these uncertainties, DOE has performed analyses, conducted extensive volcanic hazard assessments, considered alternative interpretations of the geologic data, and consulted with recognized experts. In 1995 and 1996, DOE convened a panel of recognized experts representing other Federal agencies (for example, the U.S. Geological Survey and national laboratories) and universities (for example, the University of Nevada and Stanford University) to assess uncertainties associated with the data and models used to evaluate the potential for disruption of the proposed Yucca Mountain Repository by a volcanic intrusion. The panel estimated that the chance of a volcanic disruption at or near the repository during the first 10,000 years after closure would be 1 in 7,000.

of extensive study by DOE.) DOE chose the Topopah Springs formation as the repository host rock because of (1) its depth below the ground surface that would protect nuclear materials from exposure to the environment, (2) its extent and characteristics that would enable the construction of stable openings and the accommodation of a range of temperatures, (3) its location away from major faults that could adversely affect the stability of underground openings and could provide pathways for water flow, eventually leading to radionuclide release, and (4) its location well above the present water table.

North-trending seismic faults are the characteristic geological structural elements at Yucca Mountain. The Solitario Canyon fault forms the major bounding fault on the west side of Yucca Mountain, and volcanic units in the mountain tilt eastward as a result of the displacement along this and lesser faults through the mountain. One relatively short, northwest-trending subsidiary fault, the Sundance fault, and the north-trending intrablock Ghost Dance fault transect the region. Studies at Yucca Mountain indicate that individual faults have very long recurrence intervals between the types of earthquakes that would be powerful enough to cause surface displacements. Strain can accumulate on these faults over long periods between surface-rupturing earthquakes. Little or no seismic activity might occur during this long strain buildup.

EARTHQUAKES

Experts have evaluated site data and other relevant information to assess where and how often future earthquakes could occur, how large they could be, how much offset could occur at the Earth's surface, and how much ground motion could diminish as a function of distance. DOE will use these results to design the repository to withstand the effects of earthquakes that might occur in the future.

DOE has monitored seismic activity at the Nevada Test Site since 1978. In 1992, an earthquake measuring 5.6 on the Richter scale occurred at Little Skull Mountain, about 20 kilometers (12 miles) southeast of Yucca Mountain. It caused no detectable damage in tunnels at either the Yucca Mountain site or the Nevada Test Site or at characterization facilities at the Yucca Mountain site.

S.4.1.4 Hydrology

Yucca Mountain is in the Death Valley hydrologic basin, which is within the larger area of the Great Basin. This area is characterized by a very dry climate, limited surface water, and deep aquifers. The Death Valley basin is a closed hydrologic basin, which means its surface water and groundwater can leave only by evaporation from the soil and other surfaces and transpiration from plants. Surface-water resources include drainages and streambeds, streams, springs, and playa lakes. The groundwater system includes recharge zones (where water infiltrates from the surface and reaches the saturated zone and aquifers), discharge points (where groundwater reaches the surface), unsaturated zones (above the water table), saturated zones (below the water table), and aquifers (water-bearing layers of rock that can provide water in usable quantities).

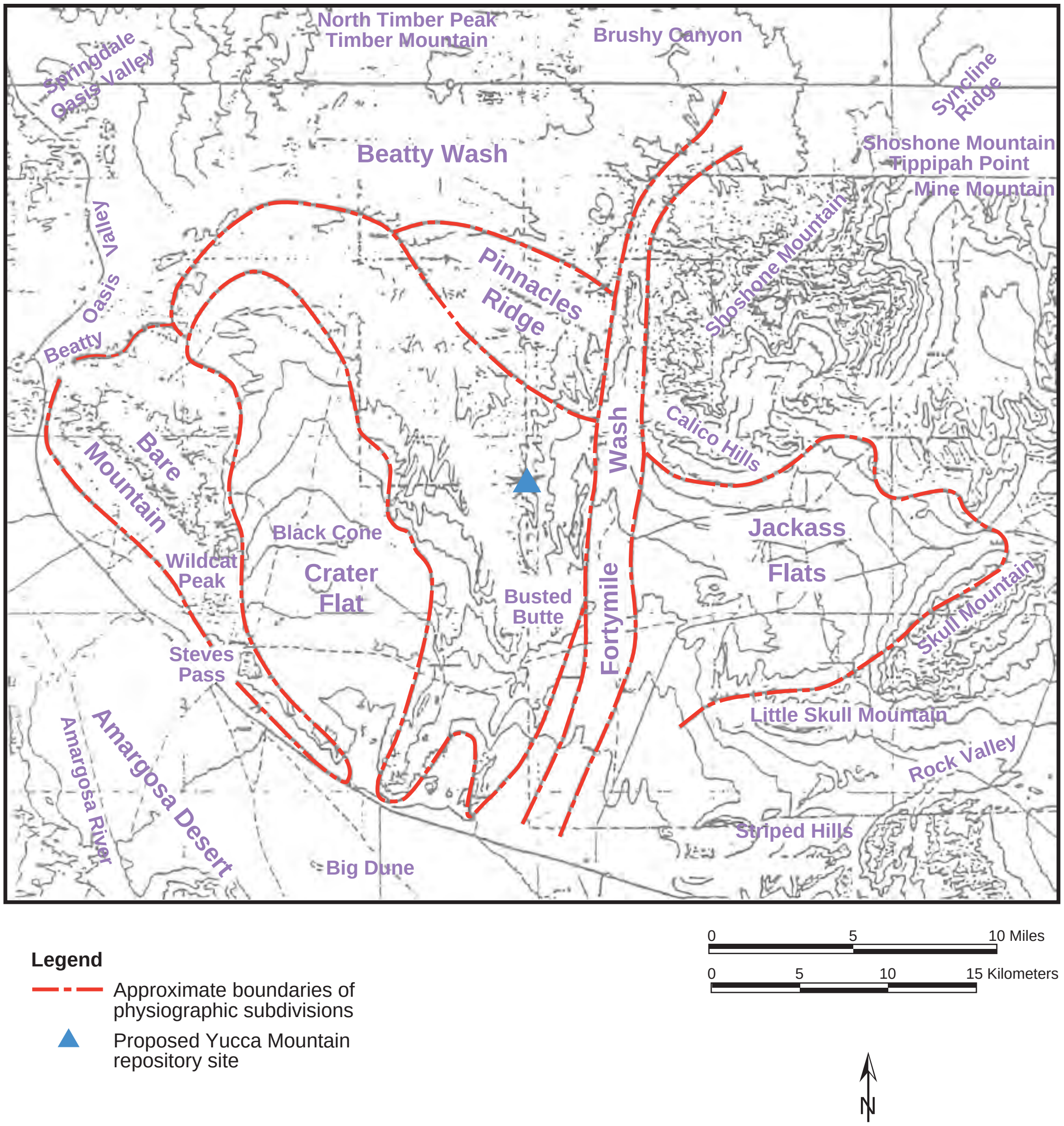


Figure S-18. Physiographic subdivisions of the Yucca Mountain area.

Surface Water. Yucca Mountain and the Death Valley Basin, like other areas in the southern Great Basin, generally lack year-around streams and other surface-water bodies. The Amargosa River system drains Yucca Mountain and the surrounding areas. Although referred to as a river, the Amargosa and its tributaries (the washes that drain to it) are dry most of the time.

Activities associated with the Proposed Action could cause minor impacts to surface hydrology at the Yucca Mountain site. The potential for contaminants to reach surface water generally would be limited to spills or leaks followed by a rare precipitation or snow melt event large enough to generate runoff. The most likely sources of potential surface-water contaminants would be the fuels (diesel and gasoline) and lubricants (oils and greases) needed for equipment. Because these materials would be used and stored inside buildings and managed in accordance with standard best management practices, there would be little potential for contamination to spread to surface water.

Disturbing the land surface probably would alter the rate at which water could infiltrate the surface. Of the approximately 3.5 square kilometers (1.4 square miles or 870 acres) needed for surface repository facilities, construction and operation and monitoring activities probably would disturb about 2 square kilometers (500 acres). However, DOE expects the resulting change in the amount of runoff actually reaching the drainage channels to be relatively minor because repository activities would disturb a relatively small amount of the natural drainage area. The eventual removal of structures and impermeable surfaces, with mitigation (soil reclamation) and rehabilitation of natural plants in disturbed areas, would decrease runoff from these areas.

Facilities at which DOE would manage radioactive materials would be able to withstand the probable maximum flood (the most severe flood that is reasonably foreseeable). The foundations would be built up as necessary so the facilities would be above the flood level. Other facilities would be designed and built to withstand a 100-year flood, consistent with common industrial practice. The water levels expected from a 100-year, 500-year, or probable maximum flood would be unlikely to reach the North and South Portal Operations Areas.

Portions of the transportation system probably would be in the 100-year floodplains of Midway Valley Wash, Drillhole Wash, Busted Butte Wash, and/or Fortymile Wash. Structures that might be constructed in a floodplain could include one or more bridges to span the washes, one or more roads that could pass through the washes, or a combination of roads and culverts in the washes. Based on an initial assessment, potential impacts from such activities would be minor. When more specific information becomes available about activities proposed to take place in floodplains and wetlands, DOE will conduct further environmental review in accordance with a floodplain/wetlands review requirement (10 CFR Part 1022).

Groundwater. The groundwater flow system of the Death Valley region is very complex, involving many groundwater basins, as shown in Figure S-19. Over distance, these layers vary in their characteristics or even their presence. In some areas, confining units allow considerable movement between aquifers; in other areas confining units are sufficiently tight to support artesian conditions (where water in a lower aquifer is under pressure in relation to water in an overlying aquifer).

Groundwater in aquifers below Yucca Mountain and in the surrounding region flows generally south toward discharge areas in the Amargosa

GROUNDWATER

Aquifer: A subsurface saturated rock unit of sufficient permeability to transmit groundwater and capable of yielding usable quantities of water to wells and springs.

Confining unit: A rock or sediment layer that restricts the movement of water into or out of adjacent aquifers.

Spring: A point (sometimes a small area) through which groundwater emerges from an aquifer to the ground surface.

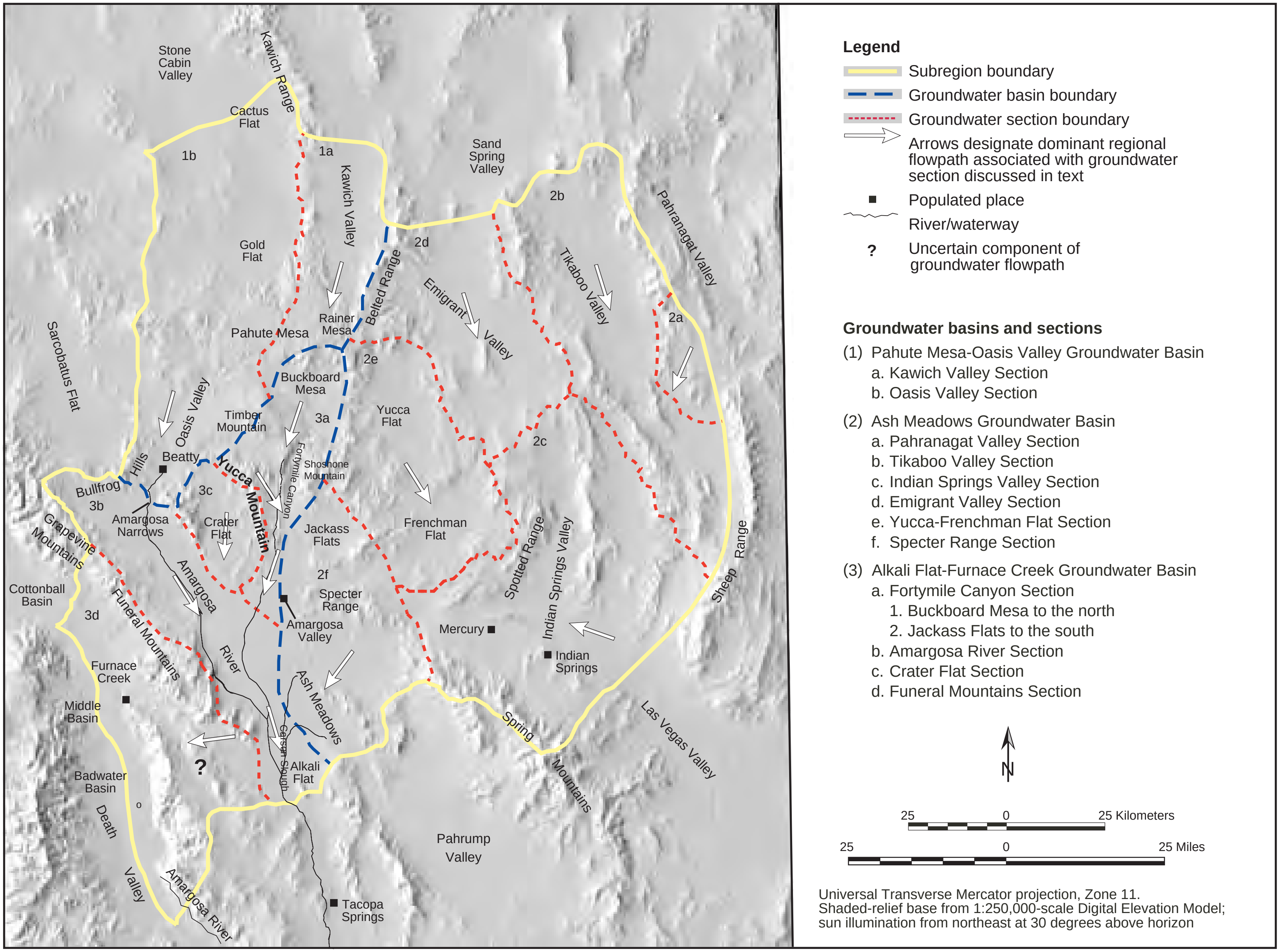


Figure S-19. Groundwater basins in the Yucca Mountain vicinity.

Desert and Death Valley. This broad area is called the Death Valley groundwater basin. The area around Yucca Mountain is in the central portion of the regional groundwater basin, which has three sub-basins: (1) Pahute Mesa-Oasis Valley, (2) Ash Meadows, and (3) Alkali Flat-Furnace Creek Ranch.

There is scientific uncertainty about the exact locations of the groundwater flow boundaries between the three sub-basins in the Death Valley groundwater basin. All interpretations of the available data, however, place the aquifers below Yucca Mountain in the central Alkali Flat-Furnace Creek Ranch sub-basin. In the region of influence for hydrology, the primary sources of groundwater recharge are infiltration on Pahute Mesa, Timber Mountain, and Shoshone Mountain to the north, and the Grapevine and Funeral Mountains to the south. Recharge in the immediate Yucca Mountain vicinity is small in comparison and consists of water reaching Fortymile Wash as well as precipitation that infiltrates the surface. DOE studies indicate that the quantity of water that might move through a repository area of 10 square kilometers (2,500 acres), assuming 6.5 millimeters (0.3 inch) of infiltration per year, would be about 0.3 percent of the estimated 23.4 million cubic meters (19,000 acre-feet) that moves from the Amargosa Desert to Death Valley on an annual basis.

To pose a threat to groundwater, a contaminant would have to be spilled or released and then carried down either by its own weight or by infiltrating water. The depth to groundwater and the arid environment would combine to reduce the potential for meaningful contaminant migration.

The most likely way to affect infiltration rates and, thus, groundwater recharge would be as the result of a land disturbance that caused additional runoff from the facilities to accumulate in areas like Fortymile Wash. That is, the additional runoff could increase groundwater recharge. However, given the dry climate and relatively small amount of potentially disturbed area in relation to the surrounding unchanged areas, the net change in infiltration would be small. After closure, the implementation of soil reclamation and revegetation would accelerate a return to more natural infiltration conditions.

DOE would meet the water demand for the Proposed Action by pumping from the groundwater in the Jackass Flats area. The perennial yield of the aquifer (the estimated quantity of groundwater that can be withdrawn annually without depleting the reservoir) in the Jackass Flats area is between 1.1 million and 4.9 million cubic meters (890 and 4,000 acre-feet). The highest demand during repository construction added to the demand from ongoing Nevada Test Site activities would be below the lowest estimate of the area’s perennial yield.

However, repository water demands during emplacement and development activities, when combined with the baseline demands from Nevada Test Site activities, would exceed the lowest perennial yield estimate under the low thermal load for all packaging scenarios. The combined water demand under the high or intermediate thermal load scenario would not exceed the lowest estimates of perennial yield. None of the water demand estimates would approach the high estimates of perennial yield.

S.4.1.5 Biological Resources and Soils

The plants and animals in the Yucca Mountain vicinity are typical of species in the Mojave and Great Basin Deserts. No plants listed as *threatened* or *endangered*, that are proposed for listing, or that are candidate species under the Endangered Species Act occur in the land withdrawal area analyzed in this EIS. No plant species classified as *sensitive* by the Bureau of Land Management are known to occur in the analyzed land withdrawal area. Several species of cacti and yucca protected from commercial collection by the State of Nevada occur throughout the Yucca Mountain region, including the analyzed land withdrawal area. Neither the removal of vegetation from the small area required for the repository nor the impacts to some species would affect regional biological diversity and ecosystem function.

One animal that lives at the Yucca Mountain site, the desert tortoise, is listed as *threatened* under the Endangered Species Act. Yucca Mountain is at the northern edge of the range of the desert tortoise, and the presence of tortoises at the site is infrequent in comparison to other portions of its range. DOE would continue to work with the Fish and Wildlife Service to minimize impacts to desert tortoises at the site. There is no critical habitat in the analyzed land withdrawal area.

Five animal species classified as *sensitive* by the Bureau of Land Management (two bats, a lizard, an owl, and a beetle) occur at the Yucca Mountain site. These species are unlikely to be affected by repository activities because loss of individuals would be rare or a small amount of habitat would be disturbed, depending on the species.

There would be small quantities of routine releases of radioactive materials from the repository. These releases would consist of gases, principally krypton and small amounts of carbon-14 from spent nuclear fuel and naturally occurring radon. The small quantities released would result in small doses to plants and animals as the gases dispersed in the atmosphere. The estimated doses would be unlikely to affect the population of any species.

There are no wetlands on the proposed repository site, so no impacts to such areas would occur as a result of repository construction, operation and monitoring, or closure. Soils at the site are from underlying volcanic rocks and mixed alluvium (sand, silt, or clay deposited on land by water) dominated by volcanic material, and in general have low water-holding capabilities. The potential for soil impacts such as erosion would increase slightly as a result of land-disturbing activities at the site, but DOE would use erosion control techniques to minimize impacts.

DOE also considered whether, during the postclosure period, the repository would affect biological resources at Yucca Mountain on the repository footprint through the heating of the ground surface and through radiation exposure to species from contaminant migration through groundwater to discharge points. After closure, heat from the decay of radionuclides in the waste would cause temperatures in the rock near the disposal containers to rise above the boiling point of water. The time that the subsurface temperature would remain above the boiling point would vary from a few hundred years (under the low thermal load) to a few thousand years (under the high thermal load). Conduction and the flow of heated air and water through the rock would carry the heat away from the disposal containers through the rock. The heat would spread to the surface above and to the aquifer below.

Although the atmosphere would remove excess heat when it reached the ground surface, the temperature of near-surface soils would be likely to increase slightly. Surface soil temperatures could increase by as much as approximately 3°C (5.4°F) in dry soil at a depth of 1 meter (3.3 feet), which could affect root growth and the growth of microbes or nutrient availability. Potential impacts from the repository on biological resources would consist of an increase of heat-tolerant species and a decrease of less heat-tolerant species. In general, areas affected by repository heating could experience a loss of shrub species and an increase in annual species. A shift in the plant community could also lead to localized changes in the animal community that depend on the plant community for food and shelter. The effects of repository heat on the surface soil temperatures would gradually decline with distance from the repository out to about 500 meters (1,640 feet). DOE expects any shift in species composition to be limited to that general area.

In the distant future (many thousands of years) groundwater would contain small quantities of radionuclides and chemically toxic substances. Because the estimated doses to humans exposed to this water would be very small, impacts to plants and animals would be small and unlikely to have adverse impacts on the population of any species.

Impacts to surface soils at Yucca Mountain in the postclosure period would be possible. If vegetation cover decreased as a result of the presence of the repository, the amount of rainfall runoff and the amount of sediment could be higher, thereby changing the surface-water quality in the Yucca Mountain area.

S.4.1.6 Cultural Resources

Land disturbances associated with the Proposed Action could have direct impacts on cultural resources around Yucca Mountain. Archaeological investigations in the immediate vicinity of the proposed surface facilities during characterization studies and infrastructure construction have identified 826 archaeological and historic sites. Most of the archaeological sites are small scatters of stone artifacts. None of the sites has been listed on the *National Register of Historic Places*, but 150 are potentially eligible.

Repository development would disturb no more than about 2 square kilometers (500 acres) of previously undisturbed land at the site. Before repository development activities began, DOE would identify and evaluate archaeological or cultural resources sites for their importance and eligibility for inclusion on the *National Register of Historic Places*. DOE would avoid such sites if possible or, if avoidance were not possible, DOE would conduct a data recovery program in cooperation with tribal representatives and other appropriate officials and would document the findings. Artifacts and knowledge from the site would be preserved. Improved access to the area could lead to indirect impacts, which could include unauthorized excavation or collection of artifacts. Training, which is ongoing during site characterization activities, would continue to be provided to workers on the laws and regulations related to the protection of cultural resources.

Studies have described several Native American sites, areas, and resources in or immediately adjacent to the analyzed land withdrawal area. DOE recognizes that Native Americans have concerns about protecting traditions and the spiritual integrity of the land in the Yucca Mountain region, and that these concerns extend to the propriety of the Proposed Action. The Consolidated Group of Tribes and Organizations in the area surrounding the Yucca Mountain site value the cultural resources in the area, viewing them in a holistic manner. They believe that the water, animals, plants, air, geology, sacred sites, and artifacts are interrelated and dependent on each other for existence. Because of the general level of importance attributed to the land by these Native Americans, and because they regard the land as part of an equally important integrated cultural landscape, these Native Americans consider the intrusive nature of the repository to be an adverse impact to all elements of the natural and physical environment. The establishment of the land withdrawal boundary and construction of the repository would continue to restrict their free access to these areas. Figure S-20 shows traditional boundaries and locations of tribes in the region.

S.4.1.7 Socioeconomics

Southern Nevada has been one of the fastest-growing areas in the country, with its economy being driven by the growth of the hotel and gaming industry. Most of the Yucca Mountain Project and Nevada Test Site onsite employees live in Clark (79 percent of employees), Lincoln (0.3 percent), and Nye (19 percent) Counties. Between 1980 and 1990, Clark County experienced a 4.8-percent annual growth rate (compared to 4 percent in Nevada and less than 1 percent in the United States as a whole), and added an average of 19,000 jobs per year. Since 1990, that pace has increased to more than 30,000 new jobs per year. Similarly, Nye County experienced a 3.7 percent annual growth rate, while Lincoln County's population increased by about 10 percent between 1990 and 1997. Because of the thousands of new jobs added to the economy each month, the area has a low unemployment rate. In addition, the residential housing market is strong and steady; steady employment and population growth are spurring the demand for housing. Public services such as education, health care, law enforcement, and fire protection are adequate. However, these services likely will require expansion if the general growth in the economy and population continues.

The DOE evaluation of impacts to the socioeconomic environment in communities in the vicinity of the proposed repository considered changes to employment, population, housing, and public services. The potential for changes in the socioeconomic environment would generally be on the order of a 1 to 5 percent change, depending on the attribute and the county. For example, the largest change in population

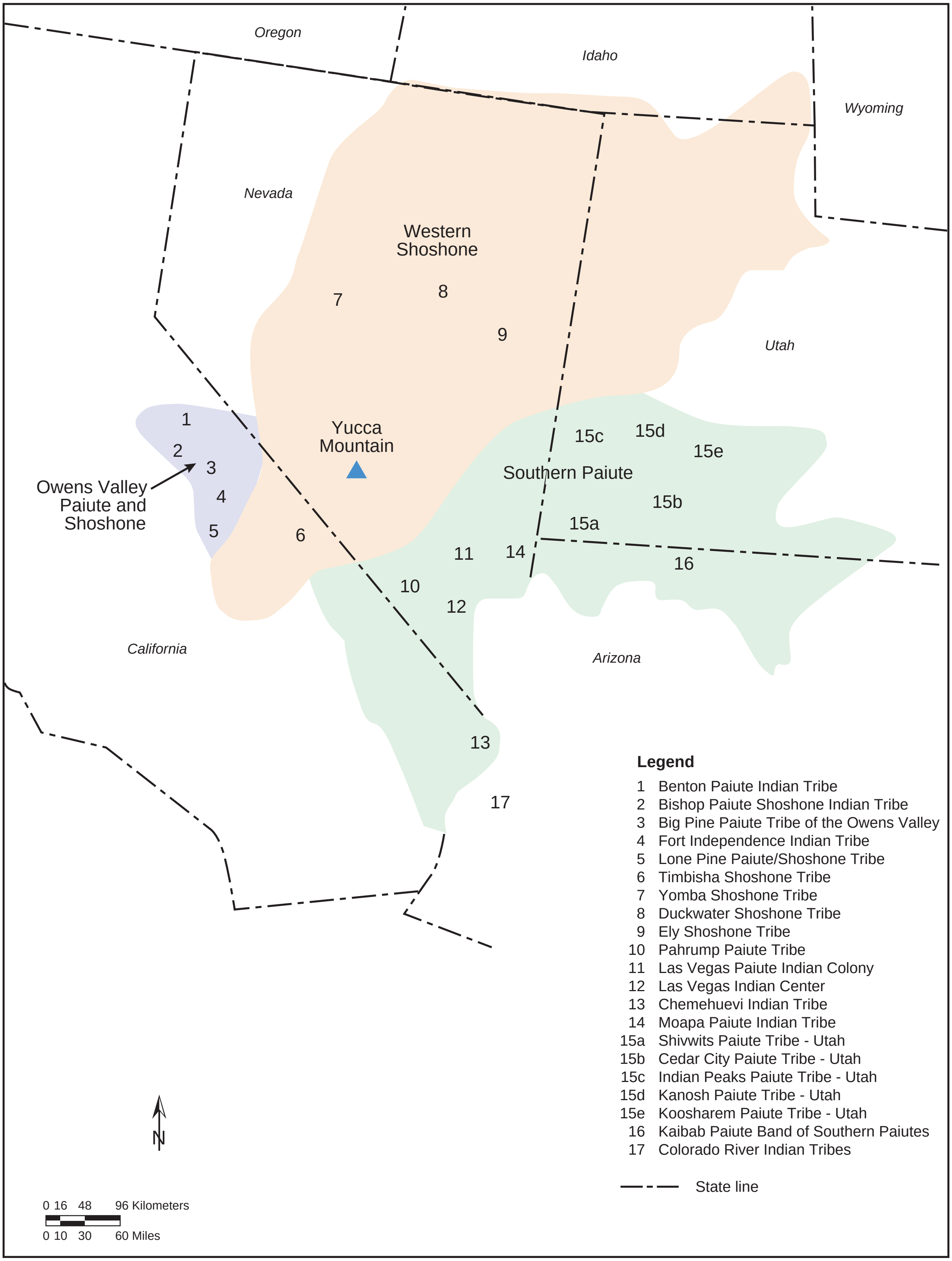


Figure S-20. Traditional boundaries and locations of tribes in the Yucca Mountain region.

would range from less than 1 percent in Clark County to about 2 percent in Nye County, to as high as 5.8 percent in Lincoln County (assuming the selection of a rail or heavy-haul transportation route in Lincoln County).

For the EIS analysis, DOE established a bounding case with which to examine the maximum potential employment levels it would need to implement design alternatives and packaging scenarios and to identify the combination that would produce the highest employment. This maximum employment case would be the combination of the low thermal load scenario and the uncanistered packaging scenario. The analysis of this bounding case determined that no large socioeconomic impacts would be likely. Maximum employment and population changes in the region as a result of the repository would not exceed one-half of 1 percent of the projected employment and population levels in 2000. Similarly, impacts to housing availability and public services from population changes in the region resulting from repository activities would be small.

S.4.1.8 Occupational and Public Health and Safety

The analysis of occupational and public health and safety considered short-term (about 100 years) health impacts from routine operations (1) to workers from hazards that are common to similar industrial settings and excavation operations, such as falling or tripping (referred to as industrial hazards), (2) to workers and the public from naturally occurring nonradiological materials in the rock under Yucca Mountain, (3) to workers as a result of exposure to radiation sources during their work activities, and (4) to the public from airborne releases of radionuclides (estimated doses are described in Section S.4.1.2). The analysis also considered involved workers (those who would participate in a particular activity) and noninvolved workers (those who would be on the site but would not participate directly in the activity in question). In addition, the analysis estimated impacts from radiological and nonradiological doses to a hypothetical maximally exposed member of the public at the site boundary 20 kilometers (12 miles) south of the repository, and the collective effect to the public within about 80 kilometers (50 miles).

HEALTH AND SAFETY IMPACTS

Workers
- Industrial hazards
  - Involved workers
  - Noninvolved workers
- Nonradiological impacts
  - Involved workers
  - Noninvolved workers
- Radiological impacts
  - Involved workers
  - Noninvolved workers

Public
- Nonradiological impacts
  - Maximally exposed individual
  - Population
- Radiological impacts
  - Maximally exposed individual
  - Population

Impacts to Workers from Industrial Hazards. Workers would be subject to industrial hazards during all phases of the Proposed Action. Examples of the types of industrial hazards that could present themselves include tripping, being cut on equipment or material, dropping heavy objects, and catching clothing in moving machine parts. Most impacts would be the result of surface facility operations (loading fuel at the Waste Handling Building) during the operation and monitoring phase, because a large fraction of the workers would be associated with surface facility operation. These workers would be mainly engaged in material handling operations in the Waste Handling Building. The next biggest component of industrial hazards would be the result of the excavation of drifts during the same phase. Other surface facility activities (equipment and facility maintenance), monitoring activities, and general office and industrial site activities would account for the remainder of the industrial hazard impacts.

The highest estimated total number of industrial hazards would occur under the combination of the low thermal load scenario and the uncanistered packaging scenario (1.9 fatalities). The lowest estimated total number would occur under the combination of the high thermal load scenario and the dual-purpose canister or disposable canister scenario (1.5 fatalities). The difference in fatalities is in part associated with the increased excavation activities and the larger operations area under the low thermal load.

In general, impacts from the high and intermediate thermal load scenarios would be about the same; those from the low thermal load scenario would be 8 to 10 percent higher. Similarly, impacts from the uncanistered packaging scenario would be 10 to 15 percent higher than for the dual-purpose and disposable canister scenarios. The differences in impacts reflect differences in the number of workers required for the scenarios.

Nonradiological Impacts to Workers and the Public. DOE would use engineering controls during subsurface work to control exposures of subsurface workers to silica dust that might contain cristobalite. If engineering controls could not keep dust concentrations below established limits, subsurface workers would have to wear respirators. Similar controls would be applied for surface workers if necessary. DOE expects that exposure of subsurface and surface workers to silica dust would be below applicable regulatory limits and that potential impacts to these workers would be low. Cristobalite concentrations at the site boundary would be small and unlikely to pose impacts to the public.

Radiological Impacts to Workers. Radiological impacts to workers are reported both in terms of the increase in likelihood of a latent cancer fatality for an individual, and the increase in the total number of latent cancer fatalities for the total worker population. DOE calculated a total increase of 3 to 4 potential latent cancer fatalities for repository workers during construction, operating and monitoring, and closure activities, depending on the thermal load. The probability of the maximally exposed worker incurring a latent cancer fatality would be small (between 0.006 and 0.008, or between 6 and 8 chances in 1,000) through the closure of the repository.

The highest estimated number of potential latent cancer fatalities to workers (4) would occur under the combination of the low thermal load scenario and the uncanistered packaging scenario. The lowest estimated number would occur under the combination of the high thermal load scenario and the dual-purpose canister or disposable-canister scenario (2.6 fatalities).

Radiological health impacts to workers would be greatest for the low thermal load scenario, about 20 percent higher than those for the high thermal load scenario because of the larger number of workers required. Worker impacts for the uncanistered scenario would be about one-third higher than those for the other packaging scenarios, again because of the larger number of workers required, and because of potential exposure to krypton-85 and carbon-14 gases.

The principal source of exposure to workers from radioactivity would be spent nuclear fuel receipt and handling activities in the surface facilities (about 50 percent). The other large contributor (about 25 percent) would be radiation exposure from the inhalation of radon-222 and the decay products by subsurface workers during construction and emplacement activities. Other important radiological contributions to worker health effects in the subsurface environment would come from naturally occurring radionuclides in the rock of the drifts.

Radiological Impacts to the Public. Short-term radiological health impacts to the public for Yucca Mountain construction, operation and monitoring, and closure would be small. (Impacts from transportation are discussed in Section S.4.2.) The likelihood that the maximally exposed individual would incur a latent cancer fatality from proposed repository activities would be less than 0.00002 (2 in 100,000) under the high thermal load scenario and about 0.00005 (5 in 100,000) under the low thermal load scenario. The estimated total number of latent cancer fatalities for the public through the closure of the repository would be less than one [ranging from 0.14 (high thermal load) to 0.41 (low thermal load)].

For the sake of comparison, the American Cancer Society reports that the Nevada cancer fatality rate per year from all sources is 185 deaths per 100,000 people. Assuming this mortality rate would remain

LATENT CANCER FATALITIES

A latent cancer fatality is a death from cancer resulting from, and occurring some time after, exposure to ionizing radiation. Exposure to radiation that results in a 1-rem (1,000-millirem) dose causes an estimated 0.0005 chance of causing a fatal cancer.

In a population of 10,000 people, national statistics indicate that about 2,224 people would die from cancer of one form or another. Using information developed by the International Commission on Radiological Protection, if all 10,000 people received a dose of 200 millirem (in addition to the normal background radiation dose), an estimated 1 additional cancer fatality would occur in that population. However, we would not be able to tell which of the 2,225 fatal cancers was caused by radiation and, possibly, the additional radiation would cause no fatal cancers.

Sometimes, calculations of the number of latent cancer fatalities associated with radiation exposure do not yield whole numbers, and, especially in environmental applications, may yield numbers less than 1.0. For example, if each individual in a population of 100,000 received a total dose of 0.001 rem, the collective dose would be 100 person-rem and the corresponding estimated number of latent cancer fatalities would be 0.05 (100,000 persons × 0.001 rem × 0.0005 latent cancer fatality per person-rem). How should one interpret a nonintegral number of latent cancer fatalities, such as 0.05? The answer is to interpret the result as a statistical estimate. That is, 0.05 is the *average* number of deaths that would result if the same exposure situation were applied to many different groups of 100,000 people. For most groups, no one would incur a latent cancer fatality from the 0.001 rem dose each member would have received. In a small fraction of the groups, 1 latent fatal cancer would result; in exceptionally few groups, 2 or more latent fatal cancers would occur. The *average* number of deaths over all of the groups would be 0.05 latent fatal cancer (just as the average of 0, 0, 0, and 1 is 1/4, or 0.25). The most likely outcome for any single group is 0 latent cancer fatalities.

unchanged over the 100-year period of repository construction, operation and monitoring, and closure, the population of about 28,000 within 80 kilometers (50 miles) of the Yucca Mountain site would experience an annual cancer mortality rate of about 50 cancer deaths per year from causes unrelated to the proposed repository at Yucca Mountain. Thus, through the closure of the repository, cancer deaths from other causes would total about 5,000.

Long-Term Radiological Health Impacts. DOE considered potential long-term human health impacts for 9,900 years after repository closure and also determined the peak dose rate during 1 million years after repository closure. The analysis estimated potential human health impacts from the undisturbed evolution of the repository, which would include such natural processes as corrosion of waste packages, dissolution of waste forms, and changing climate. In addition, it considered the effects of such disturbances as exploratory drilling or volcanic events.

The heat generated by spent nuclear fuel and high-level radioactive waste (the thermal load) could affect the long-term performance of the repository (that is, the ability of the engineered and natural barrier system to isolate the emplaced waste from the accessible environment for long periods).

UNCERTAINTY IN LONG-TERM PERFORMANCE

A substantial amount of uncertainty is associated with estimates of long-term repository performance. The uncertainty regarding a repository's long-term performance was handled in two ways. First, where the uncertainty was considered very important to the outcome, conservative assumptions were used that tended to overstate the risks that would be obtained by a more realistic model. Second, ranges of data were used in a probabilistic sampling routine to produce ranges of results that reflected the effect of the range of inputs. This ensures that the long-term performance estimates are conservative.

Different thermal loads would have different direct effects on internal and external waste package temperatures, potentially affecting the corrosion rate and integrity of the waste packages. In addition, the heat generated by the packages could affect the geochemistry, hydrology, and mechanical stability of the emplacement drifts, which in turn could influence groundwater flow and the transport of radionuclides from the engineered and natural barrier systems to the environment.

For all three thermal load scenarios, radioactive materials that entered the groundwater would produce the primary impacts from the repository to human health in the far future. Figure S-21 shows the potential movement of contaminants from the repository to the accessible environment. The analysis estimated human health impacts from the groundwater pathway at four locations in the Yucca Mountain region: water wells 5, 20, and 30 kilometers (3, 12, and 19 miles) from the repository and the nearest surface-water discharge point, which is about 80 kilometers (50 miles) away. The estimated health impact would be the probability of a resulting latent cancer fatality from lifetime use of the contaminated water.

Under all three thermal load scenarios, less than 1 latent cancer fatality would be likely over the 9,900-year analysis period. The analysis indicated that the high thermal load scenario would have a higher dose rate [1.3 millirem per year at 5 kilometers (3 miles)] and correspondingly greater health effects on the maximally exposed individual (lifetime probability of a latent fatal cancer of 0.000044) than the other scenarios. In addition, concentrations of chemically toxic materials were found to be lower than identified Maximum Contaminant Levels and Maximum Contaminant Level Goals and where no levels or goals have been established were found to be very low. Therefore, DOE does not anticipate detrimental impacts to water quality or human health from toxic materials.

In addition, DOE estimated the dose rate for 1 million years after repository closure. For the high thermal load scenario, the peak dose rate would be 9,100 millirem to a maximally exposed individual at 5 kilometers from the repository, occurring 320,000 years after closure (2,800 millirem under the intermediate thermal load scenario and 3,600 millirem under the low thermal load scenario). Variations in the peak dose rates to a maximally exposed individual among the three thermal loads would be caused by earlier waste package failures under the high thermal load, placement of waste packages in different areas of the repository, and different amounts of water infiltrating through the different repository areas.

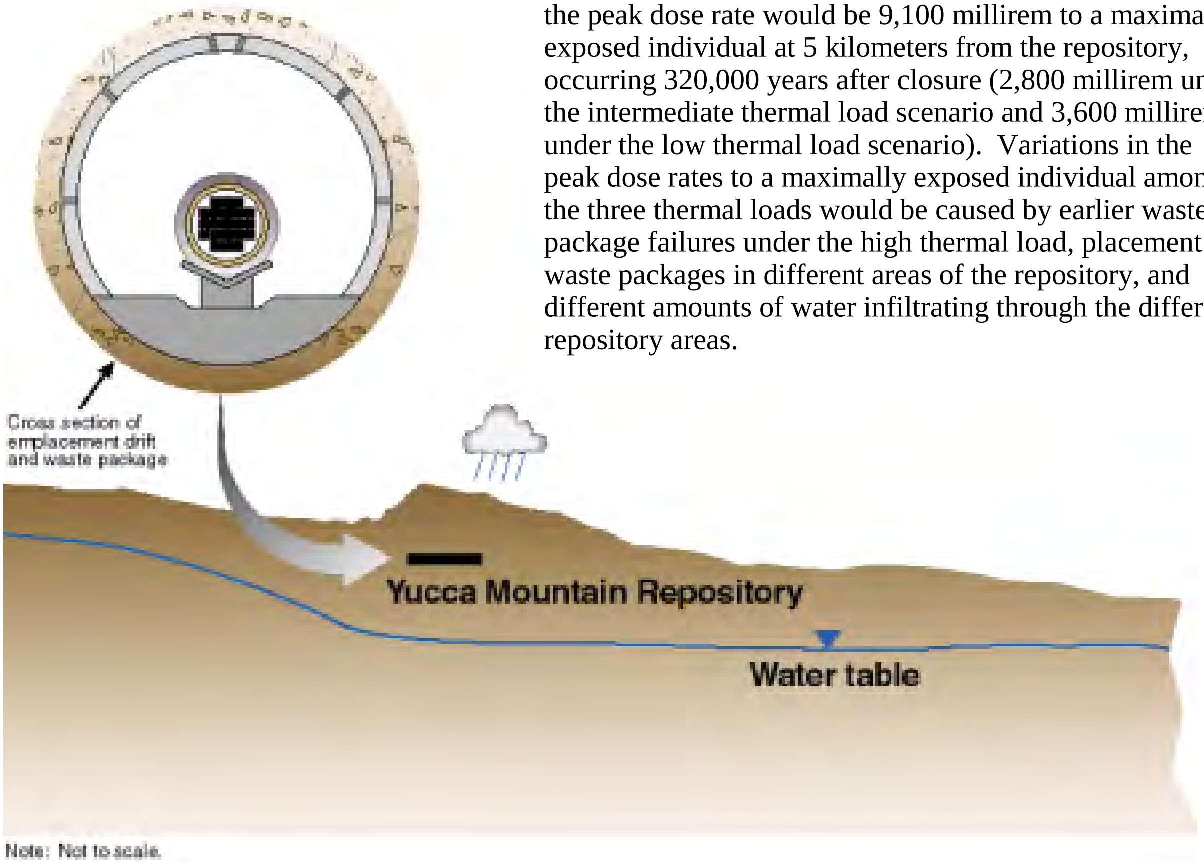


Figure S-21. Potential movement of contaminants from the repository to the accessible environment.

S.4.1.9 Accident Scenarios

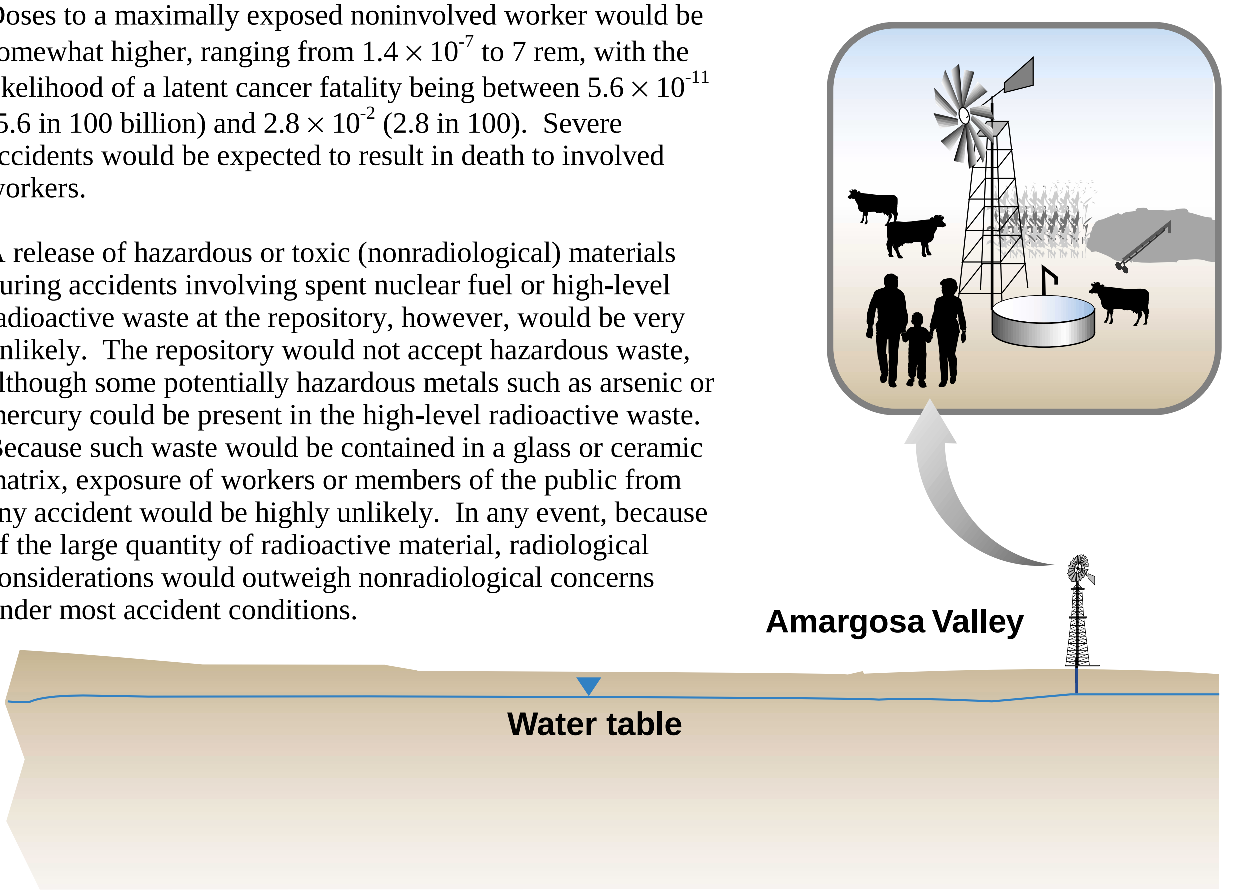
ACCIDENT

An unplanned event or sequence of events that results in undesirable consequences.

The evaluation of accident scenarios associated with the Proposed Action included the potential for radiological accidents and accidents involving exposure to hazardous and toxic substances in the first 100 years of repository activities. The potentially affected individuals considered include (1) the maximally exposed individual, a hypothetical member of the public at the point on the site boundary who would receive the largest dose, (2) the involved worker who would be handling the spent nuclear fuel or high-level radioactive waste when the accident occurred, (3) the noninvolved worker near the accident but not involved in handling the material, and (4) members of the public living within about 80 kilometers (50 miles) of the repository. The accident scenario analysis examined consequences under both median (50th-percentile) meteorological conditions and highly unfavorable meteorological conditions (95th-percentile, or those that would not be exceeded more than 5 percent of the time) that tend to maximize potential radiological impacts.

DOE analyzed 16 accident scenarios that represent all reasonably foreseeable impacts from accidents that could occur during repository operations. The frequency of these accident scenarios ranged from 0.59 per year to 1.2×10^{-7} per year. Impacts to the maximally exposed offsite individual from any of these accidents would be small, with doses ranging from 1.9×10^{-9} to 0.013 rem. The corresponding chance of a latent cancer fatality if such an accident occurred would be between 3.1×10^{-13} (3.1 in 10 trillion) and 1.6×10^{-5} (1.6 in 100,000) over the lifetime of the individual. Doses to a maximally exposed noninvolved worker would be somewhat higher, ranging from 1.4×10^{-7} to 7 rem, with the likelihood of a latent cancer fatality being between 5.6×10^{-11} (5.6 in 100 billion) and 2.8×10^{-2} (2.8 in 100). Severe accidents would be expected to result in death to involved workers.

A release of hazardous or toxic (nonradiological) materials during accidents involving spent nuclear fuel or high-level radioactive waste at the repository, however, would be very unlikely. The repository would not accept hazardous waste, although some potentially hazardous metals such as arsenic or mercury could be present in the high-level radioactive waste. Because such waste would be contained in a glass or ceramic matrix, exposure of workers or members of the public from any accident would be highly unlikely. In any event, because of the large quantity of radioactive material, radiological considerations would outweigh nonradiological concerns under most accident conditions.



S.4.1.10 Noise

Background noise at Yucca Mountain is caused by natural phenomena such as rain and wind and noise from people, including vehicles from site characterization activities and from occasional low-flying military jets. Sound-level measurements recorded in May 1997 at areas adjacent to and at the Yucca Mountain site were consistent with noise levels associated with industrial operations (sound levels from 43 to 72 decibels).

Repository activities during construction, operation, and closure that could generate elevated noise levels would include use of heavy equipment, ventilation fans, diesel generators, transformers, and a concrete batch plant.

Workers at the repository site could be exposed to elevated levels of noise. However, worker exposures to elevated noise levels during all repository phases would be controlled by the use of protective equipment, so impacts from noise would be unlikely.

The distance from the Yucca Mountain site to the nearest housing is about 22 kilometers (14 miles). Based on an estimated maximum noise level from repository operations, DOE calculated that noise from the repository would be at the lower limit of human hearing at 6 kilometers (3.7 miles). For this reason, DOE expects no meaningful noise impacts to the public from repository construction and operations.

S.4.1.11 Aesthetics

Yucca Mountain has visual characteristics fairly common to the region, and the visibility of the site from publicly accessible locations is low or nonexistent. The largest structure would be the Waste Handling Building at the North Portal Operations Area, which would be about 37 meters (120 feet) tall with a taller exhaust stack. Other buildings and structures would be smaller and at elevations equal to or lower than that of the Waste Handling Building. No building or structure would exceed the elevation of the southern ridge of Yucca Mountain [1,400 meters (4,500 feet)]. Therefore, no part of the repository would be visible to the public from the west. The intervening Striped Hills and the low elevation of the southern end of Yucca Mountain and Busted Butte would obscure the view of repository facilities from the south near Lathrop Wells and the Amargosa Valley, approximately 28 kilometers (17 miles) away. There is no public access to the north or east of the repository site to enable viewing of the facilities. DOE would provide lighting for operation areas at the repository that could be visible from public access points. Closure activities, such as dismantling facilities and reclaiming the site, would be likely to restore the visual quality of the landscape, as viewed from the site itself.

S.4.1.12 Utilities, Energy, and Materials

The scope of the analysis included electric power use, fossil-fuel consumption, consumption of construction materials, and onsite services such as emergency medical support, fire protection, and security and law enforcement. Overall, DOE does not expect large impacts to residential water, energy, materials, and emergency services from the Proposed Action.

Electricity. The repository demand for electricity would be well within the expected regional capacity for power generation. The current electric power supply line has a capacity of 10 megawatts. During the early stages of repository operations, when emplacement activities would be occurring while new drifts were being developed, the peak electric power demand would be between 34.5 and 37.5 megawatts, depending on the thermal load and packaging scenarios. Therefore, DOE could need to enhance the electric power delivery system to the Yucca Mountain site.

Fossil Fuel. Fossil fuel would include diesel fuel, gasoline, and fuel oil. During the construction phase, the low thermal load scenario and the uncanistered packaging scenario would require construction of more facilities, thereby requiring the highest use of fossil fuels. Yearly repository use during construction would be less than 1 percent of the current use in Clark, Lincoln, and Nye Counties, and should result in only small impacts to fossil-fuel supplies.

Fossil-fuel use during the operation and monitoring phase would be highest during emplacement and development operations and would decrease substantially during monitoring and maintenance activities. The highest annual use would be less than 5 percent of the 1996 use in Clark, Lincoln, and Nye Counties. Thus, the projected use of liquid fossil fuels should be within the available regional capacity and should result in only small impacts to fossil-fuel supplies.

Construction Materials. The primary materials needed to build the repository would be concrete, steel, and copper. Concrete, which consists of cement and aggregate, would be used for subsurface tunnel liners and the construction of surface facilities. DOE would use excavated rock for aggregate, and would purchase cement regionally. The low thermal load scenario would require the largest amount of concrete, which would be less than 3 percent of the amount used in Nevada in 1997. Because steel and copper have worldwide markets, DOE expects little or no impact from an increased demand for steel and copper in the region.

Emergency Services. An emergency response system would be established to respond to accidents at the repository site. The capabilities would include emergency and rescue equipment, communications, facilities, and trained professionals to respond to fire, radiological, mining, industrial, and general accidents above or below ground. The onsite service capabilities would be able to respond to most events, including underground events, without outside support. Therefore, a large impact on the emergency services of surrounding communities or counties would be unlikely.

S.4.1.13 Waste Management

The evaluation of waste management impacts considered the quantities of nonhazardous industrial, sanitary, hazardous, mixed (both radioactive and hazardous), and radioactive wastes that repository-related activities would generate. DOE would build onsite facilities to accommodate construction and demolition debris, sanitary and industrial solid wastes, sanitary sewage, and industrial wastewater, or could use the existing Nevada Test Site landfill. DOE would use less than 3 percent of the existing available offsite capacity for low-level radioactive waste disposal and a smaller fraction of the available hazardous waste disposal capacity.

The different thermal load scenarios would produce different nonradioactive waste quantities due to the different workforce sizes. Similarly, the different waste packaging scenarios would affect the volumes of hazardous and low-level radioactive waste due to the differences in handling the spent nuclear fuel and high-level radioactive waste. However, the overall impact of managing the Yucca Mountain waste streams would not differ greatly among the thermal load and packaging scenarios.

RECYCLING OF DUAL-PURPOSE CANISTERS

The dual-purpose canister packaging scenario would involve the ultimate disposal of the canisters [that is, an additional estimated 30,000 cubic meters (1 million cubic feet) of low-level radioactive waste]. DOE could decide to recycle the canister materials if doing so would be more protective of the environment and more cost-effective than disposing of them.

S.4.1.14 Environmental Justice

Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*, directs Federal agencies to work to achieve "environmental justice" by

POPULATIONS

Minority: individuals who are American Indian or Alaskan Native; Asian or Pacific Islander; Black, not of Hispanic origin; or Hispanic. For this EIS, a minority community is one in which the percent of the population of a racial or ethnic minority is 20 percentage points higher than the percent found in the population as a whole.

Low income: individuals with an income below the poverty level defined by the U.S. Bureau of the Census. A low-income population is one in which 25 percent or more of the persons in the population live in poverty.

identifying and addressing the potential for their activities to cause disproportionately high and adverse impacts to minority and low-income populations. As part of this process, DOE has identified the minority and low-income communities in Clark, Lincoln, and Nye Counties, using U.S. Bureau of the Census population designations to determine areas with high concentrations of minority or low-income populations.

DOE considered the potential for disproportionately high and adverse impacts to minority and low-income populations under both normal and accident conditions. The Department first analyzed the nature of the impacts on the population as a whole and concluded that the impacts would be low. The Department then considered whether any segment of the population, including minorities or low-income populations, would be affected disproportionately and concluded they would not. Accordingly, DOE believes that there would be no disproportionately high and adverse impacts to minority or low-income populations as a result of the Proposed Action. The Department, however, recognizes that Native American tribes in the region consider the intrusive nature of the repository and continuation of restrictions on access to lands where the repository would be located to have an adverse impact on all elements of the natural and physical environment and to their way of living within that environment.

S.4.1.15 Sabotage

Sabotage would be unlikely to contribute to impacts from the repository. The repository would not represent an attractive target to potential saboteurs due to its remote location and low population density in the area. Furthermore, security measures DOE would use to protect the waste material from intrusion and sabotage would make such attempts unlikely to succeed. At all times the waste material would be either in robust shipping or disposal containers or inside the Waste Handling Building, which would have thick concrete walls.

Under the Proposed Action, spent nuclear fuel and high-level radioactive waste would be permanently entombed in a sealed geologic repository at Yucca Mountain. Postdisposal access to the material by intruders would be extraordinarily difficult. Therefore, DOE believes that the risk of sabotage of materials for nuclear weapons purposes would be extremely remote.

S.4.2 TRANSPORTATION

The loading and shipping of spent nuclear fuel and high-level radioactive waste would take place at 72 commercial and 5 DOE sites. Legal-weight trucks and trains would travel on the Nation's highways and railroads. Barges and heavy-haul trucks would be used for the short-distance transport of spent nuclear fuel from some commercial sites to nearby railroads. Shipments of spent nuclear fuel and high-level radioactive waste arriving in Nevada would travel to the Yucca Mountain site by legal-weight truck, rail, or heavy-haul truck. Legal-weight truck shipments would use existing highways in accordance with U.S. Department of Transportation regulations. Figures 13 and 14 show the alternatives for rail corridors and intermodal transfer station locations and associated heavy-haul truck routes, respectively, in the State of Nevada.

DOE analyzed the impacts of transporting these materials to the repository under the mostly legal-weight truck and mostly rail scenarios. Under the mostly legal-weight truck scenario, most of the spent nuclear fuel and high-level radioactive waste would be shipped by legal-weight truck, while naval fuel would be shipped by rail. Under the mostly rail scenario, commercial spent nuclear fuel from most sites and DOE and naval spent nuclear fuel and high-level radioactive waste would arrive by rail. However, commercial fuel from a few commercial sites would be shipped by legal-weight truck because those sites do not have the capability to load a rail cask.

At present, there is no rail access to the Yucca Mountain site. If material was shipped by rail, a branch line that connected an existing main line to the Yucca Mountain site would have to be built or the material would have to be transferred to heavy-haul trucks at an intermodal transfer station and transported over existing highways that might need upgrading. DOE examined the environmental impacts that would be associated with a new branch rail line (five alternative rail corridors) and with an intermodal transfer station (three alternative locations) and heavy-haul routes (five alternative routes).

S.4.2.1 National Transportation Impacts

National transportation includes the impacts of transporting spent nuclear fuel and high-level radioactive waste from the commercial and DOE sites to the Yucca Mountain site. The differences in the impacts between the mostly legal-weight truck and mostly rail scenarios would result from the differing number of shipments over the 24-year transportation period. The mostly legal-weight truck scenario would involve about 49,800 cask shipments (49,500 truck shipments and 300 rail shipments), and the mostly rail scenario would involve approximately 13,400 cask shipments (10,800 rail shipments and 2,600 legal-weight truck shipments). Primarily because of the larger number of shipments, the mostly legal-weight truck scenario would have greater incident-free radiological impacts (latent cancer fatalities). The consequences of the maximum reasonably foreseeable transportation accident (an accident with the highest consequence for human health that can be reasonably foreseen) would be higher under the mostly rail scenario (31 latent cancer fatalities) than under the mostly legal-weight truck scenario (5 latent cancer fatalities) because the amount of material in a rail shipment would be larger than that in a legal-weight truck shipment.

ESTIMATED NATIONAL TRANSPORTATION IMPACTS (for 24 years of operation)

Impact	Mostly legal-weight truck scenario	Mostly rail scenario
Incident-free latent cancer fatalities		
Involved worker	11	3
Public[a]	18	3
Latent cancer fatalities from accidents		
Public	0.07	0.02
Traffic fatalities	4	4
Latent cancer fatalities from maximum reasonably foreseeable accident	5	31
Frequency of occurrence per year	1.9×10^{-7}	1.4×10^{-7}

a. These latent cancer fatalities would result from very low doses to a very large population.

Under the Proposed Action, the analysis of transportation of spent nuclear fuel and high-level radioactive waste from the 72 commercial and 5 DOE sites considered the risk of sabotage. Sabotage could result in the release of radionuclides to the environment. The potential impacts from the release of radionuclides to the environment from an act of sabotage would be bounded by the potential impacts identified under the maximum reasonably foreseeable accident scenario.

S.4.2.2 Nevada Transportation Impacts

The analysis of national transportation includes the analysis of transportation activities in the State of Nevada. The EIS discusses Nevada transportation separately as well. Spent nuclear fuel and high-level radioactive waste shipped to the repository by legal-weight truck would continue in the same vehicles to the Yucca Mountain site. Material that traveled by rail would either continue to the repository on a newly constructed branch rail line or transfer to heavy-haul trucks at an intermodal transfer station that DOE would build in Nevada for shipment on existing highways that could require upgrades. Selection of a specific rail alignment within a corridor, or the specific location of an intermodal transfer station or the need to upgrade the associated heavy-haul routes, would require additional field surveys, environmental and engineering analysis, state and local government consultation, and National Environmental Policy Act reviews.

Rail Corridor Implementing Alternatives. DOE assessed five rail implementing alternatives—the Caliente, Carlin, Caliente-Chalk Mountain, Jean, and Valley Modified corridors (see Figure S-13). The assessment considered the impacts of constructing a branch rail line in one of the five 400-meter (0.25-mile)-wide corridors. Each corridor would connect the Yucca Mountain site with an existing mainline railroad in Nevada.

Intermodal Transfer Station and Heavy-Haul Truck Route Implementing Alternative. DOE assessed alternative intermodal transfer station locations at rail terminals near Caliente, Apex/Dry Lake, and Sloan/Jean (see Figure S-14). The intermodal transfer station would transfer casks containing spent nuclear fuel and high-level radioactive waste from railcars to heavy-haul trucks and empty casks from heavy-haul trucks to railcars. In addition, DOE assessed three alternative heavy-haul truck routes from a Caliente intermodal transfer station – Caliente, Caliente-Chalk Mountain, and Caliente-Las Vegas—and one route each from the Apex/Dry Lake and Sloan/Jean locations. This implementing alternative probably would include about 110 legal-weight truck shipments of commercial spent nuclear fuel each year from the 9 sites that do not currently have the capability to load rail casks.

Impacts for any of the five alternative rail corridors or five heavy-haul truck routes over the 24 years of transport operations would include the following:

- The incident-free collective dose to members of the public would result in less than 1 latent cancer fatality.
- The cumulative radiological accident risk would be much less than 1 latent cancer fatality, taking into account both the probability of accident occurrence and the resulting consequences if an accident were to occur.
- The likelihood of the maximum reasonably foreseeable accident in an urbanized area is about 1.5 to 2 chances in 10 million per year; if such an accident were to occur, from 5 to 31 latent cancer fatalities could result.
- From 1 to 4 traffic fatalities would be likely to occur due to traffic accidents.
- The amount of land disturbed (for an intermodal transfer station and mid-route stops) would be small, generally less than 0.3 square kilometer (75 acres).
- Impacts to biological resources due to habitat disturbance and loss of individuals of affected species would be small.
- Based on an assessment, potential impacts from activities in floodplains and wetlands would be small.

RAIL CORRIDOR IMPACTS

Caliente

- 513 kilometers (319 miles) long, requiring 1 day to complete a one-way trip.
- Would disturb 18 square kilometers (4,500 acres) of land.
- 1,200 new jobs (primary and secondary) could be created during 2.5 years of construction.
- Estimated life-cycle cost is $801 million (1997 dollars).

Carlin

- 520 kilometers (323 miles) long, requiring 1 day to complete a one-way trip.
- Would disturb 20 square kilometers (4,900 acres) of land.
- 1,100 new jobs (primary and secondary) could be created during 2.5 years of construction.
- Estimated life-cycle cost is $753 million (1997 dollars).

Caliente-Chalk Mountain

- 345 kilometers (214 miles) long, requiring less than 1 day to complete a one-way trip.
- Would disturb 12 square kilometers (3,000 acres) of land.
- 910 new jobs (primary and secondary) could be created during 2.5 years of construction.
- Estimated life-cycle cost is $566 million (1997 dollars).
- Nonpreferred alternative: Strongly opposed by the U.S. Air Force because of the adverse effect on security and operations at Nellis Air Force Range.

Jean

- 181 kilometers (112 miles) long, requiring 3-4 hours to complete a one-way trip.
- Would disturb 9 square kilometers (2,000 acres) of land.
- 720 new jobs (primary and secondary) could be created during 2.5 years of construction.
- Estimated life-cycle cost is $421 million (1997 dollars).
- Other: Could affect scenic quality lands and habitat for desert tortoise; would pass near the Las Vegas metropolitan area.

Valley Modified

- 159 kilometers (98 miles) long, requiring 3 hours to complete a one-way trip.
- Would disturb 5 square kilometers (1,240 acres) of land.
- 350 new jobs (primary and secondary) could be created during 2.5 years of construction.
- Estimated life-cycle cost is $258 million (1997 dollars).
- Other: Could affect Desert National Wildlife Range on Nellis Air Force Range, would pass near Las Vegas Paiute Indian Reservation; would pass near the Las Vegas metropolitan area.

- There could be small visual impacts from the existence of the branch rail line, access road, and borrow pits in the landscape and the passage of trains to and from the repository along any rail corridor.

- There would be no effect on the general availability of gasoline, diesel fuel, steel, or concrete.

- There would be no disproportionately high and adverse impacts to minority and low-income populations. DOE considered impacts that would be associated with potential routes for rail and legal-weight and heavy-haul trucks that would pass through or near the Moapa and Las Vegas Paiute Indian Reservations.

HEAVY-HAUL ROUTE IMPACTS

Caliente

- 533 kilometers (331 miles) long, requiring 2 days to complete a one-way trip.
- 1,000 new jobs (primary and secondary) could be created during 3 years of construction.
- Estimated life-cycle cost is $619 million (1998 dollars).
- Other: Could have visual impacts to Kershaw-Ryan State Park.

Caliente-Chalk Mountain

- 282 kilometers (175 miles) long, requiring 2 days to complete a one-way trip.
- 830 new jobs (primary and secondary) could be created during 2.2 years of construction.
- Estimated life-cycle cost is $507 million (1998 dollars).
- Nonpreferred alternative: Strongly opposed by the U.S. Air Force because of the adverse effect on security and operations at the Nellis Air Force Range.
- Could have visual impacts to Kershaw-Ryan State Park.

Caliente-Las Vegas

- 377 kilometers (234 miles) long, requiring 2 days to complete a one-way trip.
- 810 new jobs (primary and secondary) could be created during 2.1 years of construction.
- Estimated life-cycle cost is $561 million (1998 dollars).
- Other: Could have visual impacts to Kershaw-Ryan State Park and would pass near the Las Vegas metropolitan area; would pass near the Moapa Indian Reservation and through the Las Vegas Paiute Indian Reservation.

Apex/Dry Lake

- 183 kilometers (114 miles) long, requiring one-half day to complete a one-way trip.
- 540 new jobs (primary and secondary) could be created during 0.5 year of construction.
- Estimated life-cycle cost is $358 million (1998 dollars).
- Other: Would pass near the Las Vegas metropolitan area; could pass near the Moapa Indian Reservation and through the Las Vegas Paiute Indian Reservation.

Sloan/Jean

- 188 kilometers (117 miles) long, requiring one-half day to complete a one-way trip.
- 720 new jobs (primary and secondary) could be created during 0.5 year of construction.
- Estimated life-cycle cost is $411 million (1998 dollars).
- Other: Would pass near the Las Vegas metropolitan area; would pass through the Las Vegas Paiute Indian Reservation.

The factors that differ among the alternative transportation corridors and routes are length and associated time of travel, land use or disturbance, industrial safety impacts, job creation, and cost. The U.S. Air Force has informed DOE that it strongly opposes the Caliente-Chalk Mountain corridor because it could adversely affect national security-related activities of the Nellis Air Force Range. The State of Nevada and the City of Las Vegas have expressed specific concerns about shipments through or near the Las Vegas metropolitan area, which would occur if either the Jean or Valley Modified corridor or the Caliente-Las Vegas, Apex/Dry Lake, or Sloan/Jean heavy-haul route was selected.

S.5 Environmental Consequences of the No-Action Alternative

Under the No-Action Alternative, DOE would terminate site characterization activities at the Yucca Mountain site. Long-term storage of spent nuclear fuel and high-level radioactive waste would continue at 77 sites.

DOE analyzed the potential impacts of two no-action scenarios: long-term storage with institutional controls (Scenario 1) and long-term storage with no effective institutional control after about 100 years (Scenario 2). The Department recognizes that neither of these scenarios is likely to occur if there is a decision not to develop a repository at Yucca Mountain, but any other scenarios would be too speculative for meaningful analysis. DOE therefore chose to include the two scenarios because they provide a baseline for comparison to the impacts from the Proposed Action.

Activities at the Yucca Mountain site would be the same under either Scenario 1 or 2, as would impacts at the commercial and DOE sites during the first 100 years. After about 100 years and for as long as the 10,000-year analysis period and beyond, Scenario 2 assumes that the storage facilities at the 72 commercial sites and 5 DOE sites would deteriorate and that the radioactive materials in the spent nuclear fuel and high-level radioactive waste would eventually escape to the environment, contaminating the atmosphere, soil, surface water, and groundwater.

S.5.1 RECLAMATION AND DECOMMISSIONING AT THE YUCCA MOUNTAIN SITE

Under the No-Action Alternative, DOE would end characterization and construction activities at the Yucca Mountain Repository site and would complete site decommissioning and reclamation. Land ownership and control would revert to the original controlling authority. Adverse impacts to any resource would be unlikely as a result of these activities.

The overall impact of the No-Action Alternative would be the loss of approximately 4,700 jobs in the Yucca Mountain region of influence, out of approximately 870,000 jobs in the region. Most of the lost jobs would be in disciplines (construction, engineering, administration, support, etc.) that are not unique or unusual and are similar to those in the region. However, some of the jobs would be in unique disciplines (nuclear engineering, nuclear safety, etc.) and might not be needed in the region. Fatalities from industrial hazards would be unlikely, as would latent cancer fatalities from worker or public exposure to naturally occurring radionuclides released by decommissioning and reclamation activities. Resources important to Native American interests would be preserved, although the integrity of archeological sites and resources could be threatened by increased public access if roads were open and site boundaries were not secure.

S.5.2 CONTINUED STORAGE AT COMMERCIAL AND DOE SITES

The No-Action Alternative assumes that the spent nuclear fuel and high-level radioactive waste would remain at the sites at which it is being generated and stored. For the EIS analysis, DOE divided the 72 commercial and 5 DOE sites among five regions of the country to organize the analysis into a framework that would promote an understanding of comparative impacts, and configured a single hypothetical site in each region. Such sites do not exist but are mathematical constructs for analytical purposes. Using this approach, DOE was able to estimate the potential release rate of the radionuclide inventory from the spent nuclear fuel and high-level radioactive waste, based on anticipated interactions of the environment (for example, rainfall and freeze-thaw cycles) with the concrete storage modules in which the nuclear materials would be stored.

The potential occupational and public health and safety impacts associated with the No-Action Alternative are described below. For purposes of this analysis, the potential occupational and public health and safety impacts are the most relevant for comparison with the impacts of the Proposed Action.

S.5.2.1 No-Action Scenario 1

Under this scenario, releases of contaminants to the ground, air, or water would be extremely small under normal conditions. Workers would perform routine industrial maintenance and maintenance unique to a nuclear materials storage facility to minimize releases of contaminants to the environment and exposures

IMPACTS FROM NO-ACTION SCENARIO 1

Industrial hazards

- 2 worker fatalities in the first 100 years, and 320 in the next 9,900 years

Radiological

- 3.0 latent cancer fatalities in exposed public population over 10,000 years (compared to 3.3 million from other causes in the areas immediately surrounding the 77 sites)
- 13 latent cancer fatalities in worker population over 10,000 years (compared to 37,600 from other causes)
- 15 latent cancer fatalities in noninvolved worker population over 100 years, after which noninvolved workers would not be present at the site (compared to 18,800 from other causes)
- No radiological releases would be expected in the event of a severe accident (a postulated aircraft crash) because of the integrity of the concrete storage modules.

to workers and the public. These activities could result in worker exposures to industrial hazards, and worker and public exposures to radiological releases.

S.5.2.2 No-Action Scenario 2

Under this scenario, after 100 years the facilities storing the materials at 72 commercial and 5 DOE sites would begin to deteriorate and would continue to do so over time. Eventually, radioactive materials from failed facilities and storage containers and exposed radioactive materials would contaminate the land surrounding the storage facilities, potentially rendering it unfit for human habitation or agricultural uses for hundreds or thousands of years. Contaminants would enter surface waters and groundwater, which would remain contaminated for the period required for the spent nuclear fuel and high-level radioactive waste materials to be depleted and contaminants to migrate out. Environmental concentrations of chemically toxic materials would be extremely low and would not result in adverse impacts. Released radioactive materials could produce chronic radiation exposures to the public, which could result in adverse health impacts. Intruders could incur severe radiation exposures, including fatal exposures. The number of people who would be affected by the migration of radioactive materials would be much greater in Scenario 2 than in Scenario 1.

IMPACTS FROM NO-ACTION SCENARIO 2

Industrial hazards

- 2 worker fatalities in the first 100 years and none in the next 9,900 years (workers not present at the site)

Radiological

- 3,300 latent cancer fatalities in exposed public population over 10,000 years (compared to 900 million expected from other causes along the 20 major waterways that would be contaminated)
- No latent cancer fatalities in worker population after 100 years
- No latent cancer fatalities in noninvolved worker population after 100 years
- Depending on the population at the site, between 3 and 13 latent cancer fatalities would be expected in the event of a severe accident (a postulated aircraft crash) at a degraded concrete storage module

S.5.2.3 Sabotage

Under the No-Action Alternative, the storage of spent nuclear fuel and high-level radioactive waste at 72 commercial and 5 DOE sites would include a risk of intruder access. Sabotage at one of these sites could result in the release of radionuclides to the environment, or intruders could attempt to remove fissile material for use in weapons production.

For No-Action Scenario 1, the analysis assumed that safeguards and security measures would remain in effect for 10,000 years to minimize potential risks from intruders. For Scenario 2, the analysis assumed that such measures would not remain in effect after 100 years.

S.6 Cumulative Impacts of the Proposed Action

DOE evaluated cumulative short-term impacts from the construction, operation and monitoring, and closure of a geologic repository at Yucca Mountain, and cumulative long-term impacts after repository closure. It also evaluated cumulative impacts from the transportation of spent nuclear fuel and high-level radioactive waste to the repository, including those from the construction and operation of a branch rail line or of an intermodal transfer station and highway upgrades for heavy-haul trucks.

CUMULATIVE IMPACTS

A cumulative impact is "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions" (Council on Environmental Quality Regulations, 40 CFR 1508.7). Cumulative impacts can result from individually minor but collectively potentially significant actions that occur over time.

An assessment of the environment around the Yucca Mountain site included the cumulative impacts of past and present actions in the area the Proposed Action would affect. Reasonably foreseeable future actions include the disposal of inventories of spent nuclear fuel and high-level radioactive waste that exceed the Proposed Action inventory of 70,000 MTHM, along with other Federal and non-Federal actions at the Nellis Air Force Range and the Nevada Test Site, DOE waste management activities, a private space launch facility, and a private intermodal transfer station.

DOE could not reasonably predict future actions for the indefinite future. For that reason, DOE did not attempt to estimate cumulative impacts beyond about 100 years with the exception of impacts of radioactive materials reaching the groundwater and resulting in potential impacts to the public.

S.6.1 INVENTORY MODULES 1 AND 2

Comments that DOE received from the public during the scoping process for this EIS expressed the concern that more spent nuclear fuel and high-level radioactive waste would be generated than the 70,000 MTHM accounted for in the Proposed Action. In response to these comments, DOE evaluated the emplacement of the total projected inventory of commercial spent nuclear fuel and DOE spent nuclear fuel and high-level radioactive waste (Inventory Module 1) and of that total inventory plus the inventories of commercial Greater-Than-Class-C waste and DOE Special-Performance-Assessment-Required waste (Inventory Module 2).

The emplacement of Inventory Module 1 or 2 at Yucca Mountain would require legislative action by Congress unless a second repository were in operation. In addition, the emplacement of commercial Greater-Than-Class-C and DOE Special-Performance-Assessment-Required wastes could require either legislative action or a determination by the Nuclear Regulatory Commission to classify these materials as high-level radioactive waste.

INVENTORIES

Proposed Action
- 63,000 MTHM of commercial spent nuclear fuel
- 2,333 MTHM of DOE spent nuclear fuel
- 8,315 canisters of DOE high-level radioactive waste (equivalent of 4,667 MTHM)

Inventory Module 1
- 105,000 MTHM of commercial spent nuclear fuel
- 2,500 MTHM of DOE spent nuclear fuel
- 22,280 canisters of DOE high-level radioactive waste (equivalent of about 11,500 MTHM)

Inventory Module 2
- 105,000 MTHM of commercial spent nuclear fuel
- 2,500 MTHM of DOE spent nuclear fuel
- 22,280 canisters of DOE high-level radioactive waste (equivalent of about 11,500 MTHM)
- 2,100 cubic meters (72,500 cubic feet) of Greater-Than-Class-C waste
- 4,000 cubic meters (142,000 cubic feet) of Special-Performance-Assessment-Required waste

The emplacement of Inventory Module 1 or 2 would increase the size of the subsurface repository facilities and, thus, the amount of land disturbed. In addition, because more time would be required to emplace more materials (an additional 14 years for emplacement and perhaps another 10 years for closure under the low thermal load scenario) emplacement of Inventory Module 1 or 2 would produce greater human health impacts to workers and to the public, increase energy use, create larger amounts of waste, and increase transportation impacts. Although such impacts would increase by as much as 70 percent with the emplacement of larger waste volumes, most of the impacts themselves would be small. The following paragraphs focus on occupational and public health and safety impacts related to the disposal of the additional inventories.

ESTIMATED NATIONAL TRANSPORTATION IMPACTS INVENTORY MODULE 1 OR 2 (for 38 years of operation)[a]

Impact	Mostly legal-weight truck scenario	Mostly rail scenario
Incident-free latent cancer fatalities		
Involved worker	19	5.5
Public[b]	31	4
Latent cancer fatalities from accidents		
Public	0.1	0.04
Traffic fatalities[c]	7	6.2
Latent cancer fatalities from maximum reasonably foreseeable accident	5	31
Frequency of occurrence per year	2.0×10^{-7}	1.6×10^{-7}

a. Modules 1 and 2 involve approximately the same number of shipments.
b. Potential latent cancer fatalities result from very small doses to a very large population.
c. Does not include 12.9 fatalities that could occur from repository workers commuting and transporting construction materials to the repository.

Occupational and Public Health and Safety

Impacts to Workers from Industrial Hazards. Two activities during the operation and monitoring phase – surface facility operations and the development of emplacement drifts – would account for more than 80 percent of the health and safety impacts from industrial hazards. Up to 3 fatalities under Module

1 or 2 could occur under the low thermal load and uncanistered packaging scenarios, compared to about 2 during the Proposed Action the first 100 years of repository operations.

Radiological Impacts to Workers. The principal sources of exposure to workers would be from spent nuclear fuel receipt and handling in the surface facilities and emplacement activities in the subsurface facilities. As many as approximately 6 fatalities under Module 1 or 2 could occur in the worker population under the intermediate thermal load and uncanistered fuel scenarios, compared to approximately 4 under the Proposed Action.

Radiological Impacts to the Public. Radiological health impacts to the public from construction, operation and monitoring, and closure of the repository would be small. The calculated likelihood that the maximally exposed individual would experience a latent cancer fatality is 3×10^{-5} or less under Module 1 or 2, compared to a range of 2.3×10^{-5} under the high thermal load scenario to 5×10^{-5} under the low thermal load scenario for the Proposed Action. Therefore, the estimated number of latent cancer fatalities would be less than 1 under either module, as it would be under the Proposed Action.

Long-Term Radiological Impacts. Long-term cumulative impacts (impacts after closure at the repository) to public health would occur from radionuclides ultimately from Yucca Mountain, past weapons testing on the Nevada Test Site, and past, present, and future disposal of radioactive waste on the Nevada Test Site and near Beatty, Nevada. Cumulative impacts over 10,000 years from radionuclides released to groundwater would result in less than about 0.003 latent cancer fatality over 10,000 years.

S.6.2 OTHER FEDERAL AND NON-FEDERAL ACTIONS

This EIS evaluates the potential cumulative impacts of other Federal and non-Federal actions. The evaluation includes activities by local governments, private citizens, the Nellis Air Force Range, the Bureau of Land Management, the National Park Service, and the Nevada Test Site. It shows that earlier underground nuclear testing potentially results in long-term (more than 10,000 years) cumulative impacts. Using conservative assumptions, the evaluation calculated the maximum potential dose from the radionuclides from underground testing to be 0.2 millirem per year. Therefore, the maximum cumulative impact of the Proposed Action in 10,000 years [using the mean impact at 20 kilometers (12 miles) from the repository] would be 0.22 millirem per year (potential Yucca Mountain Repository impact) plus 0.2 millirem per year (potential underground testing impact), or 0.42 millirem per year.

S.6.3 TRANSPORTATION

The shipment of Inventory Module 1 or 2 to the repository would use the transportation routes described for the Proposed Action but would require almost twice as many shipments and an additional 14 years. This could result in increased industrial hazards and latent cancer fatalities. For example, under the mostly legal-weight truck scenario, radiological and vehicle emission impacts from incident-free national transportation could increase from 11 to 14 occupational latent cancer fatalities, and estimated latent cancer fatalities in the general population could increase from 18 to 31 for the 38-year transportation of Inventory Module 1 or 2. The incident-free impacts of the mostly rail scenario could be smaller because there would be fewer shipments.

The implementation of the Proposed Action, together with past, present, and reasonably foreseeable future transportation of radioactive materials, could result in 140 latent cancer fatalities in the worker population and 170 in the general population under the mostly legal-weight truck scenario. Transportation of Inventory Module 1 or 2, together with past, present, and reasonably foreseeable future transportation of radioactive materials, could result in about 154 latent cancer fatalities (up to about 14 latent cancer fatalities from Module 1 or 2 plus 140 latent cancer fatalities) in the worker population and, about 200 (up to about 31 latent cancer fatalities from Module 1 or 2 plus 170 latent cancer fatalities) in the general population under the mostly legal-weight truck scenario.

S.7 Cumulative Impacts of the No-Action Alternative

DOE analyzed the cumulative impacts of the No-Action Alternative with respect to Inventory Module 1. The Department did not analyze the cumulative impacts of the No-Action Alternative with respect to Inventory Module 2 because it did not have sufficient and readily available information about the Greater-Than-Class-C and Special-Performance-Assessment-Required wastes in that module to perform a meaningful analysis. Furthermore, this information could not be obtained without an exorbitant commitment of resources. However, information was sufficient to make the determination that there would be a small incremental increase in impacts over those of Module 1.

DOE estimated that about 6,400 concrete storage modules at the 72 commercial sites and three below-grade vaults at the DOE sites would be required to store 70,000 MTHM of spent nuclear fuel and high-level radioactive waste. In comparison, an additional 4,600 concrete storage modules (11,000 total) at the commercial sites and an additional five below-grade vaults (eight total) at the DOE sites would be required to store the entire inventory of Module 1.

Impacts to Workers from Industrial Hazards. As many as 3 fatalities could occur at the storage and generator sites during the first 100 years under the No-Action Alternative with Inventory Module 1. This compares to 2 worker fatalities during the first 100 years with the 70,000-MTHM inventory. Over the next 9,900 years, approximately 490 fatalities could occur under No-Action Scenario 1 with Inventory Module 1, in comparison to 320 with the 70,000-MTHM inventory. No industrial hazard fatalities are projected for either the 70,000-MTHM inventory or Inventory Module 1 under No-Action Scenario 2 after the first 100 years because that scenario assumes there would be no workers at the sites.

Radiological Impacts to Workers. Approximately 43 latent cancer fatalities could occur at the storage and generator sites as a result of No-Action Scenario 1 with Inventory Module 1 over 10,000 years. This compares to 28 latent cancer fatalities in the worker population with the 70,000-MTHM inventory.

As with the 70,000-MTHM inventory, no latent cancer fatalities are projected in the worker population for Inventory Module 1 under No-Action Scenario 2 after 100 years because there would be no workers at the sites.

Radiological Impacts to the Public. About 5 latent cancer fatalities could occur in the exposed population over 10,000 years as a result of No-Action Scenario 1 with Inventory Module 1. This compares to about 4 latent cancer fatalities with the 70,000-MTHM inventory.

Under No-Action Scenario 2, the number of latent cancer fatalities could increase from about 3,300 in the exposed population with the 70,000-MTHM inventory over 10,000 years to about 3,700 in the same period with Inventory Module 1.

S.8 Management Actions to Mitigate Potential Adverse Environmental Impacts

DOE has identified the types of mitigation measures it could take to reduce or avoid potential adverse impacts from construction, operation and monitoring, and closure of the proposed repository. The type of actions identified to date include:

- Commitments included as part of the Proposed Action that would reduce impacts. These commitments are based on DOE’s studies of Yucca Mountain that have been ongoing for more than 10 years.

- Actions that are under consideration in the event the U.S. Nuclear Regulatory Commission grants a license for the site. DOE would continue to evaluate these additional commitments. The analyses in the EIS do not take credit for these mitigations that may be decided on in the future.

In addition, DOE continues to evaluate whether to commit to additional measures to improve the long-term performance of the repository and to reduce uncertainties in estimates of performance. These mitigations include barriers to limit releases and transport of radionuclides, measures to control heat and moisture in the underground, and various designs to support operational considerations.

S.9 Unavoidable Adverse Impacts; Short-Term Uses and Long-Term Productivity; and Irreversible or Irretrievable Commitments of Resources

The construction, operation and monitoring, and eventual closure of the proposed Yucca Mountain Repository and the associated transportation of spent nuclear fuel and high-level radioactive waste would have the potential to produce some environmental impacts that DOE could not mitigate. Similarly, some aspects of the Proposed Action could affect the long-term productivity of the environment or would require the permanent use of some resources. For example:

- The permanent withdrawal of approximately 600 square kilometers (230 square miles) of land for the repository would be likely to prevent human use of the withdrawn lands for other purposes.

- Groundwater contamination could cause an attendant loss of productivity for the affected groundwater.

- Death or displacement of individual members of some animal species, including the desert tortoise, as a result of site clearing and vehicle traffic would be unavoidable.

- Injuries to workers or worker fatalities could result from facility construction, including accidents and inhalation of cristobalite.

- Transportation of spent nuclear fuel and high-level radioactive waste would have the potential to affect workers and the public through exposure to radiation and vehicle emissions, and through traffic accidents.

Further, in the view of the Native American tribes in the Yucca Mountain region, the implementation of the proposed repository and its facilities would further degrade the environmental setting. Even after closure and reclamation, the presence of the repository would, from the perspective of Native Americans, result in an irreversible impact to traditional lands.

In addition, the Proposed Action would involve the following commitments of resources:

- Electric power, fossil fuels, and construction materials would be irreversibly committed to the project.

- DOE would use fossil fuel from the nationwide supply system to transport spent nuclear fuel and high-level radioactive waste to the repository.

S.10 Statutory and Other Applicable Requirements

Several statutes and regulations would apply to the licensing, development, operation, and closure of a geologic repository. These include the NWPA; the National Environmental Policy Act; the Atomic

Energy Act; and the Federal Land Policy and Management Act of 1976. DOE is also subject to environmental protection requirements such as those set by the Clean Air Act; Clean Water Act; Hazardous Material Transportation Act; Emergency Planning and Community Right-to-Know Act of 1986; Comprehensive Environmental Response, Compensation, and Liability Act; Resource Conservation and Recovery Act; National Historic Preservation Act; Archaeological Resources Protection Act; Endangered Species Act; and applicable Nevada State statutes and regulations. In accordance with several statutes, DOE would need several new permits, licenses, and approvals from both Federal and State agencies to construct, operate and monitor, and eventually close the proposed Yucca Mountain Repository.

Under the authority of the Atomic Energy Act, DOE is responsible for establishing a comprehensive health, safety, and environmental program for its activities and facilities. The Department has established a framework for managing its facilities through the promulgation of regulations and the issuance of DOE Orders. In general, DOE Orders set forth policies, programs, and procedures for implementing policies. Many DOE Orders contain specific requirements in the areas of radiation protection, nuclear safety and safeguards, and security of nuclear material. Because the Nuclear Regulatory Commission is authorized to license the proposed Yucca Mountain repository, DOE issued Order 250.1 exempting such a repository from compliance with provisions of DOE Orders that overlap or duplicate Nuclear Regulatory Commission licensing requirements.

DOE has interacted with agencies authorized to issue permits, licenses, and other regulatory approvals, as well as those responsible for protecting such significant resources as endangered species, wetlands, or historic properties. DOE also has coordinated with the affected units of local government, U.S. Nuclear Regulatory Commission, U.S. Air Force, U.S. Navy, U.S. Department of Agriculture, U.S. Department of Transportation, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, National Park Service, Bureau of Land Management, Nevada Department of Transportation, and Native American tribes. In addition, DOE will provide a copy of the Draft EIS to these agencies and entities.

S.11 Findings

S.11.1 MAJOR FINDINGS OF THE DRAFT EIS

In general, the Proposed Action would cause small, short-term public health impacts due primarily to the transportation of spent nuclear fuel and high-level radioactive waste from the existing commercial and DOE sites to the proposed repository. These impacts would be associated mainly with very low, nonradiological traffic fatalities and radiological doses to members of the public from the routine transportation of radioactive materials. Further, the EIS analysis demonstrated that the long-term performance of the proposed repository over 10,000 years would result in a peak dose of 1.3 millirem per year to a maximally exposed individual hypothetically located 5 kilometers (3 miles) from the repository.

Under the No-Action Alternative, there could be as many as 2 worker fatalities as a result of industrial hazards in the short term. Latent cancer fatalities would be unlikely in the short term in either the worker or public populations. These short-term impacts would be very similar to those associated with the Proposed Action. In addition, under the No-Action Alternative there would be no impacts associated with the transportation of spent nuclear fuel and high-level radioactive waste to the proposed repository. However, the obligation to store these materials continually in a safe configuration would become the responsibility of future generations.

There could be large public health and environmental consequences under the No-Action Alternative if there were no effective institutional control, causing storage facilities and containers to deteriorate and radioactive contaminants from the spent nuclear fuel and high-level radioactive waste to enter the environment. In such circumstances, there would be widespread contamination at the 72 commercial and 5 DOE sites across the United States, with resulting human health impacts.

Table S-1 compares the potential impacts associated with the Proposed Action to those associated with the No-Action Alternative.

S.11.2 AREAS OF CONTROVERSY

Native American tribes in the Yucca Mountain region value the cultural resources in the region and believe that the region's water, animals, plants, air, geology, and artifacts are interrelated and dependent on each other for existence. For this reason, these Native Americans consider the intrusive nature of the repository to be an adverse impact to all elements of the natural and physical environment. In addition, one Native American ethnic group, the Western Shoshone, continue to claim title to land in Nevada, including the Yucca Mountain site.

DOE obtained and evaluated the best information available to prepare this EIS. However, some information is from ongoing studies (such as the chlorine-36 studies used to assess the rate and quantity of water that flows from the surface to the groundwater) and, therefore, is incomplete or unavailable. Similarly, the interpretation of results might differ among researchers, or the use of different analytical methods might produce different results or conclusions (such as the variation in the depth to the water table over time, and perspectives of resource use and impacts held by Native American groups). In addition, the complexity and variability of the natural system at Yucca Mountain, the long periods evaluated, and the lack of completeness and availability of information have resulted in a degree of uncertainty associated with the results of the impact analyses (such as changes in climate, populations, society, and technology over very long periods). The EIS identifies the use of incomplete information and the unavailability of information, different views of results and conclusions, and the uncertainties associated with analysis results. In addition, the EIS describes the relevance and importance of the incomplete or unavailable information and then describes the assumptions and preliminary information used in the analysis. DOE has done this to help the reader understand the results or conclusions and their context.

S.11.3 DISTINCTIONS BETWEEN IMPACTS OF THE PROPOSED ACTION AND NO-ACTION ALTERNATIVE

The analysis of the potential short-term environmental impacts associated with the Proposed Action and with the two No-Action scenarios revealed that the impacts would be small and related to health and safety and to socioeconomics.

There would be about 22 to 50 latent cancer fatalities and nonradiological fatalities during the construction, operation and monitoring, and closure of a repository at Yucca Mountain (about 100 years). In comparison, there would be about 25 latent cancer fatalities and nonradiological fatalities from the No-Action Alternative (both scenarios) during the first 100 years. Transportation under the Proposed Action would result in about 6 to 28 latent cancer fatalities (depending on packaging and transportation scenario) and about 13 to 18 nonradiological fatalities from commuting, shipping construction materials, and shipping spent nuclear fuel and high-level radioactive waste to the repository. Under the No-Action Alternative (both scenarios), there would be no latent cancer fatalities from transportation and about 7 nonradiological fatalities from commuting and shipping construction materials. Under the Proposed Action, there would be about 3 to 4 latent cancer fatalities and 2 nonradiological fatalities during construction and operations. Under the No-Action Alternative (both scenarios) there would be about 16 latent cancer fatalities and 2 nonradiological fatalities during construction and operations.

Short-term socioeconomic impacts would occur in the Yucca Mountain region and at the existing storage locations under the Proposed Action; impacts under the No-Action Alternative would occur only in the Yucca Mountain region. Under the Proposed Action, there would be as many as about 2,400 new jobs in the three-county area around Yucca Mountain (Clark, Lincoln, and Nye Counties). In addition, under the Proposed Action there would be lost jobs at each of the sites across the United States as spent nuclear fuel

Table S-1. Impacts associated with the Proposed Action and No-Action Alternative (page 1 of 4).

	Proposed Action			No-Action Alternative		
	Short-term (through closure, about 100 years)		Long-term (after closure, about 100 to 10,000 years)	Short-term	Long-term (100 to 10,000 years)	
Resource area	Repository	Transportation		(100 years)	Scenario 1	Scenario 2
Land use and ownership	Withdraw about 600 km^2(a) of land now under Federal control; active use of about 3.5 km^2	0 to about 20 km^2 of land disturbed for new transportation routes; Air Force identified conflicts for some routes; Valley Modified rail corridor would pass near the Las Vegas Paiute Indian Reservation; some rail corridors could overlap with potential Las Vegas growth; heavy-haul trucks could slow traffic flow; some heavy-haul routes would pass near or through the Moapa and Las Vegas Paiute Indian Reservations	Potential for limited access into the area; the only surface features remaining would be markers	Small; storage would continue at existing sites	Small; storage would continue at existing sites	Potential contamination of 0.04 to 0.4 km^2 surrounding each of the 72 commercial and 5 DOE sites
Air quality	Releases and exposures well below regulatory limits (less than 5 percent of limits)	Releases and exposures below regulatory limits; pollutants from vehicle traffic and trains would be small in comparison to other national vehicle and train traffic	No air releases	Releases and exposures well below regulatory limits	Releases and exposures well below regulatory limits	Increases in airborne radiological releases and exposures (potentially exceeding current regulatory limits)
Hydrology (groundwater and surface water)	Water demand well below Nevada State Engineer's ruling on perennial yield (250 to 480 acre-feet[b] per year)	Withdrawal of up to 710 acre-feet[b] from multiple wells and hydrographic areas over 2.5 years	Low-level contamination of groundwater in Amargosa Valley after a few thousand years (estimated concentration would be below drinking water standards)	Small; usage would be small in comparison to other site use	Small; usage would be small in comparison to other site use	Potential for radiological contamination of groundwater around 72 commercial and 5 DOE sites
	Small; minor changes to runoff and infiltration rates; floodplain assessment concluded impacts would be small	Small; minor changes to runoff and infiltration rates; additional floodplain assessments would be performed in the future as necessary	Small; minor changes to runoff and infiltration rates	Small; minor changes to runoff and infiltration rates	Small; minor changes to runoff and infiltration rates	Potential for radiological releases and contamination of drainage basins downstream of 72 commercial and 5 DOE sites (concentrations potentially exceeding current regulatory limits)

Table S-1. Impacts associated with the Proposed Action and No-Action Alternative (page 2 of 4).

	Proposed Action			No-Action Alternative		
	Short-term (through closure, about 100 years)		Long-term (after closure, about 100 to 10,000 years)	Short-term	Long-term (100 to 10,000 years)	
Resource area	Repository	Transportation		(100 years)	Scenario 1	Scenario 2
Biological resources and soils	Loss of about 3.5 km^2 of desert soil, habitat, and vegetation; adverse impacts to threatened desert tortoise (individuals, not the species as a whole); reasonable and prudent measures to minimize impacts; impacts to other plants and animals and habitat small; wetlands assessment concluded impacts would be small	Loss of 0 to about 20 km^2 of desert soil, habitat, and vegetation for heavy-haul routes and rail corridors; adverse impacts to threatened desert tortoise (individuals, not the species as a whole); reasonable and prudent measures to minimize impacts; impacts to other plants and animals and habitat small; additional wetlands assessments would be performed in the future as necessary	Slight increase in temperature of surface soil directly over the repository for 10,000 years resulting in a potential temporary shift in plant and animal communities in this small area (about 8 km^2)	Small; storage would continue at existing sites	Small; storage would continue at existing sites	Potential adverse impacts at each of the 77 sites from subsurface contamination of 0.04 to 0.4 km^2
Cultural resources	Repository development would disturb about 3.5 km^2; damage to and illicit collecting at archaeological sites; programs in place to minimize impacts; opposing Native American viewpoint	Loss of 0 to about 20 km^2 of land disturbed for new transportation routes; damage to and illicit collecting at archaeological sites; programs in place to minimize impacts; opposing Native American viewpoint	Potential for limited access into the area; opposing Native American viewpoint	Small; storage would continue at existing sites; limited potential of disturbing sites	Small; storage would continue at existing sites; limited potential of disturbing sites	No construction or operation activities; no impacts
Socioeconomics	Estimated peak employment of 1,800 occurring in 2006 would result in less than a 1 percent increase in direct and indirect regional employment; therefore, impacts would be low	Employment increases would range from less than 1 percent to 5.7 percent (use of intermodal transfer station or rail line in Lincoln County, Nevada) of total employment by county; therefore, impacts would be low	No workers, no impacts	Small; population and employment changes would be small compared to totals in the regions	Small; population and employment changes would be small compared to totals in the regions	No workers; no impacts
Occupational and public health and safety						
Public						
Radiological (LCFs[c])						
MEI[c]	1.9×10^{-5} to 5.1×10^{-5}	1.6×10^{-4} to 1.2×10^{-3}	1.9×10^{-8} to 4.4×10^{-5}	4.3×10^{-6}	1.3×10^{-6}	(d)
Population	0.14 to 0.41	3 to 18	5.5×10^{-5} to 5.3×10^{-4}	0.41	3	3,300[e]
Nonradiological	Exposures well below regulatory limits	Exposures below regulatory limits; pollutants from vehicle traffic and trains	Exposures well below regulatory limits or guidelines	Exposures well below regulatory limits or guidelines	Exposures well below regulatory limits or guidelines	Increases in releases of hazardous substances in the spent nuclear fuel and high-level radioactive waste and exposures to the public

Table S-1. Impacts associated with the Proposed Action and No-Action Alternative (page 3 of 4).

	Proposed Action			No-Action Alternative		
	Short-term (through closure, about 100 years)		Long-term (after closure, about 100 to 10,000 years)	Short-term (100 years)	Long-term (100 to 10,000 years)	
Resource area	Repository	Transportation			Scenario 1	Scenario 2
Occupational and public health and safety (continued)						
Workers (involved and noninvolved)						
Radiological (LCFs)	3 to 4	3 to 11	No workers, no impacts	16	12	No workers, no impacts
Nonradiological fatalities (includes commuting traffic fatalities)	1 to 2	11 to 16[f]	No workers, no impacts	9	1,080	No workers, no impacts
Accidents						
Probability (frequency per year)	8.6×10^{-7} to 1.1×10^{-2}	1.4×10^{-7} to 1.9×10^{-7}	No credible accidents	3.2×10^{-6}	3.2×10^{-6}	3.2×10^{-6}
Public						
Radiological (LCFs)						
MEI	2.9×10^{-13} to 2.1×10^{-6}	0.002 to 0.013	Not applicable	No impacts	No impacts	Not applicable
Population	1.0×10^{-11} to 7.8×10^{-5}	0.02 to 0.07	Not applicable	No impacts	No impacts	3 to 13
Workers	For some accident scenarios workers would likely be severely injured or killed	For some accident scenarios workers would likely be severely injured or killed	No workers; no impacts	For some accident scenarios workers would likely be severely injured or killed	For some accident scenarios workers would likely be severely injured or killed	No workers; no impacts
Noise	Impacts to public would be low due to large distances to residences; workers exposed to elevated noise levels – controls and protection used as necessary	Transient and not excessive, less than 90 dBA[g]	No activities, therefore, no noise	Transient and not excessive, less than 90 dBA	Transient and not excessive, less than 90 dBA	No activities, therefore, no noise
Aesthetics	Low adverse impacts to aesthetic or visual resources in the region	Low, temporary, and transient; possible conflict with visual resource management goals for Jean rail corridor	Small; only surface features remaining would be markers	Small; storage would continue at existing sites; expansion as needed	Small; storage would continue at existing sites; expansion as needed	Small; aesthetic value decreases as facilities degrade
Utilities, energy, materials, and site services	Use of materials would be very small in comparison to amounts used in the region; electric power delivery system to the Yucca Mountain site would have to be enhanced.	Use of materials and energy would be small in comparison to amounts used nationally	No use of materials or energy	Small; materials and energy use would be small compared to total site use	Small; materials and energy use would be small compared to total site use	No use of materials or energy

Table S-1. Impacts associated with the Proposed Action and No-Action Alternative (page 4 of 4).

	Proposed Action			No-Action Alternative		
	Short-term (through closure, about 100 years)		Long-term (after closure, about 100 to 10,000 years)	Short-term (100 years)	Long-term (100 to 10,000 years)	
Resource area	Repository	Transportation			Scenario 1	Scenario 2
Management of site-generated waste and hazardous materials	Radioactive and hazardous waste generated would be a few percent of existing offsite capacity; other wastes would be managed offsite and some waste potentially at an onsite landfill	Radioactive and hazardous waste generated would be a few percent of existing offsite capacity; other wastes would be managed offsite and some waste potentially at an onsite landfill	No waste generated or hazardous materials used	Small; waste generated and materials used would be small compared to total site generation and use	Small; waste generated and materials used would be small compared to total site generation and use	No waste generated or hazardous materials used
Environmental justice	No disproportionately high and adverse impacts to minority or low-income populations; opposing Native American viewpoint	No disproportionately high and adverse impacts to minority or low-income populations; opposing Native American viewpoint	No disproportionately high and adverse impacts to minority or low-income populations; opposing Native American viewpoint	No disproportionately high and adverse impacts to minority or low-income populations	No disproportionately high and adverse impacts to minority or low-income populations	Potential for disproportionately high and adverse impacts to minority or low-income populations

a. km^2 = square kilometers; to covert to acres, multiply by 247.1.
b. To convert acre-feet to cubic meters, multiply by 1233.49.
c. LCF = latent cancer fatality; MEI = maximally exposed individual.
d. The maximally exposed individual could receive a fatal dose of radiation within a few weeks to months. Death would be caused by acute direct radiation exposure.
e. Downstream exposed population of approximately 3.9 billion over 10,000 years.
f. As many as 8 of these fatalities could be members of the public; fatalities include commuting traffic fatalities.
g. dBA = A-weighted decibels, a common sound measurement. A-weighting accounts for the fact that the human ear responds more effectively to some pitches than to others. Higher pitches receive less weighting than lower ones.

and high-level radioactive waste was removed. Under the No-Action Alternative, there would be a loss of about 2,500 jobs in the three-county area around Yucca Mountain once reclamation was completed. There would be no short-term socioeconomic impacts at the storage sites under the No-Action Alternative.

The potential long-term (100 to 10,000 years) environmental impacts of the Proposed Action and No-Action Scenario 1 (continued institutional control) would also be small. Under the Proposed Action, there would be virtually no latent cancer fatalities (much less than 1) over 10,000 years. In addition, there would be a potential for minimal impacts to vegetation and animals over the repository area as soil surface temperatures increased. Under the No-Action Scenario 1, there would be about 15 latent cancer fatalities and about 1,000 nonradiological fatalities associated with the construction and replacement of storage facilities, monitoring of facilities, worker commuting, and transportation of construction materials. Small impacts to other resources (for example, socioeconomics, biological resources, utilities and services) would occur.

There would be differences in the potential long-term environmental impacts under No-Action Scenario 2 (no institutional control after 100 years) compared to No-Action Scenario 1. Under No-Action Scenario 2, there would be about 3,300 latent cancer fatalities over 10,000 years as storage facilities across the United States degraded and radionuclides from spent nuclear fuel and high-level radioactive waste reached and contaminated the environment. There would be no fatalities associated with transportation, construction, or operation because those activities would not occur after the loss of institutional control.

CONVERSIONS

METRIC TO ENGLISH			ENGLISH TO METRIC		
Multiply	**by**	**To get**	**Multiply**	**by**	**To get**
Area					
Square meters	10.764	Square feet	Square feet	0.092903	Square meters
Square kilometers	247.1	Acres	Acres	0.0040469	Square kilometers
Square kilometers	0.3861	Square miles	Square miles	2.59	Square kilometers
Concentration					
Kilograms/sq. meter	0.16667	Tons/acre	Tons/acre	0.5999	Kilograms/sq. meter
Milligrams/liter[a]	1	Parts/million	Parts/million[a]	1	Milligrams/liter
Micrograms/liter[a]	1	Parts/billion	Parts/billion[a]	1	Micrograms/liter
Micrograms/cu. meter[a]	1	Parts/trillion	Parts/trillion[a]	1	Micrograms/cu. meter
Density					
Grams/cu. cm	62.428	Pounds/cu. ft.	Pounds/cu. ft.	0.016018	Grams/cu. cm
Grams/cu. meter	0.0000624	Pounds/cu. ft.	Pounds/cu. ft.	16,025.6	Grams/cu. meter
Length					
Centimeters	0.3937	Inches	Inches	2.54	Centimeters
Meters	3.2808	Feet	Feet	0.3048	Meters
Kilometers	0.62137	Miles	Miles	1.6093	Kilometers
Temperature					
Absolute					
Degrees C + 17.78	1.8	Degrees F	Degrees F – 32	0.55556	Degrees C
Relative					
Degrees C	1.8	Degrees F	Degrees F	0.55556	Degrees C
Velocity/Rate					
Cu. meters/second	2118.9	Cu. feet/minute	Cu. feet/minute	0.00047195	Cu. meters/second
Grams/second	7.9366	Pounds/hour	Pounds/hour	0.126	Grams/second
Meters/second	2.237	Miles/hour	Miles/hour	0.44704	Meters/second
Volume					
Liters	0.26418	Gallons	Gallons	3.78533	Liters
Liters	0.035316	Cubic feet	Cubic feet	28.316	Liters
Liters	0.001308	Cubic yards	Cubic yards	764.54	Liters
Cubic meters	264.17	Gallons	Gallons	0.0037854	Cubic meters
Cubic meters	35.314	Cubic feet	Cubic feet	0.028317	Cubic meters
Cubic meters	1.3079	Cubic yards	Cubic yards	0.76456	Cubic meters
Cubic meters	0.0008107	Acre-feet	Acre-feet	1233.49	Cubic meters
Weight/Mass					
Grams	0.035274	Ounces	Ounces	28.35	Grams
Kilograms	2.2046	Pounds	Pounds	0.45359	Kilograms
Kilograms	0.0011023	Tons (short)	Tons (short)	907.18	Kilograms
Metric tons	1.1023	Tons (short)	Tons (short)	0.90718	Metric tons
ENGLISH TO ENGLISH					
Acre-feet	325,850.7	Gallons	Gallons	0.000003046	Acre-feet
Acres	43,560	Square feet	Square feet	0.000022957	Acres
Square miles	640	Acres	Acres	0.0015625	Square miles

[a] These widely used conversions are only valid under specific temperature and pressure conditions.

METRIC PREFIXES

Prefix	Symbol	Multiplication factor
exa-	E	1,000,000,000,000,000,000 = 10^{18}
peta-	P	1,000,000,000,000,000 = 10^{15}
tera-	T	1,000,000,000,000 = 10^{12}
giga-	G	1,000,000,000 = 10^{9}
mega-	M	1,000,000 = 10^{6}
kilo-	k	1,000 = 10^{3}
deca-	D	10 = 10^{1}
deci-	d	0.1 = 10^{-1}
centi-	c	0.01 = 10^{-2}
milli-	m	0.001 = 10^{-3}
micro-	µ	0.000 001 = 10^{-6}
nano-	n	0.000 000 001 = 10^{-9}
pico-	p	0.000 000 000 001 = 10^{-12}

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Foreword

FOREWORD

The purpose of this environmental impact statement (EIS) is to provide information on potential environmental impacts that could result from a Proposed Action to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at the Yucca Mountain site. The potential repository would be located in Nye County, Nevada. The EIS also provides information on the potential environmental impacts from an alternative referred to as the No-Action Alternative, under which there would be no development of a geologic repository at Yucca Mountain.

U.S. Department of Energy Actions

The Nuclear Waste Policy Act, enacted by Congress in 1982 and amended in 1987, establishes a process leading to a decision by the Secretary of Energy on whether to recommend that the President approve Yucca Mountain for development of a geologic repository. As part of this process, the Secretary of Energy is to:

- Undertake site characterization activities at Yucca Mountain to provide information and data required to evaluate the site.

- Prepare an EIS.

- Decide whether to recommend approval of the development of a geologic repository at Yucca Mountain to the President.

The Nuclear Waste Policy Act, as amended (the EIS refers to the amended Act as the NWPA), also requires the U.S. Department of Energy (DOE) to hold hearings to provide the public in the vicinity of Yucca Mountain with opportunities to comment on the Secretary's possible recommendation of the Yucca Mountain site to the President. The hearings would be separate from the public hearings on the Draft EIS required under the National Environmental Policy Act. If, after completing the hearings and site characterization activities, the Secretary decides to recommend that the President approve the site, the Secretary will notify the Governor and legislature of the State of Nevada accordingly. No sooner than 30 days after the notification, the Secretary may submit the recommendation to the President to approve the site for development of a repository.

If the Secretary recommends the Yucca Mountain site to the President, a comprehensive statement of the basis for the recommendation, including the Final EIS, will accompany the recommendation. This Draft EIS has been prepared now so that DOE can consider the Final EIS, including the public input on the Draft EIS, in making a decision on whether to recommend the site to the President.

Presidential Recommendation and Congressional Action

If, after a recommendation by the Secretary, the President considers the site qualified for application to the U.S. Nuclear Regulatory Commission for a construction authorization, the President will submit a recommendation of the site to Congress. The Governor or legislature of Nevada may object to the site by submitting a notice of disapproval to Congress within 60 days of the President's action. If neither the Governor nor the legislature submits a notice within the 60-day period, the site designation would become effective without further action by the President or Congress. If, however, the Governor or the legislature did submit such a notice, the site would be disapproved unless, during the first 90 days of continuous session of Congress after the notice of disapproval, Congress passed a joint resolution of repository siting approval and the President signed it into law.

Actions To Be Taken After Site Designation

Once a site designation became effective, the Secretary of Energy would submit to the Nuclear Regulatory Commission a License Application, based on a particular facility design, for a construction authorization within 90 days. The NWPA requires the Commission to adopt the Final EIS to the extent practicable as part of the Commission's decisionmaking on the License Application.

Decisions Related to Potential Environmental Impacts Considered in the EIS

This EIS analyzes a Proposed Action to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. The EIS also analyzes a No-Action Alternative, under which DOE would not build a repository at the Yucca Mountain site, and spent nuclear fuel and high-level radioactive waste would remain at 72 commercial and 5 DOE sites across the United States. The No-Action Alternative is included in the EIS to provide a baseline for comparison with the Proposed Action. DOE has developed the information about the potential environmental impacts that could result from either the Proposed Action or the No-Action Alternative to inform the Secretary of Energy's determination whether to recommend Yucca Mountain as the site of this Nation's first monitored geologic repository for spent nuclear fuel and high-level radioactive waste. In making that determination, the Secretary would consider not only the potential environmental impacts identified in this EIS, but also other factors as provided in the NWPA.

As part of the Proposed Action, the EIS analyzes the potential impacts of transporting spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site from 77 sites across the United States. This analysis includes information on such matters as the comparative impacts of truck and rail transportation, alternative intermodal (rail to truck) transfer station locations, associated heavy-haul truck routes, and alternative rail transport corridors in Nevada. Although it is uncertain at this time when DOE would make any transportation-related decisions, DOE believes that the EIS provides the information necessary to make decisions regarding the basic approaches (for example, mostly rail or mostly truck shipments), as well as the choice among alternative transportation corridors. However, follow-on implementing decisions, such as selection of a specific rail alignment within a corridor, or the specific location of an intermodal transfer station or the need to upgrade the associated heavy-haul routes, would require additional field surveys, state and local government consultations, environmental and engineering analyses, and National Environmental Policy Act reviews.

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Purpose and Need for Agency Action

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1. PURPOSE AND NEED FOR AGENCY ACTION

Spent nuclear fuel and high-level radioactive waste are long-lived, highly radioactive materials that result from nuclear activities. For more than 50 years these materials have accumulated and continue to accumulate at sites across the United States. Figure 1-1 shows the 72 commercial nuclear power sites and the 5 U.S. Department of Energy (DOE) sites in 35 states that currently store these radioactive materials. Because of their nature, spent nuclear fuel and high-level radioactive waste must be isolated, confined, and monitored for long periods. The United States has focused a national effort on siting and developing a geologic repository for disposal of these materials and on developing systems for transporting the materials from their present storage locations to a repository.

Congress has determined through the passage of the Nuclear Waste Policy Act, as amended (NWPA) (42 USC 10101 *et seq.*), that:

- The Federal Government has the responsibility to dispose of these materials permanently to protect the public health and safety and the environment.

- The Federal Government needs to take precautions to ensure these materials do not adversely affect the public health and safety and the environment for this or future generations.

- The Yucca Mountain site in southern Nevada should be evaluated as a potential location for a monitored geologic repository.

A geologic repository for spent nuclear fuel and high-level radioactive waste is a system for permanently isolating radioactive materials in a deep subsurface location to ensure minimal risk to the health and safety of the public. This environmental impact statement (EIS) addresses actions that DOE proposes to take to develop a repository at Yucca Mountain, and also considers systems for the transportation of spent nuclear fuel and high-level radioactive waste from the 77 sites to the Yucca Mountain site.

ENVIRONMENTAL IMPACT STATEMENT

An *environmental impact statement* or *EIS* is a detailed analysis that addresses a major Federal action that may significantly affect the quality of the human and natural environment. An EIS describes the potential beneficial and adverse environmental effects of the proposed action and alternatives. It is a tool to assist in decisionmaking and provides public disclosure of information.

In addition, DOE has ultimate management responsibility for other highly radioactive materials. Examples of such materials include Greater-Than-Class-C and Special-Performance-Assessment-Required wastes. The Department might need to dispose of these materials in a monitored geologic repository to protect public health and safety. However, disposal of Greater-Than-Class-C and Special-Performance-Assessment-Required wastes at the proposed Yucca Mountain Repository could require additional legislative action or a determination by the U.S. Nuclear Regulatory Commission to classify them as high-level radioactive waste.

Section 1.1 describes potential actions and decisions concerning the proposed repository. Section 1.2 provides an overview of spent nuclear fuel and high-level radioactive waste. Section 1.3 describes the major steps in the process Congress has established for evaluations and decisions concerning the Yucca Mountain site. Section 1.4 provides an overview of the site, potential transportation systems for moving spent fuel and radioactive waste to the site, and studies of the site. Section 1.5 presents information on the EIS process as it applies to the proposal for a monitored geologic repository at Yucca Mountain.

Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

Symbols do not reflect precise locations.

Source: Modified from DOE (1998a, Overview, page 5).

Figure 1-1. Locations of commercial and DOE sites and Yucca Mountain.

1.1 Potential Actions and Decisions Regarding the Proposed Repository

This EIS analyzes a Proposed Action to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. The EIS also analyzes a No-Action Alternative, under which DOE would not build a repository at the Yucca Mountain site, and spent nuclear fuel and high-level radioactive waste would remain at 72 commercial and 5 DOE sites across the United States. The No-Action Alternative is included in the EIS to provide a baseline for comparison with the Proposed Action. DOE has developed the information about the potential environmental impacts that could result from either the Proposed Action or the No-Action Alternative to inform the Secretary of Energy's determination whether to recommend Yucca Mountain as the site of this Nation's first monitored geologic repository for spent nuclear fuel and high-level radioactive waste. In making that determination, the Secretary would consider not only the potential environmental impacts identified in this EIS, but also other factors as provided in the NWPA.

PROPOSED REPOSITORY

DOE has used the term *proposed repository* as a term of convenience to indicate the relationship of the Yucca Mountain Repository to the Proposed Action of this EIS. DOE could not pursue the use of Yucca Mountain as a repository until the Secretary of Energy decided whether to recommend approval of the site to the President and a Presidential site designation has become effective. At that time DOE would submit a License Application to the Nuclear Regulatory Commission seeking authorization to construct a repository at Yucca Mountain.

As part of the Proposed Action, the EIS analyzes the potential impacts of transporting spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site from 77 sites across the United States. This analysis includes information on such matters as the comparative impacts of truck and rail transportation, alternative intermodal (rail to truck) transfer station locations, associated heavy-haul truck routes, and alternative rail transport corridors in Nevada. Although it is uncertain at this time when DOE would make any transportation-related decisions, DOE believes that the EIS provides the information necessary to make decisions regarding the basic approaches (for example, mostly rail or mostly truck shipments), as well as the choice among alternative transportation corridors. However, follow-on implementing decisions, such as selection of a specific rail alignment within a corridor, or the specific location of an intermodal transfer station or the need to upgrade the associated heavy-haul routes, would require additional field surveys, state and local government consultations, environmental and engineering analyses, and National Environmental Policy Act reviews.

1.2 Radioactive Materials Considered for Disposal in a Monitored Geologic Repository

Commercial nuclear powerplants, which supply approximately 20 percent of the Nation's electricity, produce spent nuclear fuel. In addition, DOE manages a complex of large government-owned facilities that formerly produced nuclear weapons materials, and in doing so produced spent nuclear fuel and high-level radioactive waste. DOE also operates research reactors that produce spent nuclear fuel and processing facilities that produce high-level radioactive waste.

The following discussion describes spent nuclear fuel and high-level radioactive waste, including mixed-oxide fuel (a mixture of uranium oxide and plutonium oxide that could be used to power commercial nuclear reactors) and immobilized plutonium forms. The discussion also identifies other waste forms, particularly Greater-Than-Class-C wastes and Special-Performance-Assessment-Required wastes, that are currently classified as low-level radioactive wastes but that could require disposal in a monitored geologic repository.

1.2.1 GENERATION OF SPENT NUCLEAR FUEL AND HIGH-LEVEL RADIOACTIVE WASTE

The material used to power commercial nuclear reactors typically consists of cylindrical fuel pellets made of uranium oxide. Fuel pellets are placed in tubes that are ordinarily about 3.7 meters (12 feet) long and 0.64 centimeter (0.25 inch) in diameter. Sealed tubes with fuel pellets inside them are called fuel rods (Appendix A). Fuel rods are arranged in bundles called fuel assemblies (see Figure 1-2), which are placed in a reactor.

In the reactor, neutrons from the fuel strike other uranium atoms, causing them to split into parts, and producing heat, radioactive fission products, and more free neutrons. This splitting of atoms is a form of nuclear reaction called *fission*. The neutrons produced by the fission process sustain the nuclear reaction by striking other uranium atoms in the fuel pellets, causing additional atoms to split. Control of the configuration and machinery associated with the fuel assemblies provides control of the rate at which fission occurs and, consequently, the amount of heat produced.

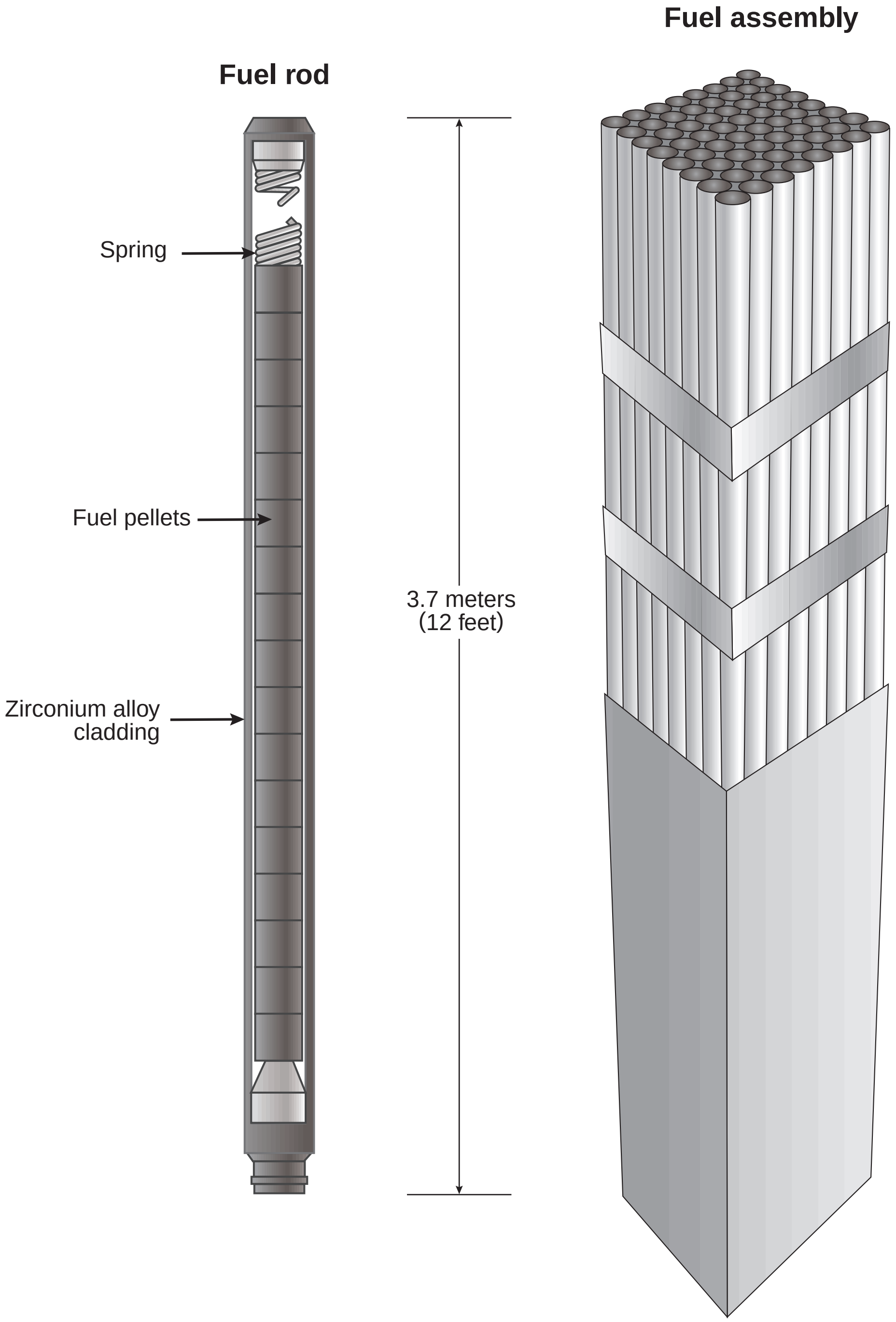
In a commercial power reactor, the heat that fission produces is used to convert water to steam. The steam turns turbine generators to produce electric energy. The reactors that power many naval vessels use the steam primarily to turn turbines to provide ship propulsion. Some research reactors also use the steam produced to generate electricity.

After a period in operation, enough of the fissile uranium atoms have undergone fission that the fuel is said to be “spent”; some of these spent nuclear fuel assemblies must be replaced with fresh fuel for operation to continue. During replacement, fresh fuel is placed in the reactor and spent fuel is placed in a pool of water. In commercial reactors, typical fuel cycles run 18 to 24 months, after which 25 to 50 percent of the spent nuclear fuel is replaced.

Nuclear reactor operators initially store spent nuclear fuel under water in spent fuel pools because of high levels of radioactivity and heat from decay of radionuclides. When the fuel has cooled and decayed sufficiently, operators can use two storage options: (1) continued in-pool storage or (2) above-ground dry storage in an independent installation. Twenty-six sites have existing or planned independent above-ground dry storage facilities. Dry storage includes the storage of spent nuclear fuel at reactor sites in approved storage casks.

Beginning in 1944, the United States operated reactors to produce materials such as plutonium for nuclear weapons. All of these reactors have been shut down for several years. When defense plutonium production reactors were operating, they used a controlled fission process to irradiate nuclear fuel and generate plutonium. DOE used chemical processes (called *reprocessing*) to extract plutonium and other materials from spent nuclear fuel for defense purposes. One of the chemical byproducts remaining after reprocessing is high-level radioactive waste. The reprocessing of limited quantities of naval reactor fuels and some commercial reactor fuels, DOE test reactor fuels, and university research reactor fuels has also produced high-level radioactive waste.

Concerns about safety and environmental hazards contributed to DOE decisions to shut down parts of the weapons production complex in the 1980s. The shutdown, which became permanent due primarily to the reduced need for weapons materials at the end of the Cold War, included both production reactors and



Source: Modified from DOE (1995a, page 1-3).

Figure 1-2. Typical nuclear fuel assembly and rod.

spent fuel reprocessing facilities. As a result, not all DOE spent nuclear fuel was reprocessed. Some of this fuel is now stored at DOE sites.

1.2.2 SPENT NUCLEAR FUEL

Spent nuclear fuel consists of nuclear fuel that has been withdrawn from a nuclear reactor following irradiation, provided that the constituent elements of the fuel have not been separated by reprocessing. Commercial spent nuclear fuel comes from nuclear reactors operated to produce electric power for domestic use. DOE manages spent nuclear fuel from DOE defense production reactors, U.S. naval reactors, and DOE test and experimental reactors, as well as fuel from university research reactors, commercial reactor fuel acquired by DOE for research and development, and fuel from foreign research reactors. Most nuclear fuel is encased in highly corrosion-resistant cladding before being placed in a reactor. The fuel remains in the cladding after it is irradiated and withdrawn as spent nuclear fuel. The purpose of the cladding is to protect its contents in operating conditions associated with a reactor, which can reach temperatures of around 370°C (700°F) and pressures of 1.4 million kilograms per square meter (2,000 pounds per square inch) (Appendix A). Cladding, if it is not damaged or corroded, has the capability to isolate the spent nuclear fuel and delay the release of radionuclides to the environment for long periods.

Spent nuclear fuel is intensely radioactive in comparison to nonirradiated fuel and would be the primary source of radioactivity and heat generation in the proposed repository.

1.2.2.1 Commercial Spent Nuclear Fuel

Commercial spent nuclear fuel typically consists of uranium oxide fuel (which also contains actinides, fission products, and other materials), the cladding that contains the fuel, and the assembly hardware. The cladding for nuclear fuel assemblies is normally made of a zirconium alloy. However, about 1 percent of the spent nuclear fuel included in the Proposed Action is clad in stainless steel (Appendix A).

The sources of commercial spent nuclear fuel are the commercial nuclear powerplants throughout the United States. Figure 1-1 shows the locations of these sites. Appendix A, Section A.2.1, provides details on spent nuclear fuel and discusses the amount currently stored and projected to be stored at each site. Mixed-oxide fuel would be part of the commercial spent nuclear fuel inventory for the proposed repository. Section 1.2.4 includes a discussion of mixed-oxide fuel.

1.2.2.2 DOE Spent Nuclear Fuel

DOE spent nuclear fuel, like commercial spent nuclear fuel, has been withdrawn from a reactor following irradiation. Much of the DOE spent nuclear fuel is associated with past operations of reactors at the Hanford and Savannah River Sites that previously produced material for DOE's defense programs and research and development programs. These reactors are no longer operating. Smaller quantities of spent nuclear fuel have resulted from experimental reactor operations and from research conducted by approximately 55 university- and government-owned test reactors. DOE spent nuclear fuel also includes spent fuel from reactors on nuclear-powered naval vessels and naval reactor prototypes.

DOE stores most of its spent nuclear fuel in pools or dry storage facilities at three primary locations: the Hanford Site in Washington State, the Idaho National Engineering and Environmental Laboratory in Idaho, and the Savannah River Site in South Carolina. Some DOE spent nuclear fuel is currently stored at the Fort St. Vrain dry storage facility in Colorado and the West Valley site in New York, a site presently owned by the New York State Energy Research and Development Authority (see Figure 1-1). Additional small quantities remain at other locations. With the exception of Fort St. Vrain, which will retain its spent nuclear fuel in dry storage until disposition, DOE plans to ship all of the spent nuclear fuel for which it is responsible from other sites to one of the three primary locations mentioned above for storage and preparation for ultimate disposition [discussed in DOE (1995b, all)]. This EIS does not analyze consolidation of spent nuclear fuel at DOE sites (see DOE 1995a, all). Appendix A, Section A.2.2, provides details on DOE spent nuclear fuel and discusses the amount currently stored and projected to be stored at each site.

1.2.3 HIGH-LEVEL RADIOACTIVE WASTE

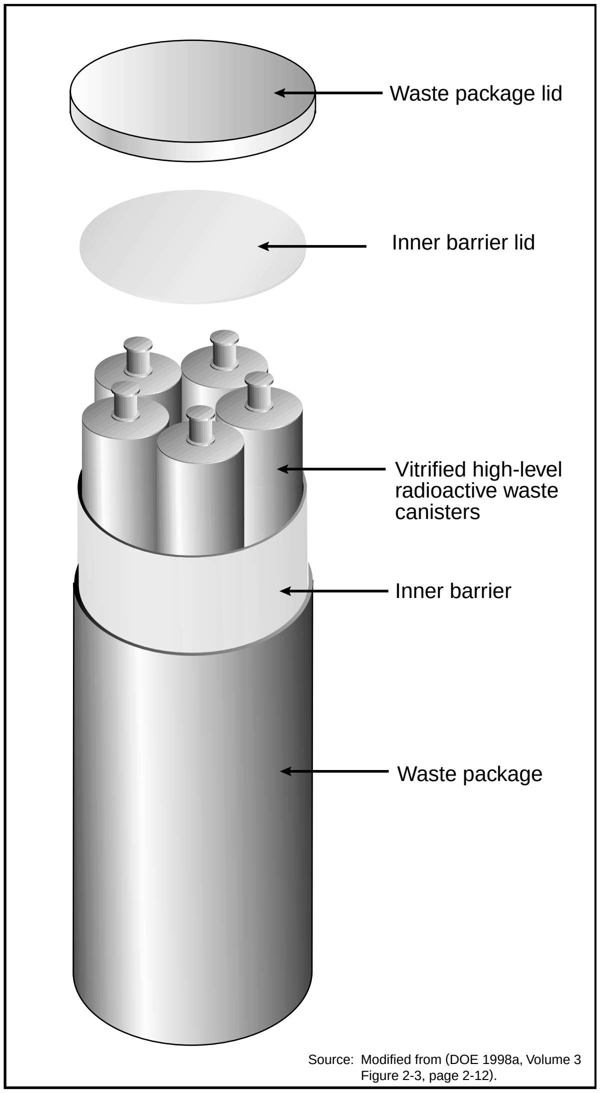
DOE stores high-level radioactive waste in below-grade tanks at the Hanford Site, the Savannah River Site, the Idaho National Engineering and Environmental Laboratory, and West Valley (see Figure 1-1 for locations). High-level radioactive waste can be in a liquid, sludge, or saltcake form, and a solid immobilized glass form (see below). Liquid waste consists of water and organic compounds that contain dissolved salts. Sludge is a mixture of insoluble (that is, materials that will not dissolve in tank liquid) metallic salt compounds that precipitated and settled out of the solution after the waste became alkaline. Saltcake is primarily sodium and aluminum salt that crystallized from the solution following evaporation. High-level radioactive waste can also include other highly radioactive material that the Nuclear Regulatory Commission determines by rule to require permanent isolation (Nuclear Waste Policy Act definitions, Section 12), as well as immobilized plutonium waste forms. Appendix A, Section A.2.3, provides details on high-level radioactive waste and discusses the amount currently stored and projected to be stored at each site. Included in this total is immobilized high-level radioactive waste that would result from the proposed electrometallurgic treatment of DOE sodium-bonded nuclear fuel at Argonne National Laboratory-West on the Idaho National Engineering and Environmental Laboratory site. DOE is preparing an EIS (64 *FR* 8553, February 22, 1999) to help it decide the disposition of this sodium-bonded fuel.

The DOE process for preparing high-level radioactive waste for disposal starts with the transfer of the waste from storage tanks to a treatment facility. Treatment ordinarily includes separation of the waste into high-activity and low-activity fractions, followed by vitrification of the high-activity fraction. Vitrification involves adding materials to the waste and heating the mixture until it melts. The melted mixture is poured into canisters, where it cools into a solid glass or ceramic form that is very resistant to the leaching of radionuclides. The solidified, immobilized glass forms have been developed to keep the waste stable, confined, and isolated from the environment when inserted into disposal containers and disposed of in a monitored geologic repository. DOE will store the solidified high-level radioactive waste on the sites in canisters (see Figure 1-3) before eventual shipment to a repository.

DOE has begun to solidify and immobilize waste at the Savannah River Site and West Valley and plans to begin solidification and immobilization at Hanford. DOE is preparing an EIS (62 *FR* 49209, September 19, 1997) to help it determine the method it will use to solidify and immobilize high-level radioactive waste at the Idaho National Engineering and Environmental Laboratory.

1.2.4 SURPLUS WEAPONS-USABLE PLUTONIUM

DOE has declared 50 metric tons (55 tons) of weapons-usable plutonium to be surplus to national security needs. This material includes purified plutonium, nuclear weapons components, and materials and residues that could be processed to produce purified plutonium (Appendix A). DOE currently stores these plutonium-containing materials at the Pantex Plant, the Rocky Flats Environmental Technology Site, the Savannah River Site, the Hanford Site, the Idaho National Engineering and Environmental Laboratory, and the Oak Ridge, Los Alamos, and Lawrence Livermore National Laboratories.



Source: Modified from (DOE 1998a, Volume 3 Figure 2-3, page 2-12).

Figure 1-3. Vitrified high-level radioactive waste canisters in waste package.

DOE could emplace surplus weapons-usable plutonium in the repository in two forms. One form would be an immobilized plutonium ceramic that DOE would dispose of as high-level radioactive waste. The second form would be mixed uranium and plutonium oxide fuel (called mixed-oxide fuel) assemblies that would be used for power production in commercial nuclear reactors and disposed of in the same manner as other commercial spent nuclear fuel. The analysis in this EIS assumed that approximately 18 metric tons (20 tons) of surplus plutonium would be immobilized plutonium and approximately 32 metric tons (35 tons) would be mixed-oxide spent nuclear fuel (Appendix A). The final waste forms would be immobilized plutonium and spent mixed-oxide fuel. The actual split could include the immobilization of between 18 and 50 metric tons (20 and 55 tons). Appendix A, Section A.2.4, contains details on sources, generation and storage status, and material characteristics of this surplus plutonium, and other high-level radioactive waste forms (for example, electrometallurgically treated sodium-bonded fuel).

1.2.5 OTHER WASTE TYPES WITH HIGH RADIONUCLIDE CONTENT

The Nuclear Regulatory Commission classifies most low-level radioactive waste into Classes A, B, and C (10 CFR Part 61), which reflect increasing levels of radioactivity. *Greater-Than-Class-C* is the term for radioactive waste generated by commercial activities that exceeds Nuclear Regulatory Commission concentration limits for Class C waste, as specified in 10 CFR Part 61. The Nuclear Regulatory Commission has determined that shallow land burial of Greater-Than-Class-C low-level radioactive waste generally is not acceptable. *Special-Performance-Assessment-Required* waste is DOE-generated low-level radioactive waste with radioactive content higher than Class C shallow land disposal limits.

1.3 National Effort To Manage Spent Nuclear Fuel and High-Level Radioactive Waste

This section provides background information on the management of spent nuclear fuel and high-level radioactive waste, and describes the Nuclear Waste Policy Act and its amendments.

1.3.1 BACKGROUND

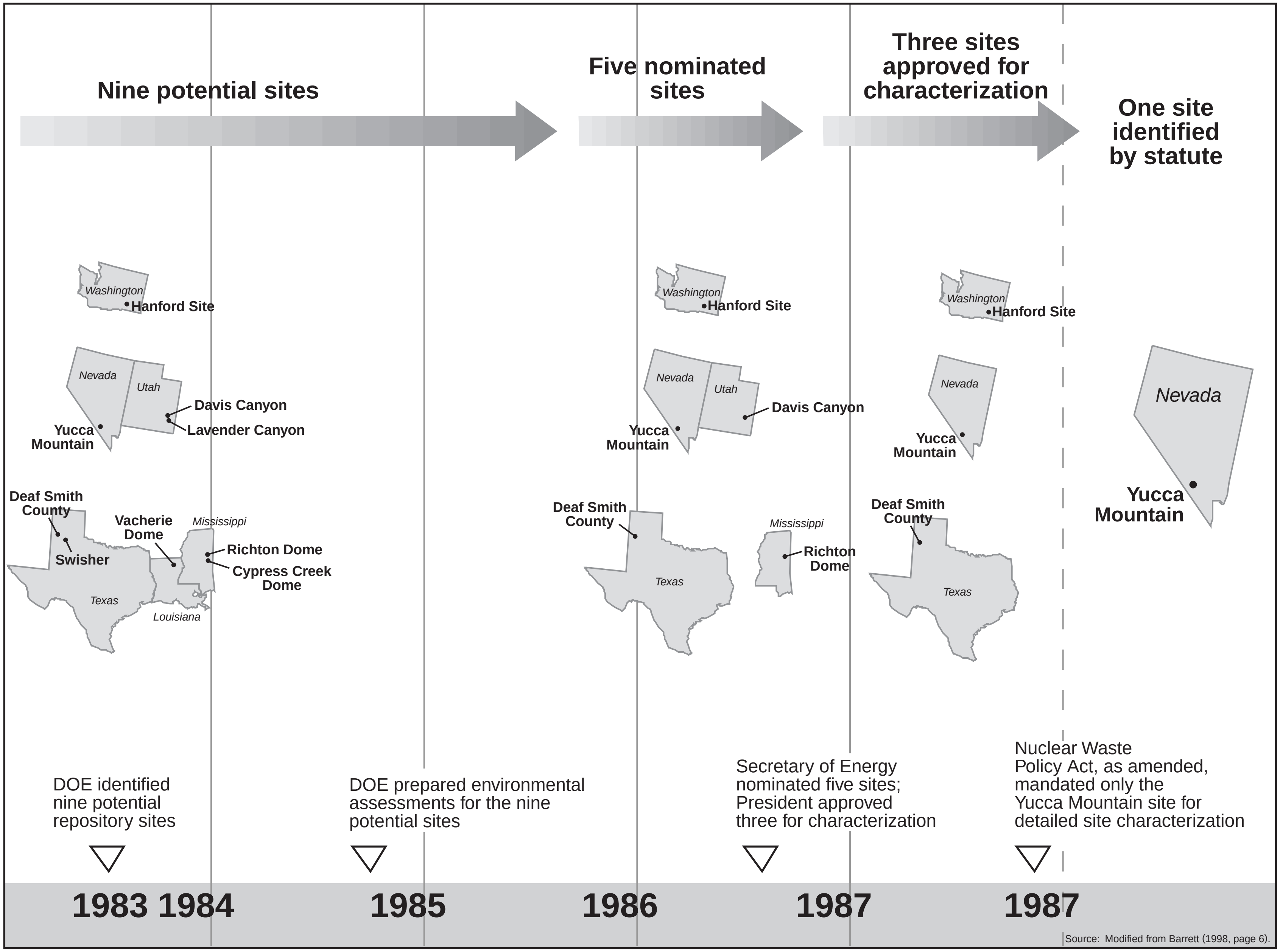
In the late 1950s, active investigation began on the concept of mined geologic repositories for the disposal of spent nuclear fuel and high-level radioactive waste. In the 1970s, the United States reprocessed a small amount of commercial spent nuclear fuel to extract plutonium and studied the feasibility of expanded reprocessing. The plutonium would have been combined with uranium and used again as reactor fuel, substantially reducing the total amount of new enriched uranium required (NRC 1976, all). President Carter cancelled consideration of this approach, leaving disposal as a primary option for spent nuclear fuel.

In a February 12, 1980, message to Congress, President Carter stated that the safe disposal of radioactive materials generated by both defense and civilian nuclear activities is a national responsibility. In fulfillment of that responsibility, he announced a comprehensive program for the management of radioactive materials and adopted an interim planning strategy focusing on “the use of mined geologic repositories capable of accepting both waste from reprocessing and unreprocessed commercial spent fuel” (DOE 1980, page 2.7). President Carter stated that he would reexamine this interim strategy and decide if changes were required after the completion of the environmental reviews required by the National Environmental Policy Act. As part of this reexamination, DOE issued the *Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste* (DOE 1980, all). That EIS analyzed the environmental impacts that could occur if DOE developed and implemented various technologies for the management and disposal of spent nuclear fuel and high-level radioactive waste. It examined several alternatives, including mined geologic disposal, very deep hole disposal, disposal in a mined cavity that resulted from rock melting, island-based geologic disposal, subseabed disposal, ice sheet disposal, well injection disposal, transmutation, space disposal, and no action. The 1981 Record of Decision for that EIS announced the DOE decision to pursue the mined geologic disposal alternative for the disposition of spent nuclear fuel and high-level radioactive waste (46 *FR* 26677, May 14, 1981).

1.3.2 NUCLEAR WASTE POLICY ACT

In 1982, Congress enacted the Nuclear Waste Policy Act (Public Law 97-425; 96 Stat 2201), which acknowledged the Federal Government’s responsibility to provide permanent disposal of the nation’s spent nuclear fuel and high-level radioactive waste, and established the Office of Civilian Radioactive Waste Management, which has the responsibility to carry out the evaluative, regulatory, developmental, and operational activities the Act assigns to the Secretary of Energy. The Nuclear Waste Policy Act began a process for selecting sites for technical study as potential geologic repository locations. In accordance with this process (shown in Figure 1-4), DOE identified nine candidate sites, the Secretary of Energy nominated five of the nine sites for further consideration, and DOE issued environmental assessments for the five sites in May 1986. DOE recommended three of the five sites (Deaf Smith County, the Hanford Site, and Yucca Mountain) for possible study as repository site candidates, and President Reagan approved the three as candidates. In addition, the Nuclear Waste Policy Act recognized a need to ensure that spent nuclear fuel and high-level radioactive waste now accumulating at commercial and DOE sites do not adversely affect public health and safety and the environment [NWPA, Section 111(a)(7)].

In 1987, Congress significantly amended the Nuclear Waste Policy Act. This Act, as amended (42 USC 10101 *et seq.*), which this EIS refers to as the NWPA, identified one of the three Presidentially approved candidate sites, Yucca Mountain, as the only site to be studied as a potential location for a geologic repository. Congress directed the Secretary of Energy to study the Yucca Mountain site and recommend whether the President should approve the site for development as a repository. Congress also required that a Final EIS accompany a Secretarial recommendation to approve the Yucca Mountain site to the President [NWPA, Section 114(a)(1)]. DOE is preparing this EIS to fulfill that requirement.



Source: Modified from Barrett (1998, page 6).

Figure 1-4. Events leading to selection of Yucca Mountain for study.

1.3.2.1 Requirement To Study and Evaluate the Site

In addition to the general responsibilities it establishes, the NWPA requires the Secretary of Energy specifically to characterize and evaluate the Yucca Mountain site for a geologic repository. The Act directs the Secretary of Energy to characterize only the Yucca Mountain site as a potential repository location and establishes a decisionmaking process to determine whether to designate Yucca Mountain as qualified for an application for repository construction authorization (NWPA, Sections 113, 114, 115, and 160).

Congress created the Nuclear Waste Technical Review Board as an independent organization to evaluate the technical and scientific validity of site characterization activities for the proposed repository and activities related to the packaging and transportation of spent nuclear fuel and high-level radioactive waste (NWPA, Section 503). The Nuclear Waste Technical Review Board must report findings, conclusions, and recommendations based on its evaluations to Congress and to the Secretary of Energy at least twice each year (NWPA, Section 508).

1.3.2.2 Elements of Site Evaluation

Sections 113, 114, and 115 of the NWPA contain specific and mostly sequential steps in the evaluation and decisionmaking process Congress has established for the Yucca Mountain site. The rest of this section and Section 1.3.2.3 describe that process.

The first steps in the evaluation and decisionmaking process for the Yucca Mountain site require the Secretary of Energy and, by extension, DOE, to gather data about Yucca Mountain and evaluate whether to recommend Yucca Mountain for approval as the site for a license application to the Nuclear Regulatory Commission for repository development. The Secretary's specific duties include:

- Undertake physical characterization of the Yucca Mountain site.

- Hold public hearings in the Yucca Mountain site vicinity.

- Prepare a description of the site, of spent nuclear fuel and high-level radioactive waste forms and packaging to be used, and of site safety.

- Make a recommendation to the President on whether to approve the site for development as a repository.

Section 1.4.3.3 describes the elements that the Secretary of Energy must develop and consider in making a site recommendation to the President and in providing a statement of the basis for that recommendation.

The NWPA directs the Secretary of Energy to evaluate a scenario under which DOE would place an inventory of material in the proposed Yucca Mountain Repository. This EIS considers a repository inventory of 70,000 metric tons of heavy metal (MTHM) comprised of 63,000 MTHM of commercial spent nuclear fuel and 7,000 MTHM of DOE spent nuclear fuel and high-level radioactive waste. This overall inventory includes approximately 50 metric tons (55 tons) of surplus weapons-usable plutonium as spent mixed-oxide fuel and immobilized plutonium. Appendix A provides additional details of the inventory of materials.

To determine the number of canisters of high-level radioactive waste included in the Proposed Action waste inventory, DOE used 0.5 MTHM per canister of defense high-level radioactive waste. DOE has used the 0.5-MTHM-per-canister approach since 1985. Using a different approach would change the number of canisters of high-level radioactive waste in the Proposed Action. Regardless of the number of canisters, the impacts of the analysis would not significantly change because long-term repository performance results would be dominated by the spent nuclear fuel inventory. In addition, the EIS analyzes the impacts from the entire inventory of high-level radioactive waste in the cumulative impacts analysis.

Operating nuclear powerplants could generate approximately 105,000 MTHM through 2046. The total projected DOE inventory of materials includes 2,500 MTHM of spent nuclear fuel and approximately 22,280 canisters of high-level radioactive waste. Chapter 8 evaluates potential consequences of using a repository at Yucca Mountain to dispose of all spent nuclear fuel and high-level radioactive waste that could be produced through 2046 for which DOE retains ultimate responsibility.

1.3.2.3 Site Qualification and Authorization Process

The Nuclear Waste Policy Act, enacted by Congress in 1982 and amended in 1987, establishes a process leading to a decision by the Secretary of Energy on whether to recommend that the President approve Yucca Mountain for development of a geologic repository. As part of this process, the Secretary of Energy is to:

- Undertake site characterization activities at Yucca Mountain to provide information and data required to evaluate the site.
- Prepare an EIS.
- Decide whether to recommend approval of the development of a geologic repository at Yucca Mountain to the President.

The Nuclear Waste Policy Act, as amended (the EIS refers to the amended Act as the NWPA), also requires DOE to hold hearings to provide the public in the vicinity of Yucca Mountain with opportunities to comment on the Secretary's possible recommendation of the Yucca Mountain site to the President. These hearings would be separate from the public hearings on the Draft EIS required under the National Environmental Policy Act. If, after completing the hearings and site characterization activities, the Secretary decides to recommend that the President approve the site, the Secretary will notify the Governor and legislature of the State of Nevada accordingly. No sooner than 30 days after the notification, the Secretary may submit the recommendation to the President to approve the site for development of a repository.

If the Secretary recommends the Yucca Mountain site to the President, a comprehensive statement of the basis for the recommendation, including the Final EIS, will accompany the recommendation. This Draft EIS has been prepared now so that DOE can consider the Final EIS, including the public input on the Draft EIS, in making a decision on whether to recommend the site to the President.

If, after the recommendation by the Secretary, the President considers the site qualified for an application to the Nuclear Regulatory Commission for a construction authorization, the President will submit a recommendation of the site to Congress. The Governor or legislature of Nevada may object to the site by submitting a notice of disapproval to Congress within 60 days of the President's action. If neither the Governor nor the legislature submits a notice within the 60-day period, the site designation would become effective without further action by the President or Congress. However, if the Governor or the legislature did submit such a notice, the site would be disapproved unless, during the first 90 days of continuous session of Congress after the notice of disapproval, Congress passed a joint resolution of repository siting approval and the President signed it into law.

If the site designation became effective, the Secretary of Energy would submit to the Nuclear Regulatory Commission a License Application, based on a particular facility design, for a construction authorization no later than 90 days after the designation. The NWPA requires the Commission to adopt the Final EIS to the extent practicable as part of the Commission's decisionmaking on the License Application.

1.3.2.4 Environmental Protection and Approval Standards for the Yucca Mountain Site

Section 121 of the Nuclear Waste Policy Act of 1982 directed the U.S. Environmental Protection Agency to establish generally applicable standards to protect the general environment from offsite releases from radioactive materials in repositories and directed the Nuclear Regulatory Commission to issue technical requirements and criteria for such repositories. In 1992, Congress modified the rulemaking authorities of the Environmental Protection Agency and the Nuclear Regulatory Commission in relation to a possible repository at Yucca Mountain. Section 801(a) of the Energy Policy Act of 1992 directed the Environmental Protection Agency to retain the National Academy of Sciences to conduct a study and issue findings and recommendations on setting reasonable standards for protecting public health and safety in relation to a repository at Yucca Mountain. Section 801(a) also directs the Environmental Protection Agency to establish Yucca Mountain-specific standards based on and consistent with the Academy's findings and recommendations. The standards will set health-based limits for any radioactive releases from a repository at Yucca Mountain. The National Academy of Sciences issued its findings and recommendations in a 1995 report (National Research Council 1995, all). The Environmental Protection Agency is in the process of establishing standards and is expected to place them in the Code of Federal Regulations (probably at 40 CFR Part 197). Chapter 11 contains a more detailed discussion of applicable regulations and other requirements.

Section 801(b) of the Energy Policy Act directs the Nuclear Regulatory Commission to revise its general technical requirements and criteria for geologic repositories (10 CFR Part 60) to be consistent with the Environmental Protection Agency site-specific Yucca Mountain standards. The Nuclear Regulatory Commission has issued draft site-specific technical requirements and criteria (proposed 10 CFR Part 63). The Commission would use these requirements and criteria, when final, to evaluate an application to construct a repository at Yucca Mountain, to receive and possess spent nuclear fuel and high-level radioactive waste at such a repository, and to close and decommission such a repository.

The Nuclear Waste Policy Act of 1982 required the Secretary of Energy to issue general guidelines for use in recommending potential repository sites for detailed site characterization. DOE issued these guidelines in 1984 (10 CFR Part 960). DOE is issuing this EIS before the Environmental Protection Agency and the Nuclear Regulatory Commission have completed their rulemaking processes and before DOE has determined whether to modify 10 CFR Part 960. The EIS provides current information on the proposed repository and presents an evaluation of the repository site, potential repository development, and anticipated repository performance measured against human health and other relevant technical criteria. DOE intends the results of the EIS evaluation to be useful for decisionmakers and to enhance the understanding and knowledge of members of the public.

1.4 Yucca Mountain Site and Proposed Repository

Spent nuclear fuel and high-level radioactive waste generate large amounts of radiation from the gradual decay of radioactive isotopes. These isotopes have the potential to cause severe human health impacts. In addition, the materials can generate heat from radioactive decay for periods lasting thousands of years. The Nuclear Waste Policy Act directs DOE to analyze and consider the disposal of spent nuclear fuel and high-level radioactive waste in a geologic repository.

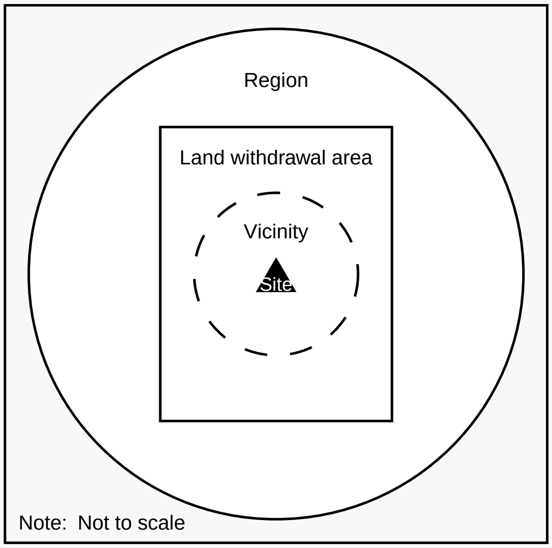
SITE-RELATED TERMS

Yucca Mountain site (the site): The area on which DOE has built or would build the majority of facilities or cause the majority of land disturbances related to the proposed repository.

Yucca Mountain vicinity: A general term used in nonspecific discussions about the area around the Yucca Mountain site. The EIS also uses terms such as area, proximity, etc., in a general context.

Land withdrawal area: An area of Federal property set aside for the exclusive use of a Federal agency. For the analyses in this EIS, DOE used an assumed land withdrawal area of 600 square kilometers, or 150,000 acres.

Region of influence (the region): A specialized term indicating a specific area of study for each of the resource areas that DOE assessed for the EIS analyses.



Note: Not to scale

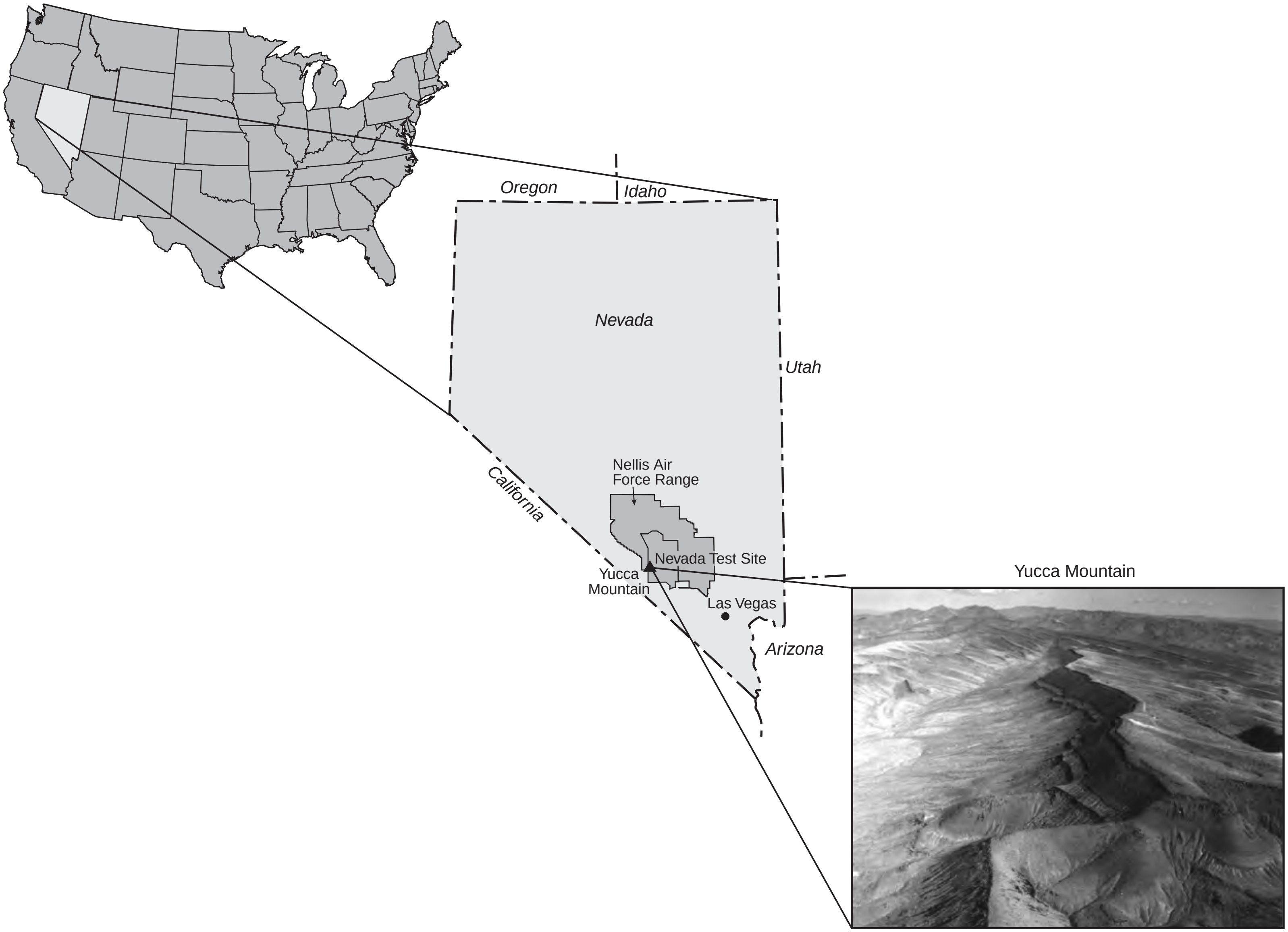
1.4.1 YUCCA MOUNTAIN SITE

The site of the proposed Yucca Mountain Repository (see Figure 1-5) is on lands administered by the Federal Government in a remote area of the Mojave Desert in Nye County in southern Nevada, approximately 160 kilometers (100 miles) northwest of Las Vegas, Nevada. The area surrounding the site is sparsely populated and receives an average of about 170 millimeters (7 inches) of precipitation per year. Chapter 3, Section 3.1, provides detailed information on the environment at the site.

The land withdrawal area analyzed in the EIS includes about 600 square kilometers (230 square miles or 150,000 acres) of land currently under the control of DOE, the U.S. Department of Defense, and the U.S. Department of the Interior (see Figure 1-6). Approximately 3.5 square kilometers (1.4 square miles or 870 acres) comprising the repository site would be needed for development of surface repository facilities, with the remainder serving as a large buffer zone. If Yucca Mountain is recommended for development as a repository, all or a portion of the land withdrawal area would have to be withdrawn permanently from public access to satisfy Nuclear Regulatory Commission licensing requirements currently at 10 CFR 60.121. If the land to be withdrawn included land that this EIS does not consider for withdrawal, DOE would perform additional analysis as required by the National Environmental Policy Act.

1.4.2 PROPOSED DISPOSAL APPROACH

The proposed monitored geologic repository at Yucca Mountain would be a large underground excavation with a network of *drifts* (tunnels) serving as the emplacement area for spent nuclear fuel and high-level radioactive waste. Rail, legal-weight trucks, or heavy-haul trucks would provide most of the transportation of spent nuclear fuel and high-level radioactive waste from the present storage sites to the repository. Barges could move spent nuclear fuel from some sites to rail and truck transfer points. Shippers would transport the materials in Nuclear Regulatory Commission-approved shipping containers designed to transport radioactive materials with minimal risk to the public health and safety and to the



Source: Modified from DOE (1998a, Overview, pages 10 and 11).

Figure 1-5. Yucca Mountain location.

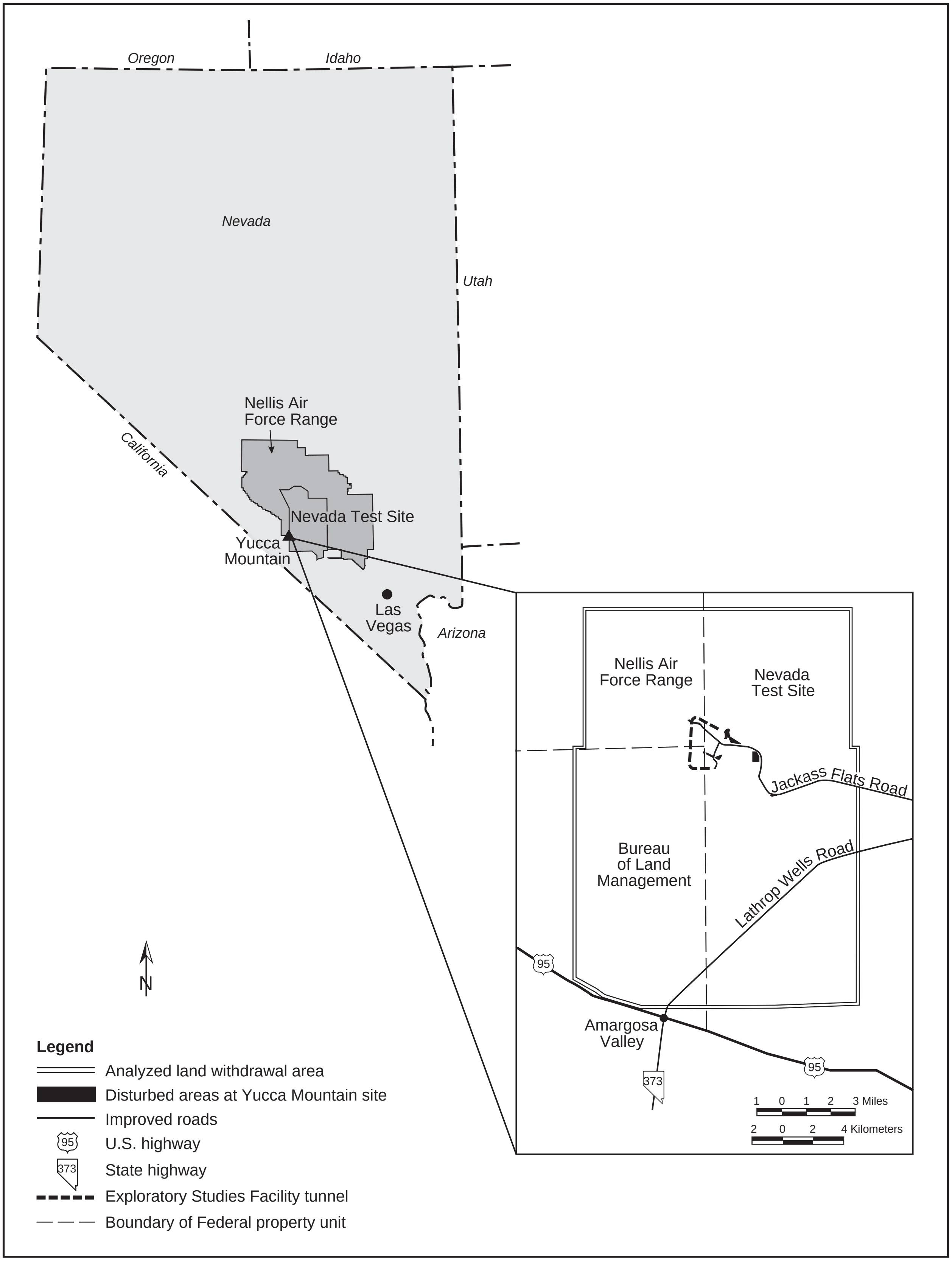


Figure 1-6. Land withdrawal area used for analytical purposes.

environment. (Chapter 6 discusses potential transportation systems.) Figure 1-7 shows the concept of temporary storage of spent nuclear fuel and high-level radioactive waste at storage sites, transporting these materials to the proposed repository, and disposing of the materials in an emplacement area.

At the repository, the material would be loaded in disposal containers. The filled disposal containers would be sealed, thereby becoming waste packages. The waste packages would be moved underground by rail. Remote-controlled handling vehicles would place the waste packages in emplacement drifts. The waste packages, which would be designed to remain intact for thousands of years (at a minimum), would be part of an engineered barrier system inside the mountain that would isolate spent nuclear fuel and high-level radioactive waste from the environment. The engineered barrier system, together with the geologic and hydrologic properties of the Yucca Mountain site, would ensure that a potential release of radioactive material after repository closure would meet applicable performance standards to contain and isolate the waste for 10,000 years or more. Chapter 5 provides detailed discussions of the natural system and of waste packages. Chapter 2 describes the Proposed Action at Yucca Mountain in additional detail, including the transportation activities required to move the spent nuclear fuel and high-level radioactive waste to the site.

Under the NWPA, the proposed repository, if authorized, would be a facility for the permanent disposal of 70,000 MTHM of spent nuclear fuel and high-level radioactive waste. The Nuclear Waste Policy Act requires the Nuclear Regulatory Commission to include in the authorization a prohibition against the emplacement of more than 70,000 MTHM in the first repository until a second repository is in operation [Nuclear Waste Policy Act, Section 114(d)]. DOE has allocated 63,000 MTHM of commercial spent nuclear fuel and 7,000 MTHM equivalent of DOE spent nuclear fuel and high-level radioactive waste to the proposed repository at Yucca Mountain. The Proposed Action that this EIS evaluates, therefore, includes the transportation of spent nuclear fuel and high-level radioactive waste from the present storage sites to Yucca Mountain and the emplacement of as much as 70,000 MTHM of spent nuclear fuel and high-level radioactive waste in the proposed repository. Chapter 8 of this EIS analyzes cumulative impacts from the disposal at Yucca Mountain of all spent nuclear fuel and high-level radioactive waste projected to be produced through 2046 for which DOE will retain ultimate responsibility. Chapter 8 also considers the disposal of Greater-Than-Class-C waste and Special-Performance-Assessment-Required waste at Yucca Mountain.

1.4.3 DOE ACTIONS TO EVALUATE THE YUCCA MOUNTAIN SITE

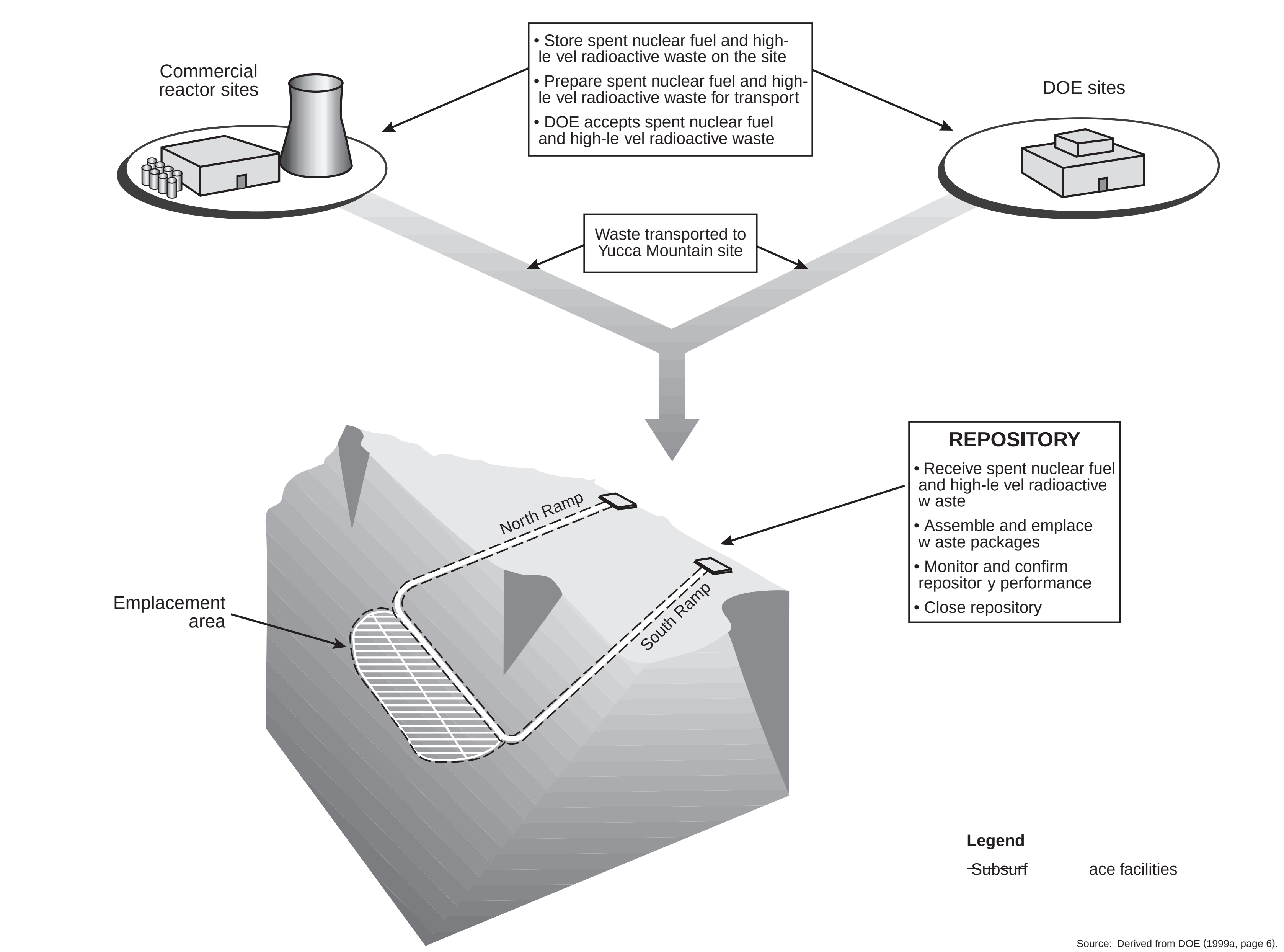
The primary evaluation activities related to the Yucca Mountain site that DOE has performed or will perform are site characterization studies, a Viability Assessment, and a potential Site Recommendation. The following sections address these activities.

1.4.3.1 Site Characterization Activities

In accordance with the NWPA [Section 113(b)], the DOE Office of Civilian Radioactive Waste Management prepared a Site Characterization Plan for the Yucca Mountain site (DOE 1988a, all). DOE has had an ongoing program of investigations and evaluations to assess the suitability of the Yucca Mountain site as a potential geologic repository and to provide information for this EIS. The program consists of scientific, engineering, and technical studies and activities.

Examples of activities, investigations, and evaluations associated with site characterization include the following:

- Construction of an Exploratory Studies Facility, including the North and South Portal Ramps (openings into the mountain)



Source: Derived from DOE (1999a, page 6).

Figure 1-7. Spent nuclear fuel and high-level radioactive waste temporary storage, transportation, and disposal.

- Excavation of underground tunnels and rooms in the Exploratory Studies Facility for scientific and engineering studies, testing, and experiments
- Investigations of such topics as hydrology, including groundwater characteristics; general site geology; and specific geologic issues such as erosion, seismicity, and volcanic activity
- Field monitoring, including air quality, meteorological, radiological, and water resources monitoring
- Cultural resources studies, including Native American interests
- Terrestrial ecosystem studies

1.4.3.2 Viability Assessment

Pursuant to the Energy and Water Development Appropriations Act for Fiscal Year 1997 (Public Law 104-206), DOE issued the *Viability Assessment of a Repository at Yucca Mountain* in December 1998 (DOE 1998a, all). The Viability Assessment provides information on the progress of the Yucca Mountain Site Characterization Project to Congress, the President, regulatory agencies, stakeholder organizations, and the general public. In addition, the Viability Assessment identifies issues to be addressed before the Secretary of Energy can make a recommendation to the President on whether to approve the site for development as a repository. Further, the Viability Assessment provides an understanding of Yucca Mountain's capability to contain and isolate spent nuclear fuel and high-level radioactive waste in the repository system and limit releases to the accessible environment. The Viability Assessment includes the following:

- The preliminary design concept for the critical elements of the repository and waste package
- A total system performance assessment, based on the design concept and the scientific data and analyses available by 1998, that describes the probable behavior of the repository in the Yucca Mountain geologic setting
- A plan and cost estimate for the remaining work required to complete and submit a License Application to the Nuclear Regulatory Commission
- An estimate of the costs to construct and operate the repository in accordance with the design concept

This EIS summarizes results from the Viability Assessment, where applicable (see Chapter 5), and data analyses that continued after the completion of the Viability Assessment.

TOTAL SYSTEM PERFORMANCE ASSESSMENT

The *total system performance assessment* is an analysis tool to evaluate one particular environmental impact—possible future radioactivity doses to people living near the proposed repository. If it occurred, this impact would take place thousands of years in the future. Therefore, calculations must be used, based on the best available knowledge today of future phenomena. The analysis brings together computer simulations of the processes in the natural and engineered components of the repository, transport of radioactive substances to the affected people via available pathways, and effects of these materials on people and the environment. Because we cannot know definitively what will happen, the analysis considers a range of possible inputs. Therefore, the results are statistical ranges of outcomes.

1.4.3.3 Site Recommendation

Section 114(a) of the Nuclear Waste Policy Act requires that the recommendation be based on the record of information developed during site characterization and be submitted to the President together with a comprehensive statement of the basis of that recommendation. The recommendation is to be supported by:

- A description of the proposed repository, including preliminary engineering specifications for the facility
- A description of the material forms or packaging proposed for use at the repository, and an explanation of the relationship between the forms or packaging and the geologic medium of the site
- A discussion of data obtained in site characterization activities that relate to the safety of the site
- A Final EIS prepared for the Yucca Mountain site accompanied by comments from the Secretary of the Interior, the Council on Environmental Quality, the Environmental Protection Agency, and the Nuclear Regulatory Commission
- The preliminary comments of the Nuclear Regulatory Commission on the extent to which the material form proposal and the at-depth site characterization analysis are sufficient for inclusion in a License Application
- The views and comments of the governor and legislature of any state and of the governing bodies of affected Native American tribes
- Any impact report submitted under Section 116(c)(2)(B) of the Nuclear Waste Policy Act, as amended, by the State of Nevada
- Other information the Secretary considers appropriate

1.4.3.4 No-Action Alternative

Under the No-Action Alternative, DOE would end site characterization activities at Yucca Mountain and begin site decommissioning and reclamation. The commercial utilities and DOE would continue to store spent nuclear fuel and high-level radioactive waste. For purposes of analysis, the No-Action Alternative assumes that those sites would treat and package the materials, as necessary, in a condition ready for shipment to a repository. The potential environmental impacts from two No-Action scenarios, described below, serve as a baseline to compare the potential environmental impacts of the Proposed Action.

- Scenario 1 assumes that spent nuclear fuel and high-level radioactive waste would remain at the commercial and DOE sites under institutional control for at least 10,000 years.
- Scenario 2 assumes that spent nuclear fuel and high-level radioactive waste would remain at the commercial and DOE sites in perpetuity, but under institutional control for only about 100 years. This scenario assumes no effective institutional control of the stored spent nuclear fuel and high-level radioactive waste after 100 years.

INSTITUTIONAL CONTROL

Monitoring and maintenance of storage facilities to ensure that radiological releases to the environment and radiation doses to workers and the public remain within Federal limits and DOE Order requirements.

DOE recognizes that neither scenario would be likely if there were a decision not to develop a repository at Yucca Mountain; however, they are part of the EIS analysis to provide a baseline for comparison to the Proposed Action. There are a number of possibilities that DOE could pursue, including continued storage of the material at its current locations or at one or more centralized location(s); the study and selection of another location for a deep geologic repository; development of new technologies; or reconsideration of alternatives to deep geologic disposal. However, these potential actions are speculative.

1.5 Environmental Impact Analysis Process

The National Environmental Policy Act of 1969, as amended, and regulations promulgated by the Council on Environmental Quality established the procedures for Federal agencies to use when considering potential beneficial and adverse environmental consequences of proposed major Federal actions. This process requires Federal agencies to analyze potential impacts of proposed major Federal actions on the human and natural environments to assist the agencies in making informed decisions on those actions. A major emphasis of the EIS process is to promote public awareness of the proposed actions and provide opportunities for public involvement.

An agency prepares an EIS in a series of steps: (1) soliciting comments from Federal and state agencies, stakeholders, Tribal Nation representatives, and the general public to assist in defining the proposed action, alternatives, and issues requiring analysis (a process known as *scoping*); (2) preparing a Draft EIS for public distribution and comment; (3) receiving and responding to public comments on the Draft EIS; and (4) preparing a Final EIS that incorporates or summarizes (if the public comments are exceptionally voluminous) and responds to public comments on the Draft EIS. DOE conducted the scoping process for this EIS from August to December 1995 (see Section 1.5.1). After a public comment period on this Draft EIS, and after considering comments received, DOE will prepare a Final EIS. The Final EIS is scheduled for publication in August 2000.

The NWPA includes four specific provisions relevant to this EIS. Under the NWPA, the Secretary is not required to consider in this EIS (1) the need for a geologic repository, (2) the time at which a repository could become available, and (3) alternatives to isolating spent nuclear fuel and high-level radioactive waste in a repository. The fourth provision addresses the issue of potential alternative sites by providing that the EIS does not need to consider any site other than Yucca Mountain for repository development [NWPA, Section 114(f)(2) and (3)]. However, DOE has focused the EIS analysis on two alternatives: (1) the Proposed Action of constructing, operating and monitoring, and eventually closing a repository at Yucca Mountain, and (2) the No-Action Alternative, which assumes that site characterization activities at Yucca Mountain would end, resulting in spent nuclear fuel remaining at commercial sites and spent nuclear fuel and high-level radioactive waste remaining at DOE facilities.

1.5.1 NOTICE OF INTENT AND SCOPING MEETINGS

The EIS scoping process is intended to determine the scope and the significant issues to be analyzed in depth in the EIS. The scoping process must begin early and must be open, and must include public notice of public meetings and of the availability of environmental documents to inform those persons and agencies who might be interested in or affected by a proposed action.

On August 7, 1995, DOE published a Notice of Intent announcing that it would prepare an EIS for a proposed repository at Yucca Mountain, Nevada (60 *FR* 40164, August 7, 1995). To encourage broad participation by the public, before publishing the Notice of Intent DOE notified stakeholders, the media, Congressional representatives with jurisdiction over nuclear issues, the Nevada Congressional delegation, the Office of the Governor of Nevada, affected units of local government in the Yucca Mountain site vicinity, Native American tribes, the Nuclear Regulatory Commission, and the Nuclear Waste Technical

Review Board. The notification discussed the Proposed Action and No-Action Alternative, the proposed schedule of scoping meetings, and the means by which DOE intended to solicit public comments.

DOE representatives met with 13 Native American tribes and organizations to describe the EIS scoping process and to request tribal involvement in the process. In addition, DOE invited public interest groups, transportation interests, industry and utility organizations, regulators, and members of the general public to participate in the process. The Department mailed a series of information releases to Yucca Mountain stakeholders and members of the public notifying them of the opportunity to comment; submitted press releases and public service announcements to newspapers and television and radio stations; and made information about Yucca Mountain, the EIS, and the scoping process available to the public on the Internet (at *http://www.ymp.gov*) and in designated public reading rooms around the country. DOE solicited written comments and held 15 public scoping meetings across the country between August 29 and October 24, 1995, to enable interested parties to present comments on the scope of this EIS. The scoping period officially closed on December 5, 1995 (DOE 1997a, page 7).

PUBLIC SCOPING MEETING LOCATIONS

Sacramento, California
Denver, Colorado
College Park, Georgia (near Atlanta)
Boise, Idaho
Chicago, Illinois
Linthicum, Maryland (near Baltimore)
Kansas City, Missouri
Caliente, Nevada
Las Vegas, Nevada
Pahrump, Nevada
Reno, Nevada
Tonopah, Nevada
Troy, New York (near Albany)
Dallas, Texas
Salt Lake City, Utah

A total of 568 people submitted more than 1,000 comment documents during the public scoping period. DOE responded to these comments in the *Summary of Public Scoping Comments Related to the Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE 1997a, all).

DOE considered all comments received during the scoping process. Several of these comments led to changes in the analytical approach to the EIS. The two most notable changes were the consideration of additional inventories and the addition of new Nevada transportation route alternatives. A number of commenters asked that the EIS discuss the history of the Yucca Mountain site characterization program and requirements of the NWPA; address DOE's responsibility to begin accepting waste in 1998 (including an analysis of the potential for receipt of spent nuclear fuel and high-level radioactive waste prior to the start of emplacement); describe the potential decisions that the EIS would support; and examine activities other than construction, operation and monitoring, and eventual closure of a repository at Yucca Mountain.

Other concerns raised by the public during scoping emphasized that DOE needed to ensure that the EIS thoroughly addresses the impacts of constructing and operating a geologic repository and related facilities (including the use of a rail line, heavy-haul truck routes, and intermodal transfer stations) on:

- Land uses in the Yucca Mountain vicinity (including consistency with existing land-use plans)
- Regional air quality and meteorology
- Geology (including the effects of earthquakes and volcanism and the potential for transport of radioactive and hazardous materials from the repository)
- Regional hydrology (including groundwater quality in Amargosa Valley, Ash Meadows, and Death Valley National Park)

- Biological resources (including postclosure effects on wildlife from potential increased surface temperatures)
- Health and safety (including past radiation exposures from activities at the Nevada Test Site for both pre- and postclosure periods)
- Long-term performance assessment for the repository (including an evaluation of the ability of the overall system to meet potential performance objectives, waste package performance and degradation given different thermal loads, infiltration rates, corrosion models, and other relevant factors)
- Sabotage and safeguards and security measures during waste transport and disposal
- Cultural and historic resources and environmental justice
- Socioeconomics
- Mitigation (including the mitigation of impacts from both routine operations and accident conditions)

DOE included discussions and analyses in the EIS that respond to these public issues and concerns. In addition, DOE received many requests for more formal involvement in the EIS preparation process by representatives of the affected units of local government and Native American tribes. In response, DOE tasked (and funded) the American Indian Writers Subgroup to prepare a document setting forth Native American perspectives and views regarding the repository and Yucca Mountain; that document is quoted and referenced in the EIS. A similar opportunity was extended to the State of Nevada and the affected units of local government to prepare their own documents setting forth perspectives and views on a variety of issues of local and regional concern, which DOE agreed to incorporate by reference in the EIS. At Draft EIS publication, Nye County (Buqo 1999, all) had prepared such a document. In addition, other documents related to the Yucca Mountain region have been prepared in the past by several local government units including Clark, Lincoln, and White Pine Counties.

Many other public scoping comments presented views and concerns not related to the scope or content of the Proposed Action. Examples of such comments include statements in general support of or opposition to Yucca Mountain, repositories, and nuclear power; lack of public confidence in the Yucca Mountain program; inequities and political aspects of the siting process by which Yucca Mountain was selected for further study by Congress; the constitutional basis for waste disposal in Nevada; psychological costs or effects; risk perception and stigmatization; legal issues involving Native American land claims and treaty rights; and unrelated DOE activities. DOE considered and recorded these concerns in the comment summary document on the scoping process (DOE 1997a, all), but has not included analyses of these issues in the EIS.

1.5.1.1 Additional Inventory Studies

The Proposed Action is to construct, operate and monitor, and eventually close a geologic repository for the disposal of 70,000 MTHM of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. During the scoping period, DOE received many comments that noted the potential existence of more than 70,000 MTHM of these materials and encouraged DOE to evaluate the total projected inventory. For example, presently operating nuclear powerplants could generate approximately 105,000 MTHM of spent nuclear fuel eligible for disposal by 2046 if all commercial licenses were extended. In addition, some commenters requested that the EIS evaluate the disposal of radioactive waste types that might require permanent isolation, such as Greater-Than-Class-C waste and Special-Performance-Assessment-Required waste. For these reasons, DOE has included in the EIS cumulative impact analysis an evaluation of the cumulative environmental impacts that could occur as a result of the disposal of all projected spent nuclear fuel and high-level radioactive waste and the disposal of quantities of Greater-Than-Class-C and Special-Performance-Assessment-Required waste in the Yucca Mountain Repository (see Chapter 8).

1.5.1.2 Additional Nevada Transportation Analyses

In response to public comments, DOE decided to analyze a fifth branch rail line and a fifth route for heavy-haul trucks in Nevada. The Department added analyses of the Caliente-Chalk Mountain branch rail line and the Caliente-Chalk Mountain route for heavy-haul trucks to the analyses of four rail corridors and four heavy-haul routes it had previously identified for potential transportation impacts in Nevada. Chapter 6 and Appendix J describe the transportation analyses. The U.S. Air Force opposes the use of the Caliente-Chalk Mountain rail corridor and heavy-haul truck route because of national security concerns; at this time DOE regards these routes as nonpreferred alternatives.

APPROXIMATE WASTE INVENTORIES
(Measurement methods differ among waste types)

Commercial spent nuclear fuel
- Projected total: 105,000 MTHM in 2046
- Current disposal plan: 63,000 MTHM (includes as much as 32 metric tons of plutonium disposed of as mixed oxide spent nuclear fuel)

DOE spent nuclear fuel
- Projected total: 2,500 MTHM
- Current disposal plan: 2,333 MTHM (one-third of the 7,000-MTHM total of DOE material proposed for disposal, which includes high-level radioactive waste)

High-level radioactive waste
- Projected total: 22,280 canisters (would include as much as 50 metric tons of immobilized plutonium)
- Current disposal plan: 8,315 canisters (includes 18 metric tons of immobilized plutonium)

Greater-Than-Class-C waste
- Projected total: 2,100 cubic meters
- Disposal evaluated in Chapter 8

Special-Performance-Assessment-Required waste
- Projected total: 4,000 cubic meters
- Disposal evaluated in Chapter 8

1.5.2 CONFORMANCE WITH DOCUMENTATION REQUIREMENTS

DOE has performed formal documented reviews of data to identify gaps, inconsistencies, omissions, or other conditions that would cause data to be suspect or unusable.

DOE planned analyses to ensure consistency and thoroughness in the environmental studies conducted for this EIS. DOE has also used configuration control methods to ensure that EIS inputs are current, correct, and appropriate, and that outputs reflect the use of appropriate inputs.

All work products for this EIS have undergone documented technical, editorial, and managerial reviews for adequacy, accuracy, and conformance to project and DOE requirements. Work products related to impact analyses (for example, calculations, data packages, and data files) have also undergone formal technical and managerial reviews. Calculations (manual or computer-driven) generated to support impact analyses have been verified independently and completely in accordance with project management procedures.

1.5.3 RELATIONSHIP TO OTHER ENVIRONMENTAL DOCUMENTS

A number of completed, in-preparation, or proposed DOE National Environmental Policy Act documents relate to this EIS. In addition, other Federal agencies have prepared related EISs. As directed by the Council on Environmental Quality regulations that implement the National Environmental Policy Act, DOE has used information from these documents in its analysis and has incorporated this material by reference as appropriate throughout this EIS. Table 1-1 lists the documents that formed a basis for decisions associated with a geologic disposal program and investigation of Yucca Mountain as a potential repository site; these include the EIS for Management of Commercially Generated Radioactive Waste (DOE 1980, all), the Surplus Plutonium Disposition Draft EIS (DOE 1998b, all), and the Yucca Mountain Site Environmental Assessment (DOE 1986a, all).

Table 1-1. Related environmental documents[a] (page 1 of 3).

Document	Material type	Relationship to Yucca Mountain Repository EIS
Nuclear materials activities		
Final EIS, Management of Commercially Generated Radioactive Waste (DOE 1980, all)	Commercial SNF; DOE SNF and HLW	Examines different disposal alternatives. ROD documented DOE decision to pursue geologic disposal for SNF and HLW.
EA, Yucca Mountain Site, Nevada Research and Development Area (DOE 1986a, all)	Commercial SNF; DOE SNF and HLW	Examines impacts of site characterization activities and possible geologic repository at Yucca Mountain.
Final Supplemental EIS, Defense Waste Processing Facility, Savannah River Site, Aiken, South Carolina (DOE 1994a, all)	HLW	Examines impacts of constructing and operating DWPF, which processes HLW at SRS. SRS HLW could be eligible for repository disposal.
Final EIS, Waste Management, Savannah River Site (DOE 1995c, all)	HLW	Examines impacts of managing five types of waste (including liquid HLW) at SRS over 10 years. SRS HLW could be eligible for repository disposal.
Final EIS, Interim Management of Nuclear Materials at the Savannah River Site (DOE 1995d, all)	HLW	Examines impacts of stabilization and interim storage of plutonium, uranium, and other nuclear materials. SRS SNF and HLW could be eligible for repository disposal.
Final EIS, Management of Spent Nuclear Fuel from the K-Basins at the Hanford Site, Richland, Washington (DOE 1996a, all)	DOE SNF	Examines impacts of managing SNF in K-Basins at Hanford. Hanford SNF could be eligible for repository disposal.
Draft EIS, Completion of the West Valley Demonstration Project and Closure or Long-Term Management of Facilities at the Western New York Nuclear Service Center (DOE 1996b, all)	HLW	Examines impacts of solidifying liquid HLW obtained from reprocessing commercial SNF. WVDP HLW could be eligible for repository disposal.
Final EIS, Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel (DOE 1996c, all)	DOE SNF	Examines impacts of managing SNF from foreign research reactors in accordance with U.S. policy to reduce nuclear weapons proliferation. SNF from foreign research reactors stored at SRS and INEEL could be eligible for repository disposal.
Final EIS, Hanford Site Tank Waste Remediation System (DOE 1996d, all)	HLW	Examines impacts of long-term management and disposal of Hanford tank waste, including HLW. Hanford HLW could be eligible for repository disposal.
Draft EIS, Surplus Plutonium Disposition (DOE 1998b, all)	Plutonium	Examines the alternatives for and impacts of disposition of 50 metric tons (55 tons) of surplus plutonium. Ultimate disposition of the plutonium could involve repository disposal.

Table 1-1. Related environmental documents[a] (page 2 of 3).

Document	Material type	Relationship to Yucca Mountain Repository EIS
Nuclear materials activities (continued)		
Supplement to the Surplus Plutonium Disposition Draft Environmental Impact Statement (DOE 1999b, all)	Plutonium	Examines potential environmental impacts of using mixed oxide fuel in six reactors as well as program changes made since the publication of the Draft EIS.
Draft EIS, Idaho High-Level Waste and Facilities Disposition (in preparation)	HLW	Examines impacts of treatment, storage, and disposal of INEEL HLW and facilities disposition. INEEL HLW could be eligible for repository disposal.
Draft EIS, Savannah River Site Spent Nuclear Fuel Management (DOE 1998c, all)	DOE SNF	Examines impact of several technologies for management of SNF at SRS, including placing these materials in forms suitable for ultimate disposition. Information from this EIS aids the study of packaging, transportation, and disposition of SNF.
Record of Decision (USN 1997a, all) and the Second Record of Decision (USN 1997b, all) for a Container System for the Management of Naval Spent Nuclear Fuel Final EIS (USN 1996a, all)	DOE SNF	Evaluates potential impacts of using alternative container systems for management of naval SNF following examination at INEEL. Naval SNF processed and stored at INEEL could be eligible for repository disposal. DOE used information from this EIS to estimate impacts from manufacture of disposal containers and shipping casks.
Supplement Analysis for a Container System for the Management of DOE Spent Nuclear Fuel Located at INEEL (DOE 1999e, all)	DOE SNF	Determines the use of a multipurpose canister or comparable system for the management of DOE SNF at INEEL that might be suitable for shipment using existing transportation casks.
Record of Decision for a Multi-Purpose Canister or Comparable System for Idaho National Engineering and Environmental Laboratory Spent Nuclear Fuel (DOE 1999f, all)	DOE SNF	Evaluates the impacts of using dual-purpose canisters to prepare DOE SNF located at INEEL for interim storage and transport outside the State of Idaho.
Generic Environmental Impact Statement for License Renewal of Nuclear Plants, Main Report, Final Report NUREG-1437 (NRC 1996, all) and the Draft Supplement for the Generic Environmental Impact Statement for License Renewal of Nuclear Plants, Addendum 1 (NRC 1999, all)	Commercial SNF	Addresses the cumulative impacts of transportation of commercial spent nuclear fuel in the vicinity of the proposed repository at Yucca Mountain, Nevada, and the impacts of transporting higher-burnup fuel.
Programmatic examination of waste management		
Record of Decision (DOE 1995b, all) for the Final Programmatic EIS, Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs (DOE 1995a, all)	DOE SNF	Examines programmatic impacts of storage of DOE SNF that could be eligible for repository disposal. In the associated ROD, DOE decided where DOE SNF would be managed.
Final Programmatic EIS, Storage and Disposition of Weapons-Usable Fissile Materials (DOE 1996e, all)	DOE SNF and HLW	Examines impacts of long-term storage of plutonium and highly enriched uranium at several DOE sites. Spent mixed-oxide fuel and immobilized plutonium could be eligible for repository disposal.
Final Programmatic EIS, Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste (DOE 1997b, all)	HLW	Examines impacts of managing five types of waste at DOE sites. Examines storage of HLW canisters and transportation of HLW canisters between DOE sites and Yucca Mountain.

Table 1-1. Related environmental documents[a] (page 3 of 3).

Document	Material type	Relationship to Yucca Mountain Repository EIS
Programmatic examination of waste management (continued)		
Final EIS, Nevada Test Site and Off-Site Locations in the State of Nevada (DOE 1996f, all)		Examines potential impacts of future mission activities at NTS. DOE used information from NTS EIS for Yucca Mountain site description and environmental impacts of NTS waste management activities. Cumulative impact analysis included activities analyzed in NTS EIS.
Regional description and cumulative impact information		
Final EIS, Withdrawal of Public Lands for Range Safety and Training Purposes at Naval Air Station Fallon, Nevada (USN 1998, all)		Examines impacts of land withdrawal around Naval Air Station Fallon. Repository EIS analysis of cumulative impacts considered proposed actions at Naval Air Station Fallon.
Legislative EIS for Nellis Air Force Range Renewal (USAF 1999, all)		Examines impacts of renewal of land withdrawal for Nellis Air Force Range. Yucca Mountain site is partly on range, and Repository EIS considers proposed actions at Nellis in its cumulative impacts analysis.
Proposed Caliente Management Framework Plan Amendment and FEIS for the Management of Desert Tortoise Habitat (BLM 1999a, all)		Examines the implementation of BLM management goals and actions for the administration of the desert tortoise habitat in Lincoln County, Nevada.
Final EIS for the Cortez Pipeline Gold Deposit (BLM 1996, all)		Examines potential for impacts from mining-related activities at a location in western Nevada.
EA, Pipeline Infiltration Project (BLM 1999b, all)		Examines potential for impacts from mining-related activities at a location in western Nevada.
Environmental Impact Analysis process for a Draft Secretarial Report to Congress regarding a proposal to establish permanent Timbisha Shoshone Tribal land use in and around Death Valley National Park (64 *FR* 19193 to 19194, April 19, 1999)		Examines the potential for impacts from creating a Timbisha Shoshone Tribal reservation in and around Death Valley National Park.

a. Abbreviations: BLM = Bureau of Land Management; DOE = U.S. Department of Energy; DWPF = Defense Waste Processing Facility; EA = environmental assessment; EIS = environmental impact statement; HLW = high-level radioactive waste; INEEL = Idaho National Engineering and Environmental Laboratory; NTS = Nevada Test Site; ROD = Record of Decision; SNF = spent nuclear fuel; SRS = Savannah River Site; WVDP = West Valley Demonstration Project.

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2

Proposed Action and No-Action Alternative

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2. PROPOSED ACTION AND NO-ACTION ALTERNATIVE

Under the Proposed Action, the U.S. Department of Energy (DOE) would construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain (see Section 2.1). The Proposed Action includes transportation of spent nuclear fuel and high-level radioactive waste from commercial and DOE sites to the Yucca Mountain site (see Figure 2-1).

Under the No-Action Alternative (see Section 2.2), DOE would end site characterization activities at Yucca Mountain, and the commercial and DOE sites would continue to manage their spent nuclear fuel and high-level radioactive waste (see Figure 2-1). The No-Action Alternative assumes that spent nuclear fuel and high-level radioactive waste would be treated and packaged as necessary for its safe onsite management. DOE does not intend to represent the No-Action Alternative as a viable long-term solution but rather to use it as a baseline against which the Proposed Action can be evaluated.

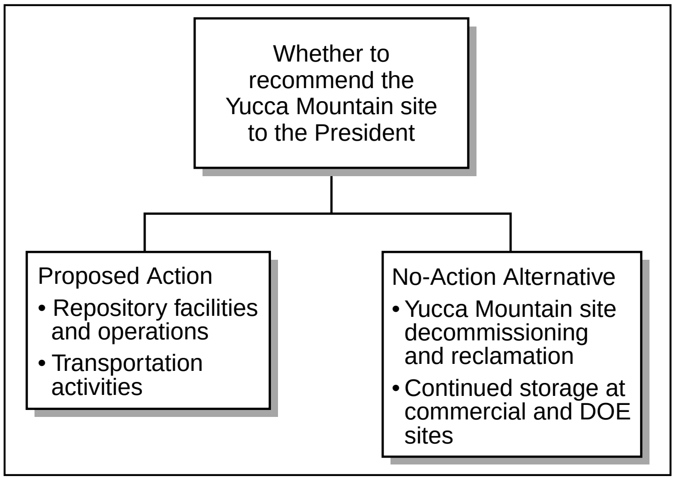


Figure 2-1. General activity areas evaluated under the Proposed Action and No-Action Alternative.

Section 2.3 discusses the alternatives that DOE considered but eliminated from detailed study in this environmental impact statement (EIS). Section 2.4 summarizes findings from the EIS and compares the potential environmental impacts of the Proposed Action and the No-Action Alternative. Section 2.5 addresses the collection of information and analyses performed for the EIS. Section 2.6 identifies the preferred alternative.

DOE has developed the information about the potential environmental impacts that could result from either the Proposed Action or the No-Action Alternative to inform the Secretary of Energy's determination whether to recommend Yucca Mountain as the site of this Nation's first monitored geologic repository for spent nuclear fuel and high-level radioactive waste.

As part of the Proposed Action, the EIS analyzes the impacts of transporting spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site from 77 sites across the United States. This analysis includes information on such matters as the comparative impacts of truck and rail transportation, alternative intermodal (rail to truck) transfer station locations, associated heavy-haul truck routes, and alternative rail transport corridors in Nevada. Although it is uncertain at this time when DOE would make any transportation-related decisions, DOE believes that the EIS provides the information necessary to make decisions regarding the basic approaches (for example, mostly rail or mostly truck shipments), as well as the choice among alternative transportation corridors. However, follow-on implementing decisions, such as selection of a specific rail alignment within a corridor, or the specific location of an intermodal transfer station or the need to upgrade the associated heavy-haul routes, would require additional field surveys, state and local government consultations, environmental and engineering analyses, and National Environmental Policy Act reviews.

2.1 Proposed Action

DOE proposes to construct, operate and monitor, and eventually close a geologic repository at Yucca Mountain for the disposal of spent nuclear fuel and high-level radioactive waste. About 600 square kilometers (230 square miles or 150,000 acres) of land in Nye County, Nevada, could be permanently withdrawn from public access for DOE use for the repository (see Figure 2-2 for location of area). DOE would dispose of spent nuclear fuel and high-level radioactive waste in the repository using the inherent, natural geologic features of the mountain and engineered (manmade) barriers to ensure the long-term isolation of the waste from the human environment. DOE would build the repository inside Yucca Mountain between 200 and 425 meters (660 and 1,400 feet) below the surface and between 175 and 365 meters (570 and 1,200 feet) above the water table.

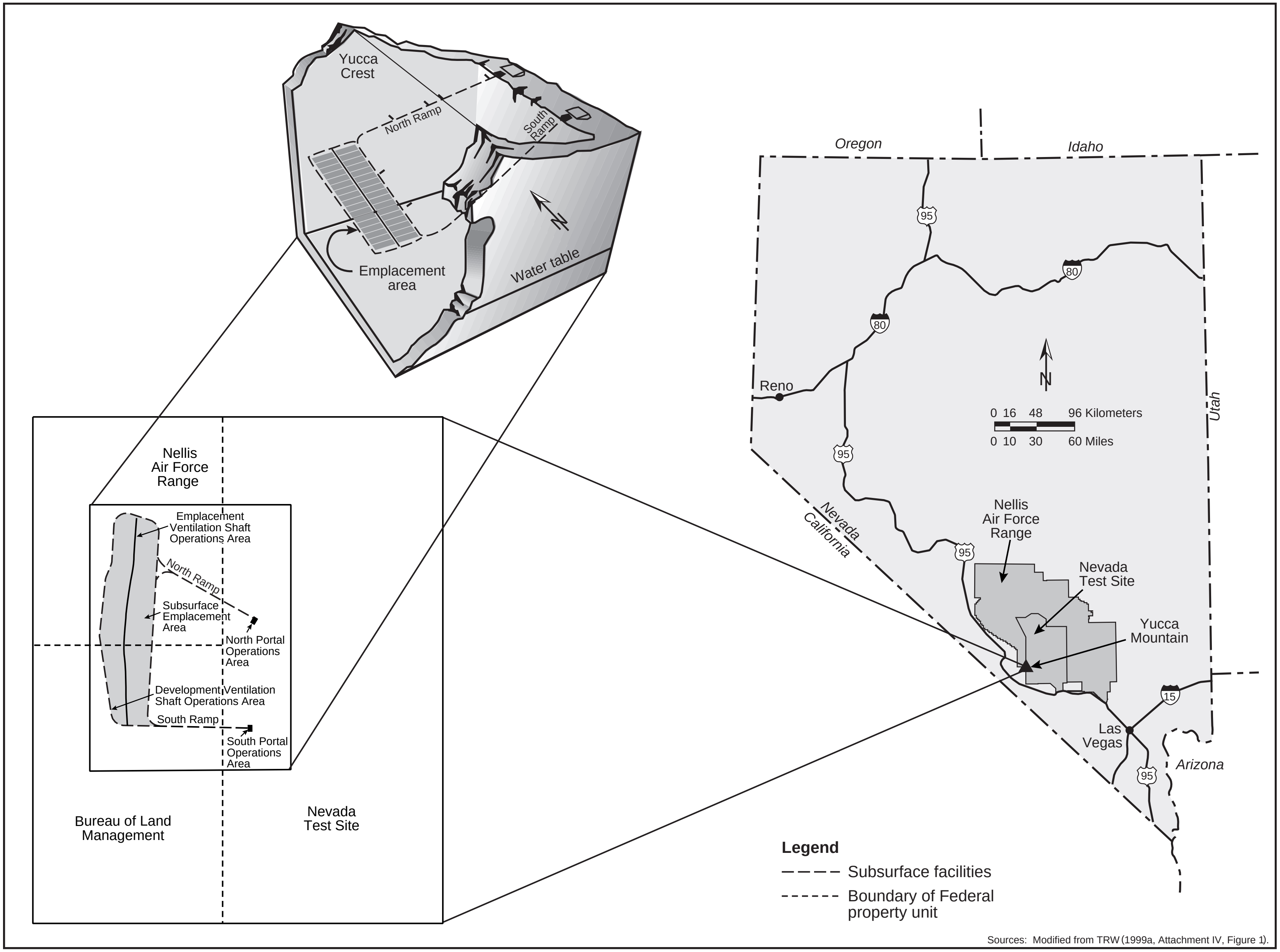
Under the Proposed Action, DOE would permanently place approximately 10,000 to 11,000 waste packages containing no more than 70,000 metric tons of heavy metal (MTHM) of spent nuclear fuel and high-level radioactive waste in the repository. Of the 70,000 MTHM to be emplaced in the repository, 63,000 MTHM would be spent nuclear fuel assemblies from boiling-water and pressurized-water reactors (Figure 2-3) that DOE would ship from commercial nuclear sites to the repository. The remaining 7,000 MTHM would consist of about 2,333 MTHM of DOE spent nuclear fuel and 8,315 canisters (4,667 MTHM) containing solidified high-level radioactive waste (see Figure 2-3) that the Department would ship to the repository from its facilities. The 70,000 MTHM inventory would include 50 metric tons (55 tons) of surplus weapons-usable plutonium as spent mixed-oxide fuel or immobilized plutonium. Appendix A contains additional information on the inventory and characteristics of spent nuclear fuel, high-level radioactive waste, and other materials that DOE could emplace in the proposed repository. For this EIS, a connected action includes the offsite manufacturing of the containers that DOE would use for the transport and disposal of spent nuclear fuel and high-level radioactive waste.

DEFINITION OF
METRIC TONS OF HEAVY METAL

Quantities of spent nuclear fuel are traditionally expressed in terms of *metric tons of heavy metal* (typically uranium), without the inclusion of other materials such as cladding (the tubes containing the fuel) and structural materials. A metric ton is 1,000 kilograms (1.1 tons or 2,200 pounds). Uranium and other metals in spent nuclear fuel (such as thorium and plutonium) are called *heavy metals* because they are extremely dense; that is, they have high weights per unit volume. One metric ton of heavy metal disposed of as spent nuclear fuel would fill a space approximately the size of a typical household refrigerator.

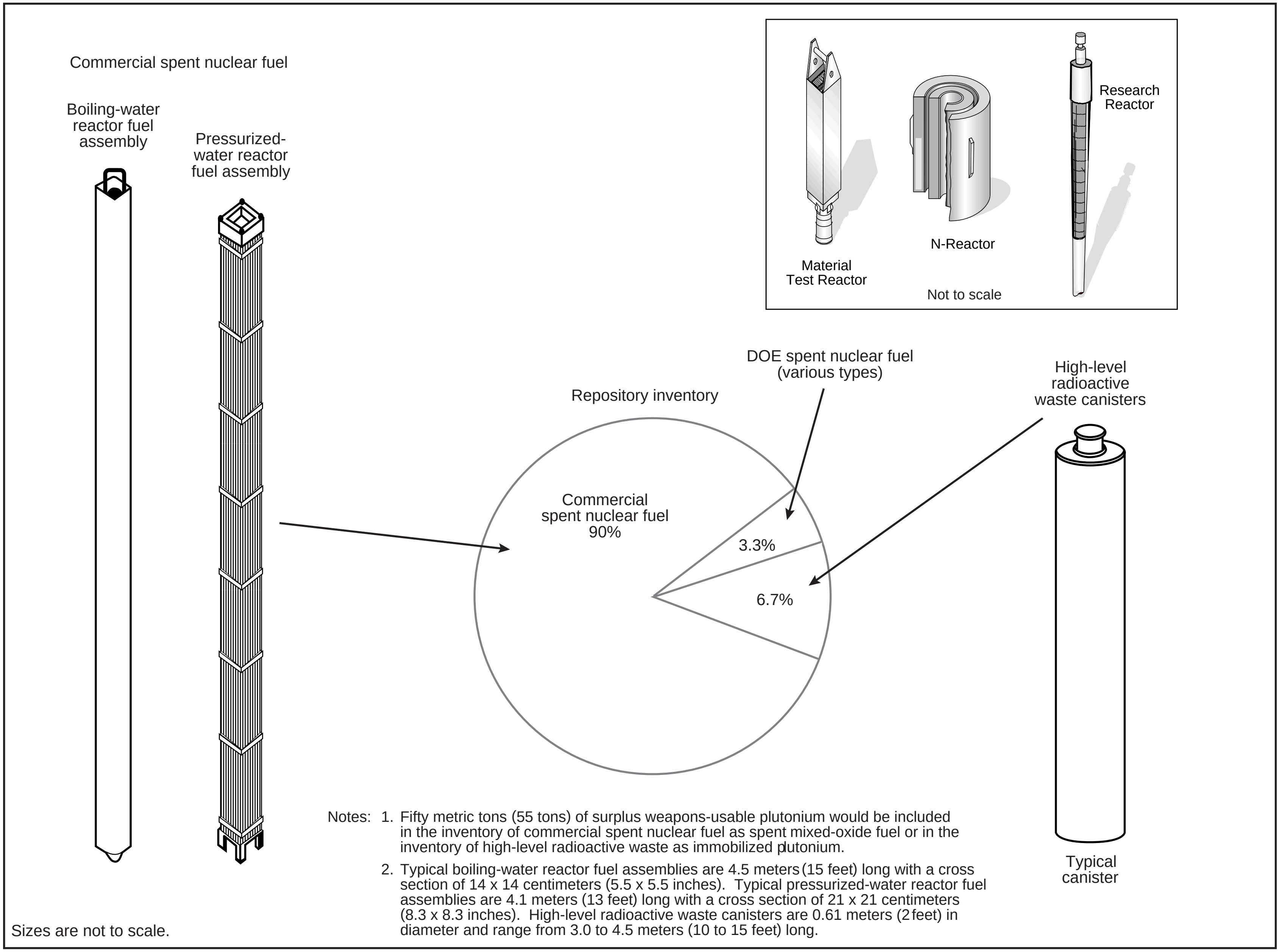
Figure 2-4 is an overview of components or activities associated with the Proposed Action. The implementing alternatives and scenarios analyzed in this EIS, as described in Section 2.1.1, represent the potential range of variables associated with implementing the Proposed Action that could affect environmental impacts. The Proposed Action would require surface and subsurface facilities and operations for the receipt, packaging, and emplacement of spent nuclear fuel and high-level radioactive waste (see Section 2.1.2) and transportation of these materials to the repository (see Section 2.1.3). Section 2.1.4 summarizes the estimated cost of the Proposed Action. Chapters 4, 5, and 6 evaluate potential environmental impacts from the Proposed Action. As part of the process to develop implementing concepts, mitigation techniques have been designed into the Proposed Action through the use of best engineering and management practices, as applicable.

The Proposed Action would use two types of institutional controls—active and passive. Active institutional controls (monitored and enforced limitations on site access; inspection and maintenance of waste packages, facilities, equipment, etc.) would be used through closure. Passive institutional controls (markers, engineered barriers, etc., that are not monitored or maintained) would be put in place during closure and used to minimize inadvertent exposures to members of the public in the future.



Sources: Modified from TRW (1999a, Attachment IV, Figure 1).

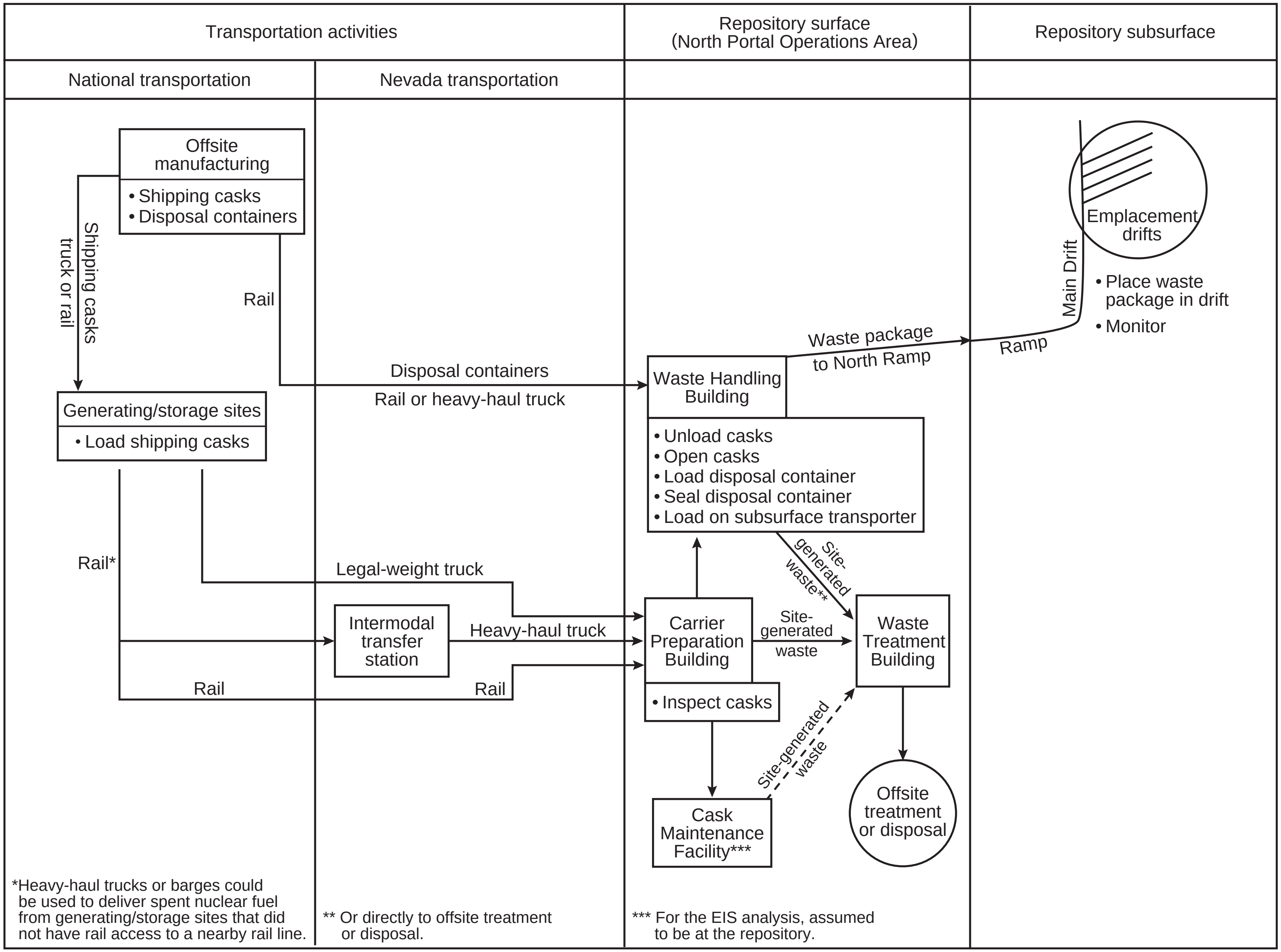
Figure 2-2. Diagram and location of the proposed repository at Yucca Mountain.



Notes:
1. Fifty metric tons (55 tons) of surplus weapons-usable plutonium would be included in the inventory of commercial spent nuclear fuel as spent mixed-oxide fuel or in the inventory of high-level radioactive waste as immobilized plutonium.
2. Typical boiling-water reactor fuel assemblies are 4.5 meters (15 feet) long with a cross section of 14 x 14 centimeters (5.5 x 5.5 inches). Typical pressurized-water reactor fuel assemblies are 4.1 meters (13 feet) long with a cross section of 21 x 21 centimeters (8.3 x 8.3 inches). High-level radioactive waste canisters are 0.61 meters (2 feet) in diameter and range from 3.0 to 4.5 meters (10 to 15 feet) long.

Sizes are not to scale.

Figure 2-3. Sources of spent nuclear fuel and high-level radioactive waste proposed for disposal at the Yucca Mountain Repository.



*Heavy-haul trucks or barges could be used to deliver spent nuclear fuel from generating/storage sites that did not have rail access to a nearby rail line.

** Or directly to offsite treatment or disposal.

*** For the EIS analysis, assumed to be at the repository.

Figure 2-4. Overview flowchart of the Proposed Action.

2.1.1 OVERVIEW OF IMPLEMENTING ALTERNATIVES AND SCENARIOS

This EIS describes and evaluates the current preliminary design concept for repository surface facilities, subsurface facilities, and disposal containers (waste packages), and the current plans for the construction, operation and monitoring, and closure of the repository. DOE recognizes that plans for the repository would continue to evolve during the development of the final repository design and as a result of the U.S. Nuclear Regulatory Commission licensing review of the repository. In addition, decisions on how spent nuclear fuel and high-level radioactive waste would be shipped to the repository (for example, truck or rail) and how spent nuclear fuel would be packaged (uncanistered or in disposable or dual-purpose canisters) would be part of future transportation planning efforts.

For these reasons, DOE developed implementing alternatives and analytical scenarios to bound the environmental impacts likely to result from the Proposed Action (see Figure 2-5). The Department selected the implementing alternatives and scenarios to accommodate and maintain flexibility for potential future revisions to the design and plans for the repository. Because of uncertainties, DOE selected implementing alternatives and scenarios that incorporate conservative assumptions that tend to overstate the risks to address those uncertainties.

The following paragraphs describe the packaging scenarios, thermal load scenarios, national transportation scenarios, Nevada transportation scenarios, and implementing rail and intermodal alternatives evaluated in the EIS. In addition, these paragraphs discuss the continuing investigation of options DOE is considering for the repository design at the next major program milestones (that is, Site Recommendation and License Application).

DOE will evaluate future repository design revisions in accordance with its regulations for implementing the National Environmental Policy Act (10 CFR 1021.314) to determine if there are substantial changes in the proposal or significant new circumstances or information relevant to environmental concerns. Based on these regulations, DOE will determine whether it will conduct further National Environmental Policy Act reviews.

2.1.1.1 Packaging Scenarios

DOE operations at repository surface facilities would differ depending on how the spent nuclear fuel in shipping casks was packaged. Commercial spent nuclear fuel could be received either uncanistered or in disposable or dual-purpose canisters.

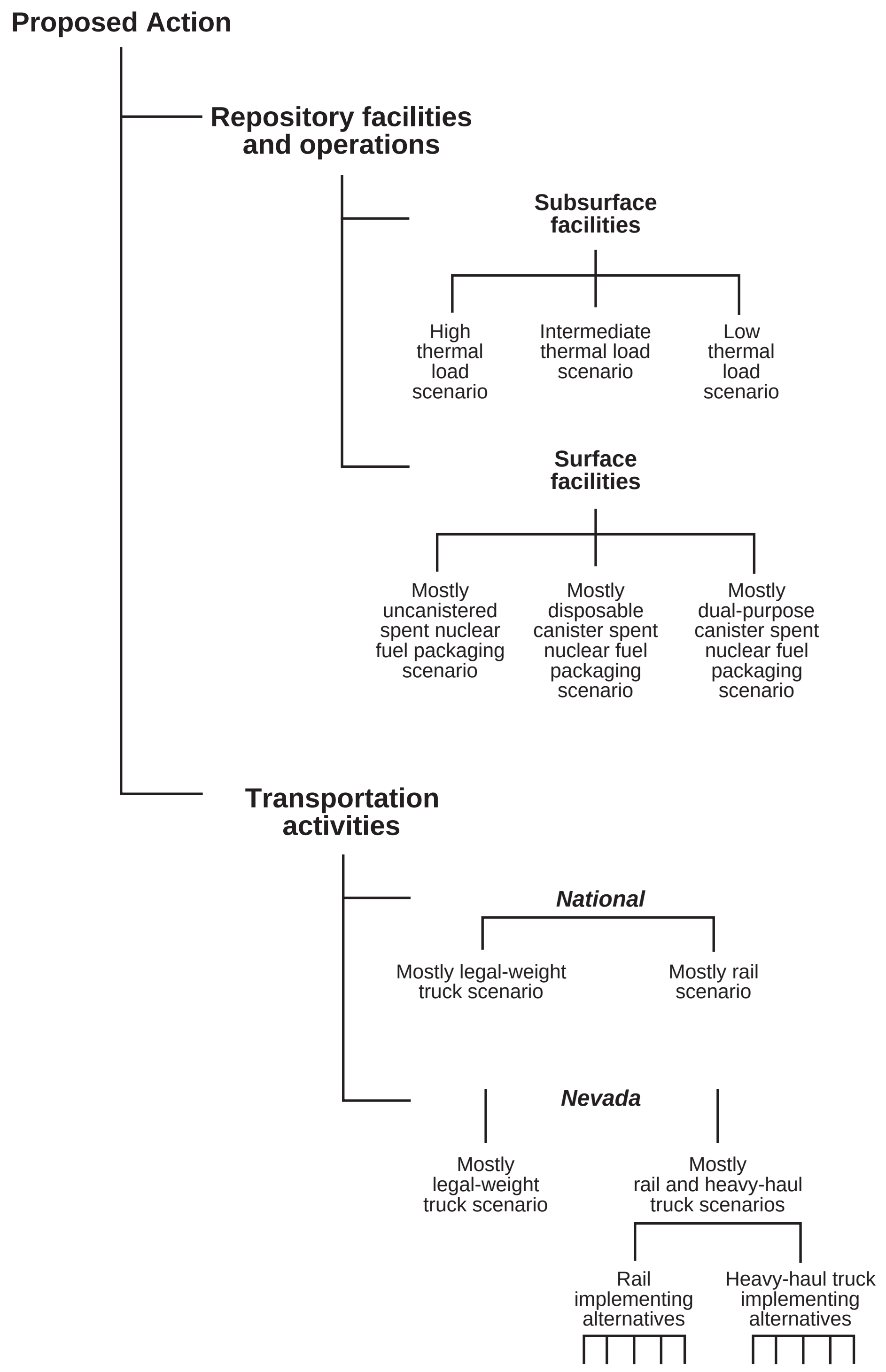
The EIS assumes that DOE spent nuclear fuel and high-level radioactive waste would be shipped to the repository in disposable canisters. In addition, it evaluates the following packaging scenarios for commercial spent nuclear fuel to cover the potential range of environmental impacts from repository surface facility construction and operation:

- A mostly uncanistered fuel scenario
- A mostly canistered fuel scenario that includes:
  - Disposable canisters
  - Dual-purpose canisters

Table 2-1 summarizes these scenarios.

DISPOSAL CONTAINERS AND WASTE PACKAGES

A *disposal container* is the vessel consisting of the barrier materials and internal components in which the spent nuclear fuel and high-level radioactive waste would be placed. The filled, sealed, and tested disposal container is referred to as the *waste package*, which would be emplaced in the repository.



Note: Thermal load scenarios also affect surface facilities.

Figure 2-5. Analytical scenarios and implementing alternatives associated with the Proposed Action.

Table 2-1. Packaging scenarios (percentage based on number of shipments).

		Mostly canistered fuel	
Material[a]	Mostly uncanistered fuel	Disposable canister	Dual-purpose canister
Commercial SNF	100% uncanistered fuel	About 80% disposable canisters; about 20% uncanistered fuel	About 80% dual-purpose canisters; about 20% uncanistered fuel
HLW	100% disposable canisters	100% disposable canisters	100% disposable canisters
DOE SNF	100% disposable canisters	100% disposable canisters	100% disposable canisters

a. SNF = spent nuclear fuel; HLW = high-level radioactive waste.

DEFINITIONS OF PACKAGING TERMS

Shipping cask: A thick-walled vessel that meets applicable regulatory requirements for shipping spent nuclear fuel or high-level radioactive waste.

Canister: A thin-walled metal vessel used to hold spent nuclear fuel assemblies or solidified high-level radioactive waste.

Dual-purpose canister: A canister suitable for storing (in a storage facility) and shipping (in a shipping cask) spent nuclear fuel assemblies. At the repository, dual-purpose canisters would be removed from the shipping cask and opened. The spent nuclear fuel assemblies would be removed from the canister and placed in a disposal container. The opened canister would be recycled or disposed of offsite as low-level radioactive waste.

Disposable canister: A canister for spent nuclear fuel assemblies or solidified high-level radioactive waste suitable for storage, shipping, and disposal. At the repository, the disposable canister would be removed from the shipping cask and placed directly in a disposal container.

Uncanistered spent nuclear fuel: Fuel placed directly into storage canisters or shipping casks without first being placed in a canister. At the repository, spent nuclear fuel assemblies would be removed from the shipping cask and placed in a disposal container.

Disposal container: A container for spent nuclear fuel and high-level radioactive waste consisting of the barrier materials and internal components. The filled, sealed, and tested disposal container is referred to as the *waste package*, which would be emplaced in the repository.

Waste package: The filled, sealed, and tested disposal container that would be emplaced in the repository.

2.1.1.2 Thermal Load Scenarios

The heat generated by spent nuclear fuel and high-level radioactive waste (the thermal load) could affect the long-term performance of the repository (that is, the ability of the engineered and natural barrier systems to isolate the emplaced waste from the human environment). Different thermal loads would have a direct effect on internal and external waste package temperatures, thereby potentially affecting the corrosion rate and integrity of the waste package. The heat generated by the waste packages would also affect the geochemistry, hydrology, and mechanical stability of the emplacement drifts, which in turn would influence the flow of groundwater and the transport of radionuclides from the engineered and natural barrier systems to the environment. The thermal load would depend on factors related to the design of the repository including, but not limited to, the age of the spent nuclear fuel at the time of emplacement, the spacing of the emplacement drifts and the waste packages in them, the repository ventilation, and the decision on whether to backfill the emplacement drifts.

DOE evaluated three thermal load scenarios. These scenarios include a relatively high emplacement density of spent nuclear fuel and high-level radioactive waste (high thermal load – 85 MTHM per acre), a relatively low emplacement density (low thermal load – 25 MTHM per acre), and an emplacement density between the high and low thermal loads (intermediate thermal load – 60 MTHM per acre). The additional spacing required for the lower thermal loads would increase the subsurface area and the amount of excavation. In addition, the different thermal loads would affect the area requirements for the excavated rock pile on the surface.

2.1.1.3 National Transportation Scenarios

The national transportation scenarios evaluated in this EIS encompass the transportation options or modes (legal-weight truck and rail) that are practical for DOE to use to ship spent nuclear fuel and high-level radioactive waste from the commercial and DOE sites to the Yucca Mountain site. DOE would use both legal-weight truck and rail transportation, and would determine the number of shipments by either mode as part of future transportation planning efforts. Therefore, the EIS evaluates two national transportation scenarios (mostly legal-weight truck and mostly rail) that cover the possible range of transportation impacts to human health and the environment.

TERMS ASSOCIATED WITH TRANSPORTATION

Legal-weight trucks have a gross vehicle weight (both truck and cargo weight) of less than 36,300 kilograms (80,000 pounds), which is the loaded weight limit for commercial vehicles operated on public highways without special state-issued permits. In addition, the dimensions, axle spacing, and, if applicable, axle loads of these vehicles must be in compliance with Federal and state regulations.

An **intermodal transfer station** is a facility for transferring freight from one transportation mode to another (for example, from railcar to truck). In this EIS, intermodal transfer station refers to a facility DOE would use to transfer rail shipping casks containing spent nuclear fuel or high-level radioactive waste from railcars to heavy-haul trucks, and to transfer empty rail shipping casks from heavy-haul trucks to railcars.

Heavy-haul trucks are overweight, overdimension vehicles that must have permits from state highway authorities to use public highways. In this EIS, heavy-haul trucks refers to vehicles DOE would use on public highways to move spent nuclear fuel or high-level radioactive waste shipping casks designed for a railcar.

2.1.1.4 Nevada Transportation Scenarios and Rail and Intermodal Implementing Alternatives

The transportation of spent nuclear fuel and high-level radioactive waste to the proposed repository would affect all the states through which the shipments would travel, including Nevada. However, to highlight the impacts that could occur in Nevada, DOE has chosen to discuss them separately. DOE is looking at three transportation scenarios for Nevada. These scenarios include legal-weight truck and rail, which are the same as the national scenarios but highlight the Nevada portion of the transportation, and heavy-haul truck. The heavy-haul truck scenario includes the construction of an intermodal transfer station with associated highway improvements for heavy-haul trucks in the State. DOE has identified five potential rail corridors leading to Yucca Mountain and three potential intermodal transfer station locations with five associated potential highway routes for heavy-haul trucks. Section 2.1.3.3 describes these implementing alternatives.

2.1.1.5 Continuing Investigation of Design Options

As noted, this EIS describes and evaluates the current preliminary design concept for the repository and current plans for repository construction, operation and monitoring, and closure (see Section 2.1.2). DOE continues to investigate design options for possible incorporation in the final repository design; Appendix E identifies design features and alternative design concepts that DOE is considering for the final design (for example, smaller waste packages, a waste package design using two corrosion-resistant materials, and a long-term ventilated repository). The criteria for selecting these design options are related to improving or reducing uncertainties in repository performance (the potential to provide containment and isolation of radionuclides) and operation (for example, worker and operational safety, ease of operation).

DOE has assessed each of the design options still being considered for the expected change it would have on short- and long-term environmental impacts and has compared these impacts to the potential impacts determined for the packaging, thermal load, and transportation scenarios evaluated in the EIS. This assessment, which is described in Appendix E, found that the changes in environmental impacts for the design options would be relatively minor in relation to the potential impacts evaluated in this EIS. Therefore, DOE has concluded that the analytical scenarios and implementing alternatives evaluated in this EIS provide a representative range of potential environmental impacts the Proposed Action could cause. Chapter 9 discusses mitigation from design options that could be beneficial in reducing impacts associated with repository performance or operation.

2.1.2 REPOSITORY FACILITIES AND OPERATIONS

This section describes proposed repository surface and subsurface facilities and operations (Sections 2.1.2.1 and 2.1.2.2), repository closure (Section 2.1.2.3), and the performance confirmation program (Section 2.1.2.4). The description is based on TRW (1999a, all), TRW (1999b, all), and TRW (1999c, all), unless otherwise noted. The following paragraphs contain an overview of the repository facilities and operations and the sequence of planned repository construction, operation and monitoring, and closure. DOE would design the repository based on the extensive information collected during the Yucca Mountain site characterization activities. These activities are summarized in semiannual site characterization reports. [See the semiannual Site Characterization Progress Reports that the Department prepares in accordance with Section 113(b)(3) of the NWPA (for example, DOE 1991a, all).] The facilities used for site characterization activities at Yucca Mountain would be incorporated in the repository design to the extent practicable. (See Chapter 3, Section 3.1, for additional information on existing facilities at Yucca Mountain developed during site characterization activities.)

DOE would construct surface facilities at the repository site to receive, prepare, and package spent nuclear fuel and high-level radioactive waste for underground emplacement. In addition, surface facilities would support the construction of subsurface facilities. These facilities include the following primary surface operations areas:

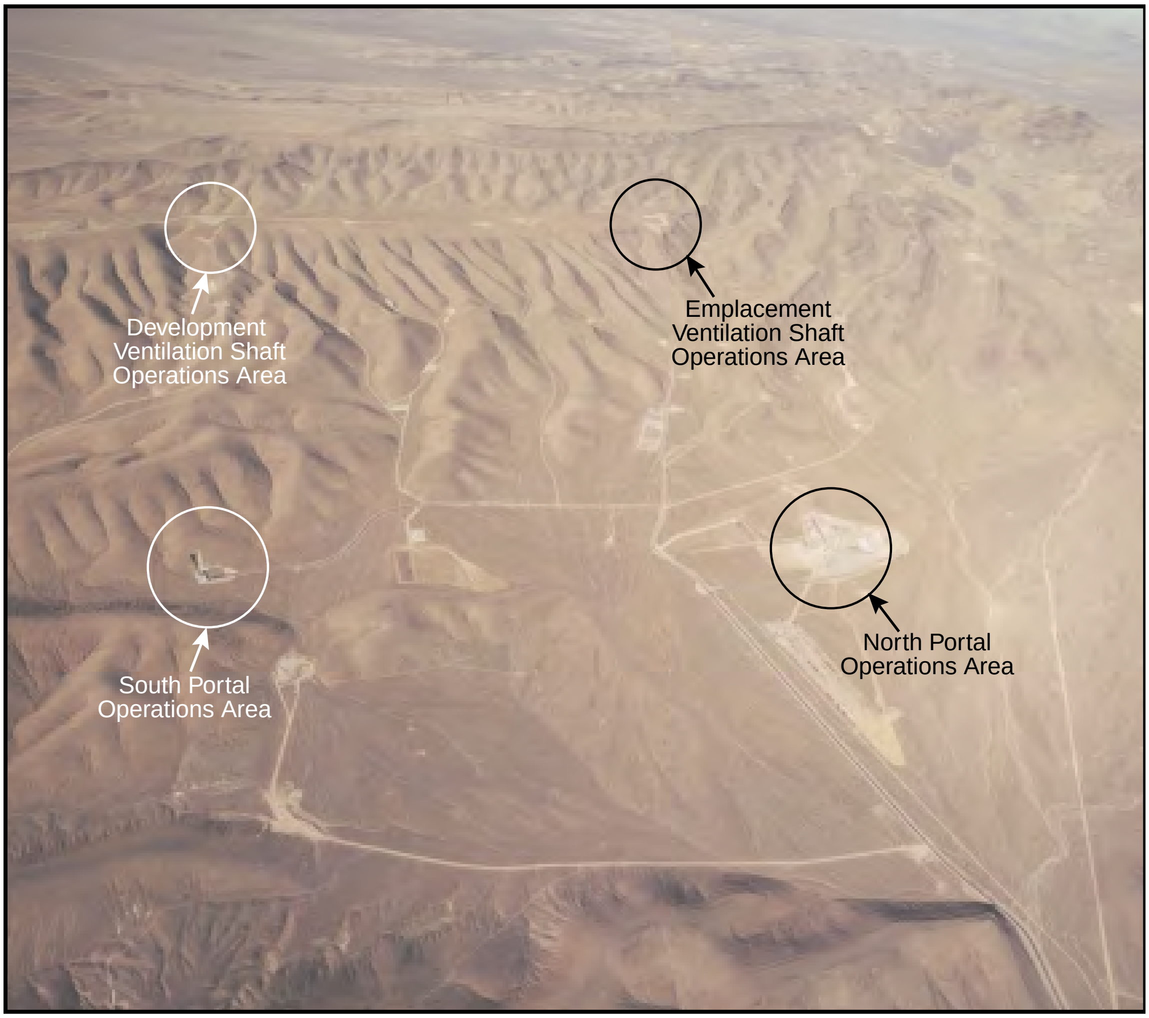
- North Portal Operations Area – Receive, prepare, and package spent nuclear fuel and high-level radioactive waste for underground emplacement

- South Portal Operations Area – Support the construction of subsurface facilities

- Emplacement Ventilation Shaft Operations Area – Exhaust air from the subsurface facilities where waste packages would be emplaced (emplacement side)

- Development Ventilation Shaft Operations Area – Supply air to subsurface facilities where construction activities would occur (development side)

Figure 2-6 is an aerial photograph of the Yucca Mountain site showing the locations of these surface facilities. Figure 2-7 is an illustration of the repository surface facilities at the North Portal Operations Area. The spent nuclear fuel and high-level radioactive waste would be handled remotely with workers shielded from exposure to radiation using design and operations practices in use at licensed nuclear facilities to the maximum extent practicable. The repository operations areas and supporting areas, utilities, roads, etc., would require the active use of about 3.5 square kilometers (870 acres) of land. Of this total area, about 1.5 square kilometers (370 acres) have been disturbed by previous activities.



Note: The North and South Portal Operations Areas are approximately 2.7 kilometers (1.7 miles) apart.

Figure 2-6. Surface facilities at the proposed Yucca Mountain Repository.

Source: DOE (1998a, Overview, page 13).

Figure 2-7. Artist's conception of proposed repository surface facilities at the North Portal Operations Area.

Figure 2-8 shows the subsurface layout of the repository, which would consist of tunnels (called *drifts*) and vertical ventilation shafts that DOE would excavate in the mountain. Along with the main drifts, gently sloping ramps from the surface to the subsurface facilities would move workers, equipment, and waste packages. Waste packages of spent nuclear fuel and high-level radioactive waste would be placed in the emplacement drifts. The ventilation systems would move air for workers and would cool the repository.

Figure 2-9 shows the expected timing for construction, operation and monitoring, and closure of the proposed repository at Yucca Mountain. If a recommendation was made to proceed with the development of the repository, DOE would continue performance confirmation activities to support a License Application to the Nuclear Regulatory Commission. Preconstruction performance confirmation activities at and in the vicinity of the Yucca Mountain site would be similar to those performed during site characterization. These activities could require surface excavations, subsurface excavations and borings, and in-place testing of rock characteristics.

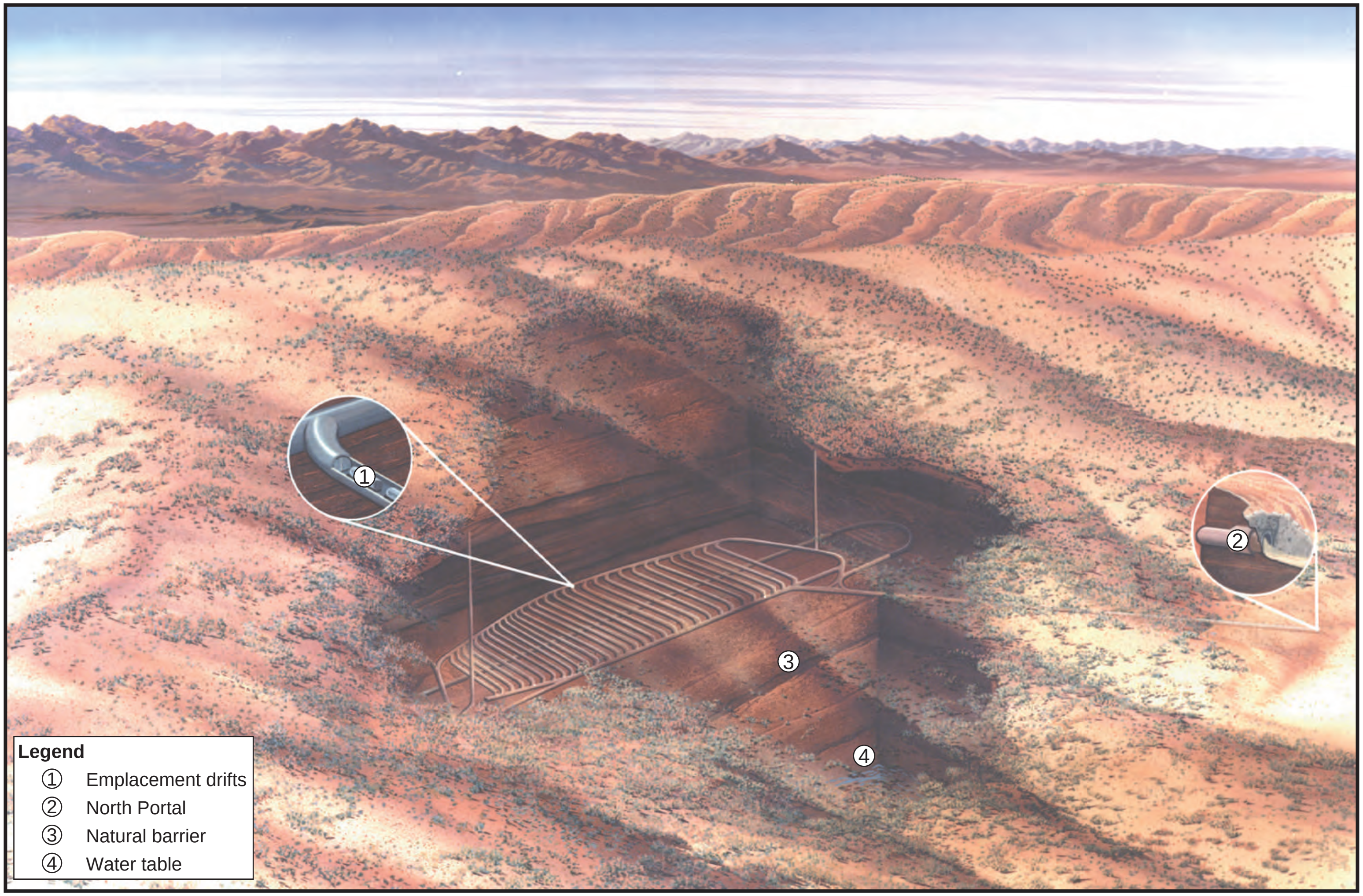
The construction of repository facilities for the handling of spent nuclear fuel and high-level radioactive waste could begin only after the receipt of construction authorization from the Nuclear Regulatory Commission. For this EIS, DOE assumed that construction would begin in 2005. The repository surface facilities, the main drifts, ventilation system, and initial emplacement drifts would be built in approximately 5 years, from 2005 to 2010.

Repository operations would begin after DOE received a license from the Nuclear Regulatory Commission to receive and possess spent nuclear fuel and high-level radioactive waste. For this EIS, DOE assumed that the receipt and emplacement of these materials would begin in 2010 and that emplacement would occur over a 24-year period ending in 2033, based on the emplacement of 70,000 MTHM at approximately 3,000 MTHM per year.

The construction of emplacement drifts would continue during emplacement and would end in about 2032. The repository design would enable simultaneous construction and emplacement operations, but it would physically separate activities on the construction or development side from activities on the emplacement side.

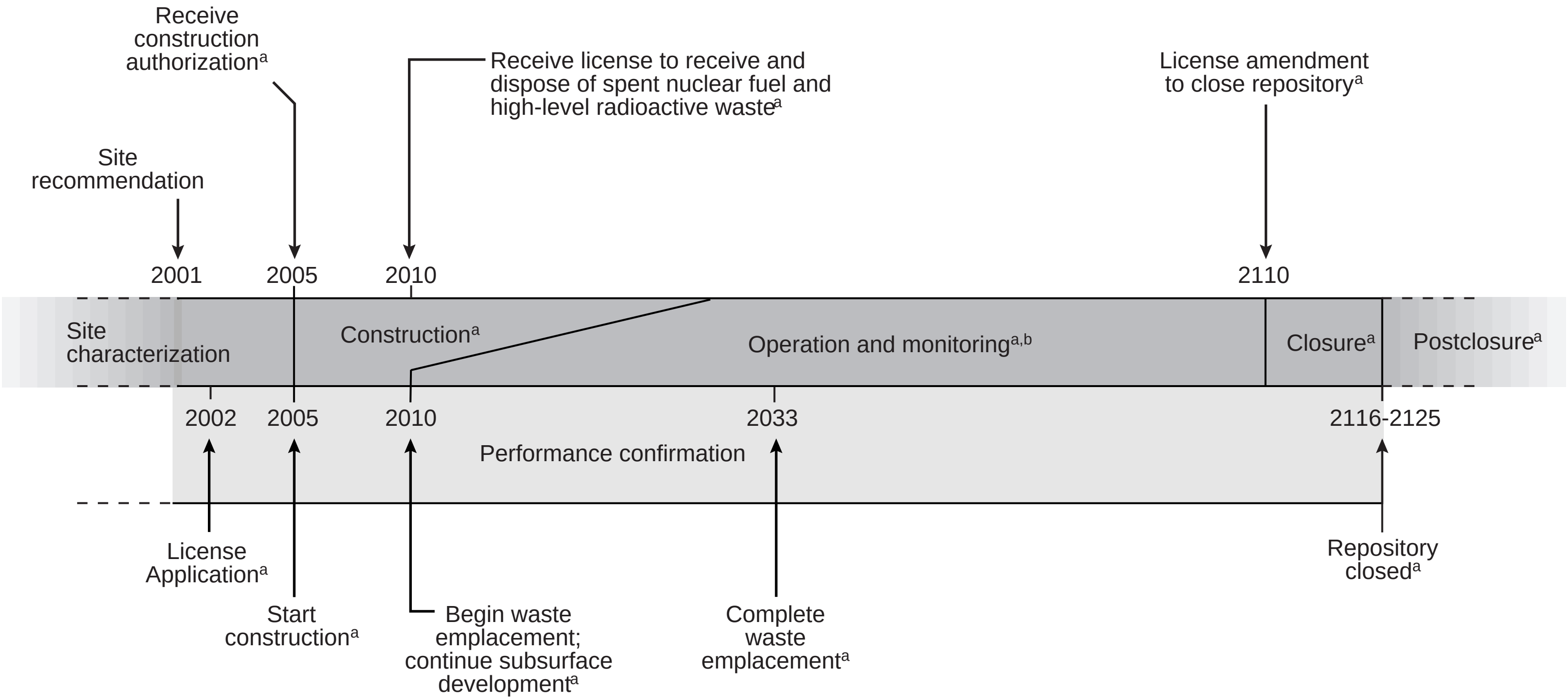
Monitoring and maintenance activities would start with the first emplacement of waste packages and would continue through repository closure. After the completion of emplacement, DOE would maintain those repository facilities, including the ventilation system and utilities (air, water, electric power) that would enable continued monitoring and inspection of the emplaced waste packages, continued investigations in support of predictions of long-term repository performance, and the retrieval of waste packages if necessary. Immediately after the completion of emplacement, DOE would decontaminate and close the facilities that handled nuclear materials on the surface to eliminate a potential radioactive material hazard. However, DOE would maintain an area of the Waste Handling Building for the possible recovery and testing of waste packages as a quality assurance contingency in the performance confirmation program (see Section 2.1.2.4). Future generations would decide whether to continue to maintain the repository in an open monitored condition or to close it. To ensure flexibility to future decisionmakers, DOE is designing the repository with the capability for closure as early as 50 years or as late as 300 years after the start of emplacement. This EIS assumes that closure would begin 100 years after the start (76 years after the completion) of emplacement, but assesses impacts (in Chapter 4) for closure beginning 50 and 300 years after the start of emplacement.

Repository closure would occur after DOE received a license amendment from the Nuclear Regulatory Commission. The period to accomplish closure would range from about 6 years for the high thermal load scenario to about 15 years for the low thermal load scenario. The closure of the repository facilities



Source: Modified from DOE (1998a, Overview, page 9).

Figure 2-8. Artist's conception of proposed repository subsurface layout.



a. If Yucca Mountain is approved.

b. The EIS analysis assumed that waste emplacement would occur over a 24-year period ending in 2033.

Source: Modified from TRW (1999b, Figure 1.5-1, page 1-3).

Figure 2-9. Expected monitored geologic repository milestones.

would include closing the subsurface facilities, decontamination and decommissioning the surface facilities, reclaiming the site, and establishing long-term institutional barriers, including land records and warning systems to limit or prevent intentional or unintentional activity in and around the closed repository (see Section 2.1.2.3).

The performance confirmation program would continue some site characterization activities through repository closure, including various types of tests, experiments, and analytical procedures. DOE would conduct performance confirmation activities to evaluate the accuracy and adequacy of the information it used to determine with reasonable assurance that the repository would meet the performance objectives for the period after permanent closure (see Section 2.1.2.4).

2.1.2.1 Repository Surface Facilities and Operations

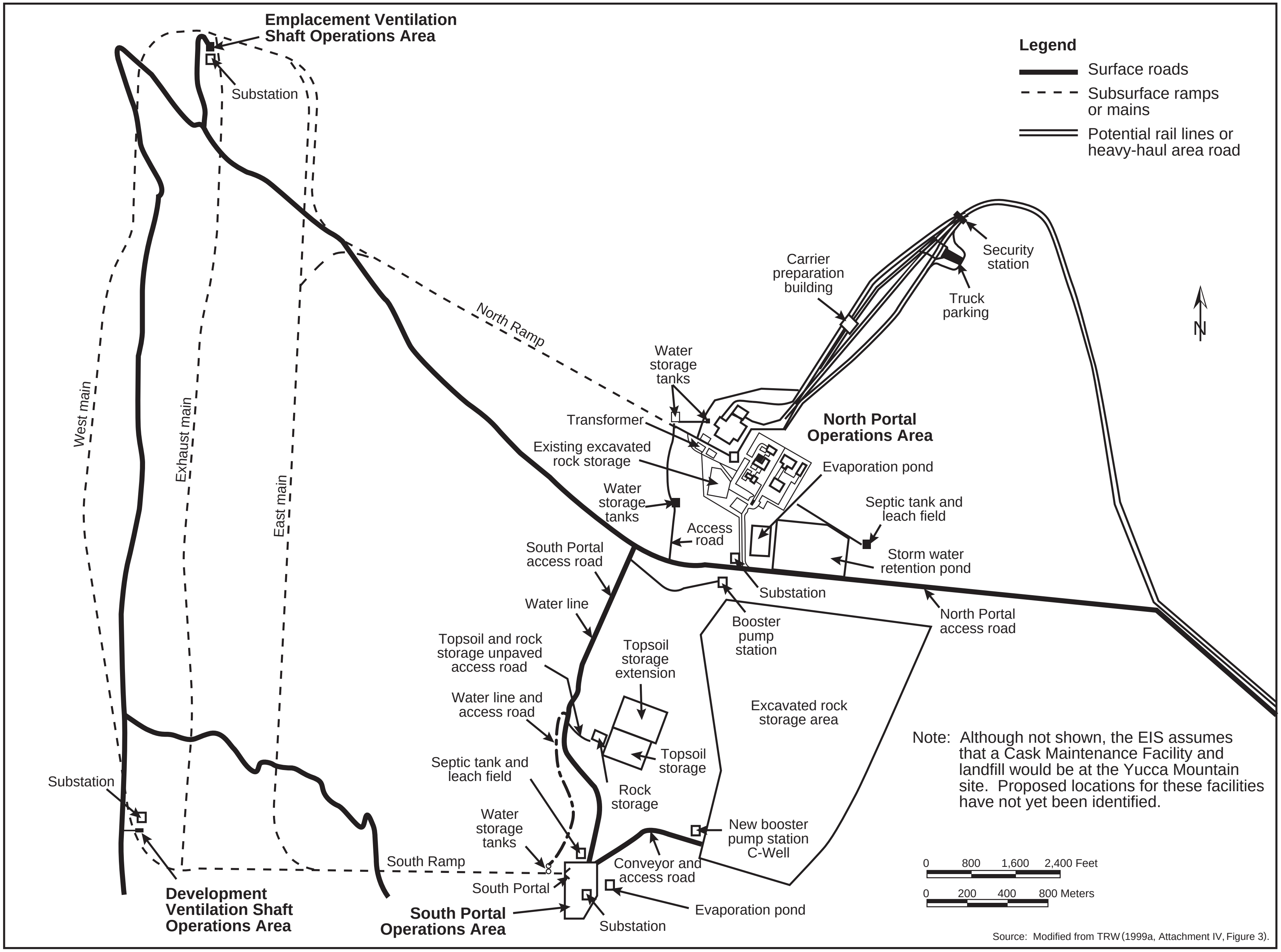
Surface facilities at the repository site would be used to receive, prepare, and package spent nuclear fuel and high-level radioactive waste for subsurface emplacement. Surface facilities would also support the construction of the subsurface facilities. DOE would upgrade some facilities built for site characterization, but most surface facilities would be new. Most facilities would be in four areas—the North Portal Operations Area, the South Portal Operations Area, the Emplacement Ventilation Shaft Operations Area(s), and the Development Ventilation Shaft Operations Area(s)—as shown on Figure 2-10. Facilities to support waste emplacement would be concentrated near the North Portal, and facilities to support subsurface facility development would be concentrated near the South Portal.

2.1.2.1.1 *North Portal Operations Area*

This area, shown in Figure 2-11, would be the largest of the primary operations areas, covering about 0.6 square kilometer (150 acres) at the North Portal. It would include two areas: a Restricted Area for receipt of spent nuclear fuel and high-level radioactive waste handling and packaging for emplacement, and a Balance of Plant Area for support services (administration, training, emergency, and general maintenance). The Restricted Area (called the *Radiologically Controlled Area* in other DOE documents) would be enclosed by a fence and monitored to ensure adequate safeguards and security for radioactive materials. The two principal facilities in the Restricted Area would be the Carrier Preparation Building and the Waste Handling Building. Other support facilities planned for the North Portal Operations Area include basic facilities for personnel support, warehousing, security, and transportation (motor pool).

When a legal-weight truck or railcar hauling a cask containing spent nuclear fuel or high-level radioactive waste arrived at the repository site, it would move through the security check into the Restricted Area parking area or to the Carrier Preparation Building. Rail casks arriving on heavy-haul trucks might be transferred to a railcar outside the Restricted Area before entering it. Operations in the Carrier Preparation Building would include performing inspections of the vehicle and cask, removing barriers from the vehicle that protected personnel during shipment, and removing impact limiters from the cask. The vehicle would then move to the Waste Handling Building for unloading or to a storage yard until space became available for unloading. In the Waste Handling Building shipping casks would be removed from the vehicle and placed on carts (see Figure 2-12). The carts would move through the Waste Handling Building airlock to cask preparation areas, where the casks would be checked for contamination and the interior gases sampled. The casks would then be vented and cooled, and the cask lids would be unbolted.

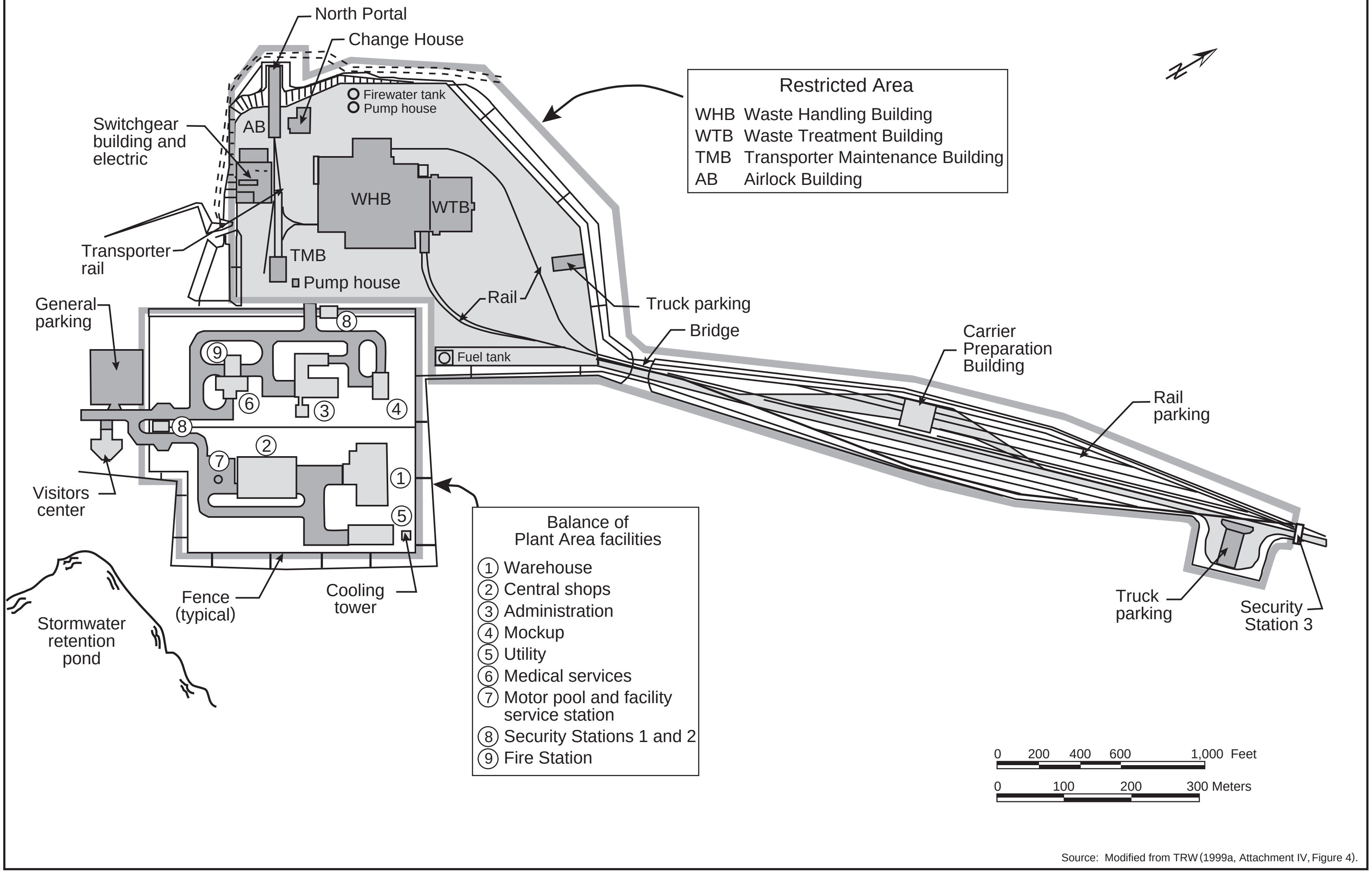
After cask preparation operations, receipt and packaging operations would begin; the nature of these operations would depend on how the spent nuclear fuel in the shipping cask was packaged. The following paragraphs describe the different receipt and packaging operations for different types of packages.



Note: Although not shown, the EIS assumes that a Cask Maintenance Facility and landfill would be at the Yucca Mountain site. Proposed locations for these facilities have not yet been identified.

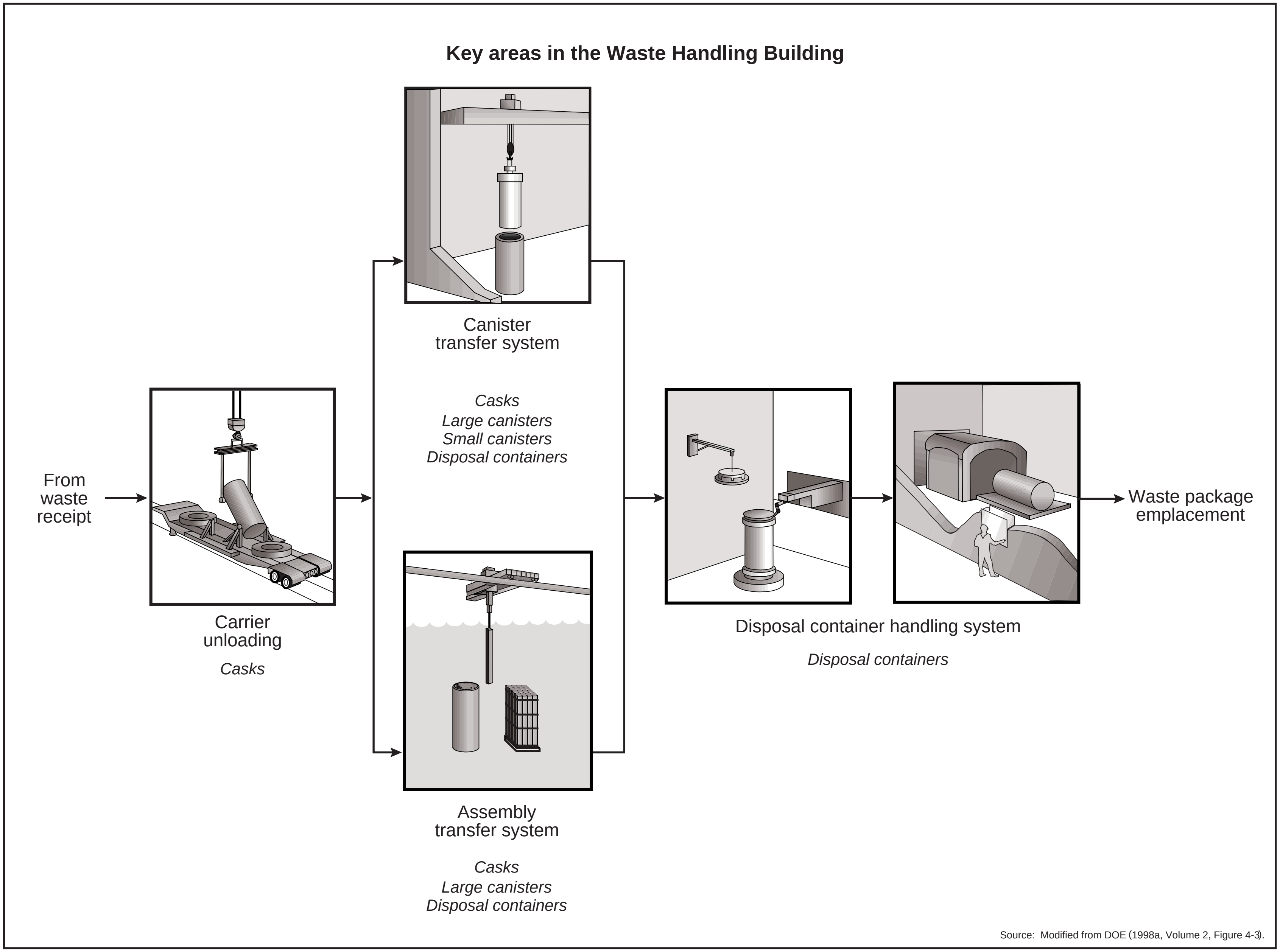
Source: Modified from TRW (1999a, Attachment IV, Figure 3).

Figure 2-10. Repository surface facilities site plan.



Source: Modified from TRW (1999a, Attachment IV, Figure 4).

Figure 2-11. North Portal Operations Area site plan.



Source: Modified from DOE (1998a, Volume 2, Figure 4-3).

Figure 2-12. Key components of the waste handling operations.

Uncanistered spent nuclear fuel in a cask would be placed in a water transfer pool in the Waste Handling Building. The cask lid would be removed and each fuel assembly would be removed and placed in a transfer basket. When the transfer basket was loaded, it would be *staged* or moved from the pool to an assembly transfer cell and dried. The dried assemblies would be loaded in a disposal container, which would be decontaminated, and either transferred directly to a welding area or stored temporarily until a welding area was available. Welding operations would include installing and welding the inner and outer lids of the disposal container. The disposal container would be filled with an inert gas such as helium after the inner lid was welded. Each welding operation would be followed by nondestructive weld examination and certification. After weld certification, the loaded disposal container is called a *waste package* (see Section 2.1.2.2). Each waste package would be decontaminated and loaded in a shielded waste package transporter for transfer to the repository or held in the Waste Handling Building until a transporter became available.

Shipping casks containing spent nuclear fuel or high-level radioactive waste in disposable canisters would be moved directly to a dry canister transfer handling area. The shipping cask lid would be removed and the disposable canisters would be staged, or transferred directly into a disposal container. The disposal container sealing and welding process would be similar to that described for uncanistered spent nuclear fuel.

Shipping casks containing spent nuclear fuel assemblies in dual-purpose canisters would be placed in a water transfer pool. The shipping cask lid would be removed, the canister inside would be removed and opened, and the assemblies would be unloaded to a transfer basket. Once the assemblies were in the basket, the process would be the same as that described for uncanistered fuel.

DOE would decontaminate empty canisters, shipping casks, and related components as required in the Waste Handling Building. After decontamination, the empty canisters and shipping casks would be loaded on truck or rail carriers, sent to the Carrier Preparation Building for processing, and shipped off the site.

Waste generated at the repository from the decontamination of canisters and shipping casks and from other repository housekeeping activities would be collected, processed, packaged, and staged in the Waste Treatment Building before being shipped off the site for disposal at permitted facilities. Waste minimization and pollution prevention measures would reduce the amount of site-generated waste requiring such management. For example, decontamination water could be treated and recycled to the extent practicable. Site-generated wastes would include low-level radioactive waste, hazardous waste, and industrial solid waste. Operations would not be likely, but that could occur, could produce small amounts of mixed wastes (wastes containing both radioactive and hazardous materials). The repository design would include provisions for collecting and storing mixed waste for offsite disposal.

The ventilation systems for the Waste Handling Building and the Waste Treatment Building would provide confinement of radioactive contamination by using pressure differentials to ensure that the air would flow from areas free of contamination to areas potentially contaminated to areas that are normally contaminated. The monitored exhaust air from both buildings would pass through high-efficiency particulate air filters before being released through a single exhaust stack.

2.1.2.1.2 *South Portal Operations Area*

The South Portal Operations Area would cover about 0.15 square kilometer (37 acres) immediately adjacent to the South Portal of the subsurface facility. The structures and equipment in this area, which would support the development of subsurface facilities, would include a concrete plant for fabricating and curing precast components and supplying concrete for in-place casting, and basic facilities for personnel support, maintenance, warehousing, material staging, security, and transportation. From this area, overland conveyors would transport excavated rock from the repository to the excavated rock pile.

2.1.2.1.3 *Emplacement Ventilation Shaft Operations Areas*

DOE would develop these areas where ventilation shafts from the emplacement side of the subsurface reached the surface. The number of shafts required to ventilate the subsurface would depend on the thermal load scenario for the repository. A repository design with a high or intermediate thermal load would require a single ventilation shaft with a corresponding surface operations area for the emplacement side. A design with a low thermal load would require three emplacement ventilation shafts with corresponding surface operations areas because of the increased area to be ventilated. Two of these operations areas would contain fans to pull air from the emplacement area; the other would not contain fans but would supply air to the emplacement area.

An Emplacement Ventilation Shaft Operations Area would cover about 12,000 square meters (3 acres) and would normally be unstaffed. An emplacement side ventilation system would contain two fans, each driven by a 2,000-horsepower electric motor with a capacity of about 17,000 cubic meters (600,000 cubic feet) per minute. One fan would be in continuous operation and the other would be on standby. Section 2.1.2.2 contains a description of the subsurface ventilation design.

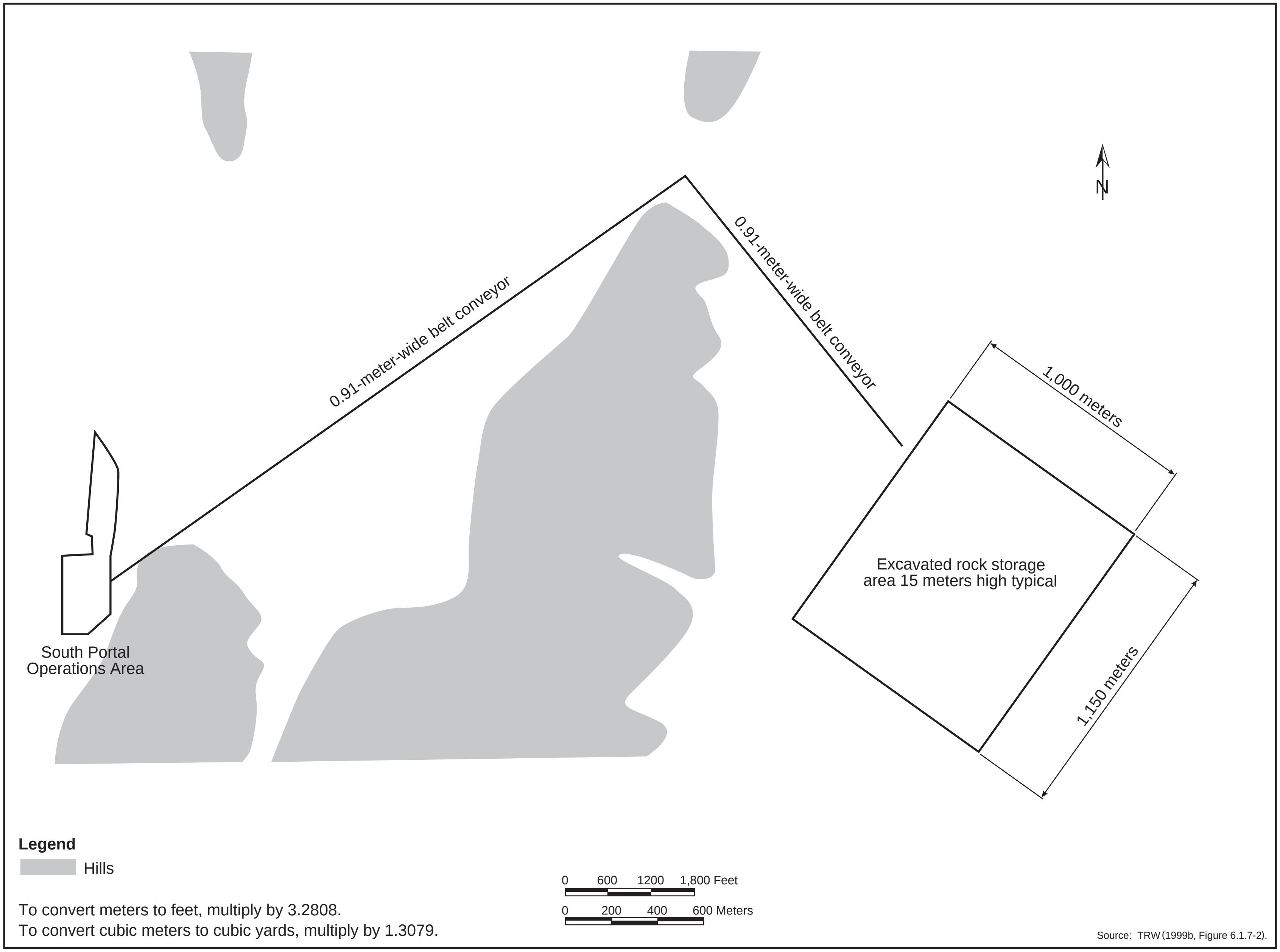
2.1.2.1.4 *Development Ventilation Shaft Operations Areas*

Development ventilation shafts would supply air to the development side of the repository. A repository design with a high or intermediate thermal load would require a single development ventilation shaft with a corresponding surface operations area. A design with a low thermal load would require two development ventilation shafts with corresponding surface operations areas because of the increased area to be ventilated. Each Development Ventilation Shaft Operations Area would be similar in size to the Emplacement Ventilation Shaft Operations Areas, and would contain two fans, each with a capacity of about 17,000 cubic meters (600,000 cubic feet) per minute and driven by a 2,000-horsepower electric motor. One fan would be in continuous operation, forcing air into the repository, and the other fan would be on standby. Section 2.1.2.2 contains a description of the subsurface ventilation design.

2.1.2.1.5 *Support Equipment and Utilities*

Repository support equipment and utilities would be on the surface in the general vicinity of the North and South Portal Operations Areas (see Figure 2-10). The storage area for excavated rock would be the largest support area. For the high or intermediate thermal load scenario, the excavated rock storage area would be between the North and South Portals, as shown in Figure 2-10, and would require about 1.0 and 1.2 square kilometers (250 and 300 acres), respectively. For the low thermal load scenario, the excavated rock storage area would be about 5 kilometers (3 miles) east of the South Portal Operations Area, as shown on Figure 2-13. Because the excavated rock pile would be higher at this location, the area required would be about 1.1 square kilometers (270 acres).

The repository site would have two evaporation ponds for industrial wastewater, one at the North Portal and one at the South Portal. Sources of industrial wastewater would include water used for dust suppression during construction, water used for cooling tower operations at the North Portal, and water used for concrete mixing and for form cleanup at the South Portal. Heavy plastic sheets would line both ponds to prevent water migration into the soil. The North Portal pond would cover about 24,000 square meters (6 acres). The evaporation pond at the South Portal would be about 2,300 square meters (0.6 acre). The North Portal area would also include an approximately 130,000-square-meter (32-acre) stormwater retention pond to control stormwater runoff from the North Portal Operations Area.



To convert meters to feet, multiply by 3.2808.
To convert cubic meters to cubic yards, multiply by 1.3079.

Source: TRW (1999b, Figure 6.1.7-2).

Figure 2-13. Location of excavated rock storage area for low thermal load scenario.

DOE would develop an appropriately sized landfill [approximately 0.036 square kilometer (9 acres)] at the repository site for nonhazardous and nonradiological construction and sanitary solid waste and for similar waste generated during the operation and monitoring and closure phases. The South Portal Operations Area would have a septic tank and leach field for the disposal of sanitary sewage. The North Portal Operations Area has an existing septic system that would be adequate for use during repository operations.

At present, electric power is obtained from the Nevada Test Site power distribution system. For the repository, electric power would be distributed throughout the surface and subsurface areas and to remote areas such as the Ventilation Shaft Operations Areas, construction areas, environmental monitoring stations, transportation lighting and safety systems, and water wells. To accommodate the expected demand for the repository, DOE would upgrade existing electrical transmission and distribution systems. Backup equipment and uninterruptable electric power would be provided to ensure personnel safety and operations requiring electric power continuity. Diesel generators and associated switchgear would provide the backup power capability.

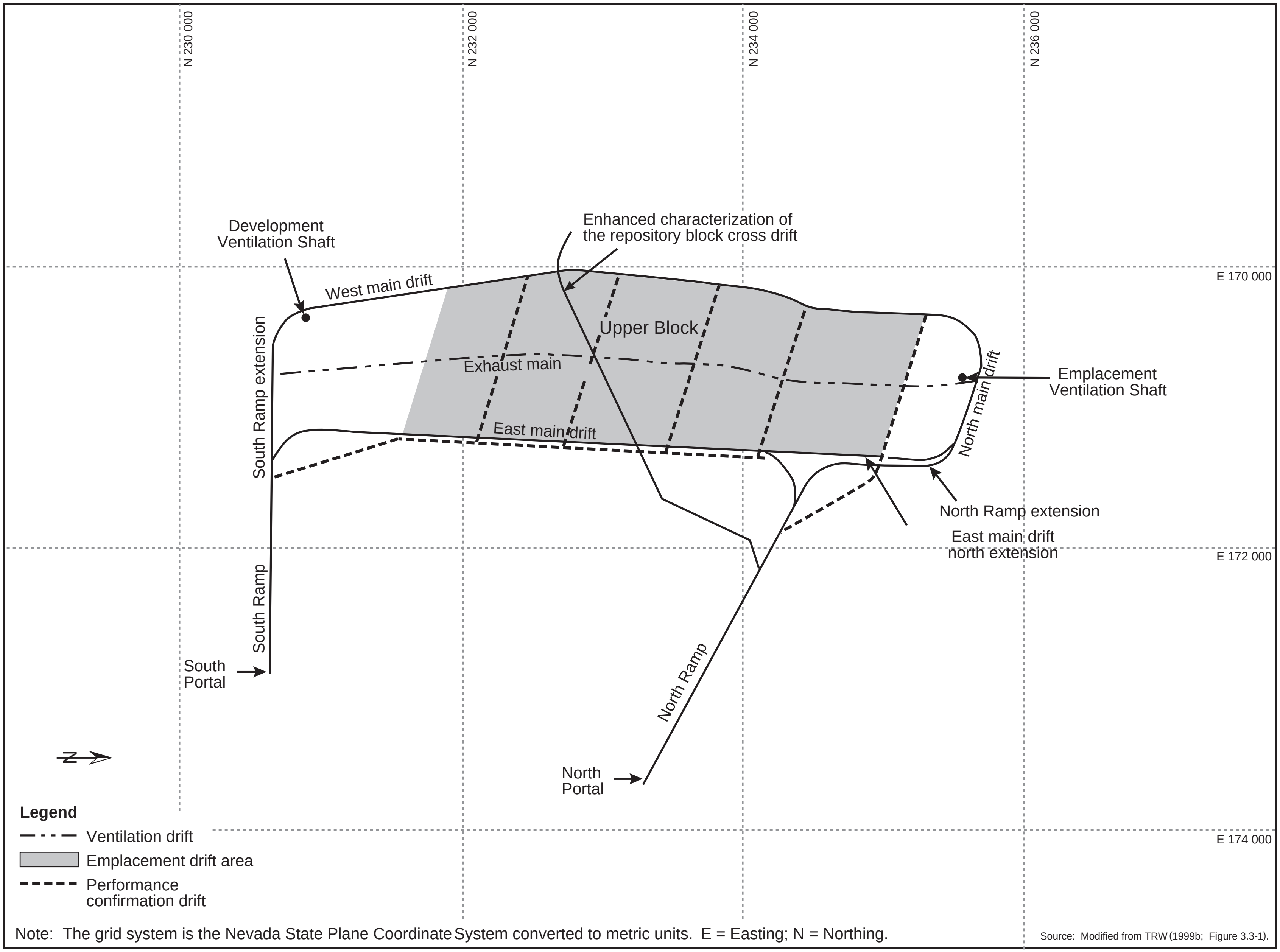
DOE would use existing wells about 5.6 kilometers (3.5 miles) southeast of the North Portal Operations Area to supply water for repository activities. These wells have supplied water for site characterization activities at Yucca Mountain. Water would be pumped to a booster pump station and then to potable and nonpotable water systems that would distribute the water to the Restricted and Balance of Plant Areas and to the subsurface.

Fuel supply systems would include fuel oil for a central heating (hot water) plant, which would consist of a 950,000-liter (250,000-gallon) main tank and a 57,000-liter (15,000-gallon) day tank. In addition, there would be fuel supply systems for generating steam to cure precast concrete, for fire water system tank heaters, for diesel-powered standby generators and air compressors, and for backup fire pumps. Diesel fuel and gasoline would also be provided to fuel vehicles during the construction, operation and monitoring, and closure of the repository.

2.1.2.2 Repository Subsurface Facilities and Operations (Including Waste Packages)

DOE would construct the subsurface facilities of the repository and emplace the waste packages above the water table in a mass of volcanic rock known as the Topopah Spring Formation (welded tuff) (see Chapter 3, Section 3.1.3.1). The specific area in this formation where DOE would build the repository would satisfy several criteria. The primary criteria would be to (1) be within select portions of the Topopah Spring formation that have desirable properties, (2) avoid major faults for reasons related to both hydrology and seismic hazard (see Section 3.1.3.2), (3) be at least 200 meters (660 feet) below the surface, and (4) be at least 100 meters (330 feet) above the water table (TRW 1993, pages 5-99 to 5-101).

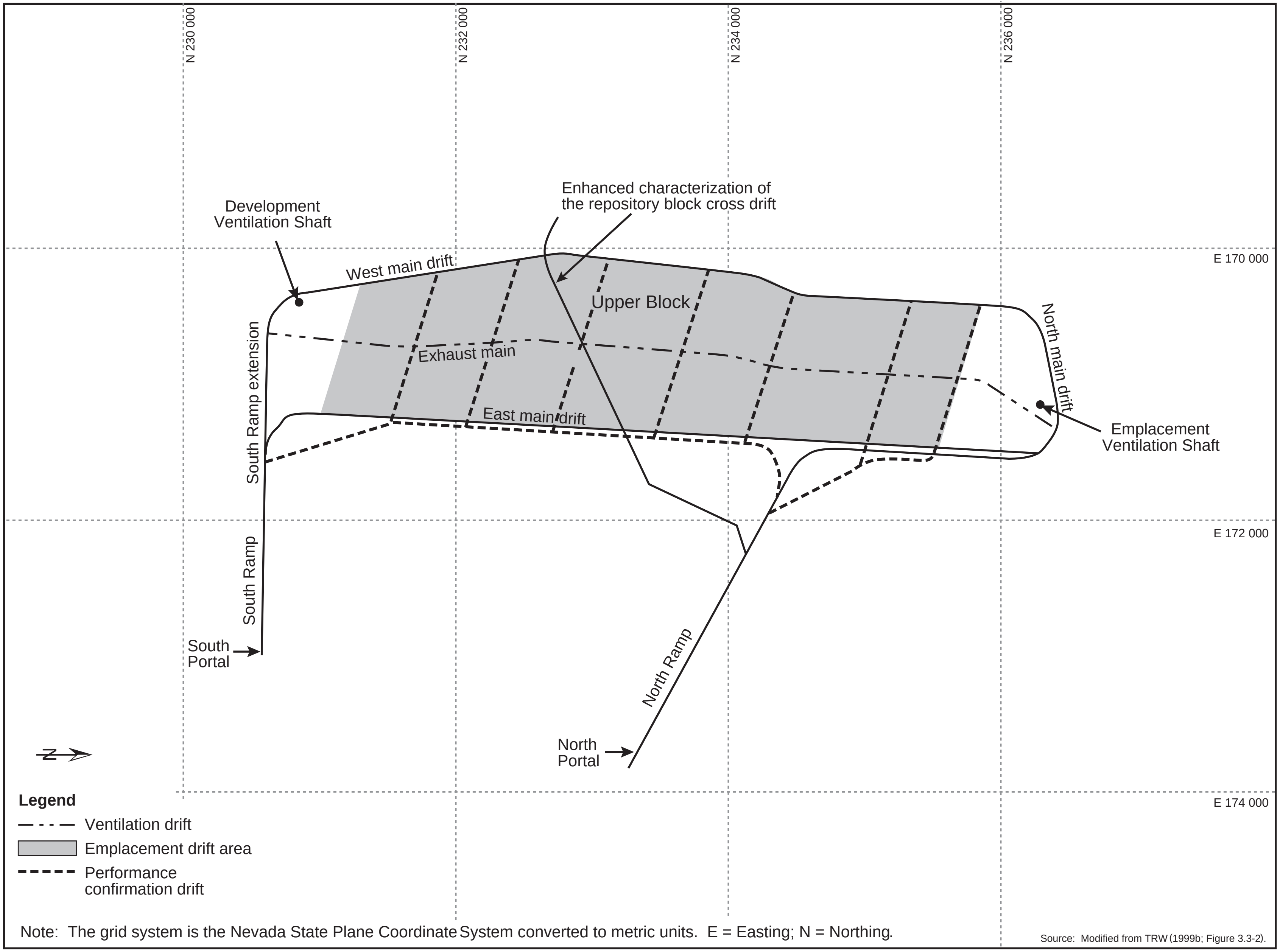
Figures 2-14, 2-15, and 2-16 show the repository footprint for the emplacement of spent nuclear fuel and high-level radioactive waste for the high, intermediate, and low thermal load scenarios, respectively. DOE would develop a high thermal load repository in the upper emplacement block, using 3 square kilometers (740 acres), with two ventilation shafts to the surface, one on the emplacement side and one on the development side (Figure 2-14). An intermediate thermal load repository would also be in the upper emplacement block, would have an area of 4.25 square kilometers (1,050 acres), and would require two ventilation shafts to the surface (Figure 2-15). A low thermal load repository would be in the upper and lower emplacement blocks and in Area 5, would use an area of approximately 10 square kilometers (2,500 acres), and would require three emplacement and two development ventilation shafts (Figure 2-16).



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999b; Figure 3.3-1).

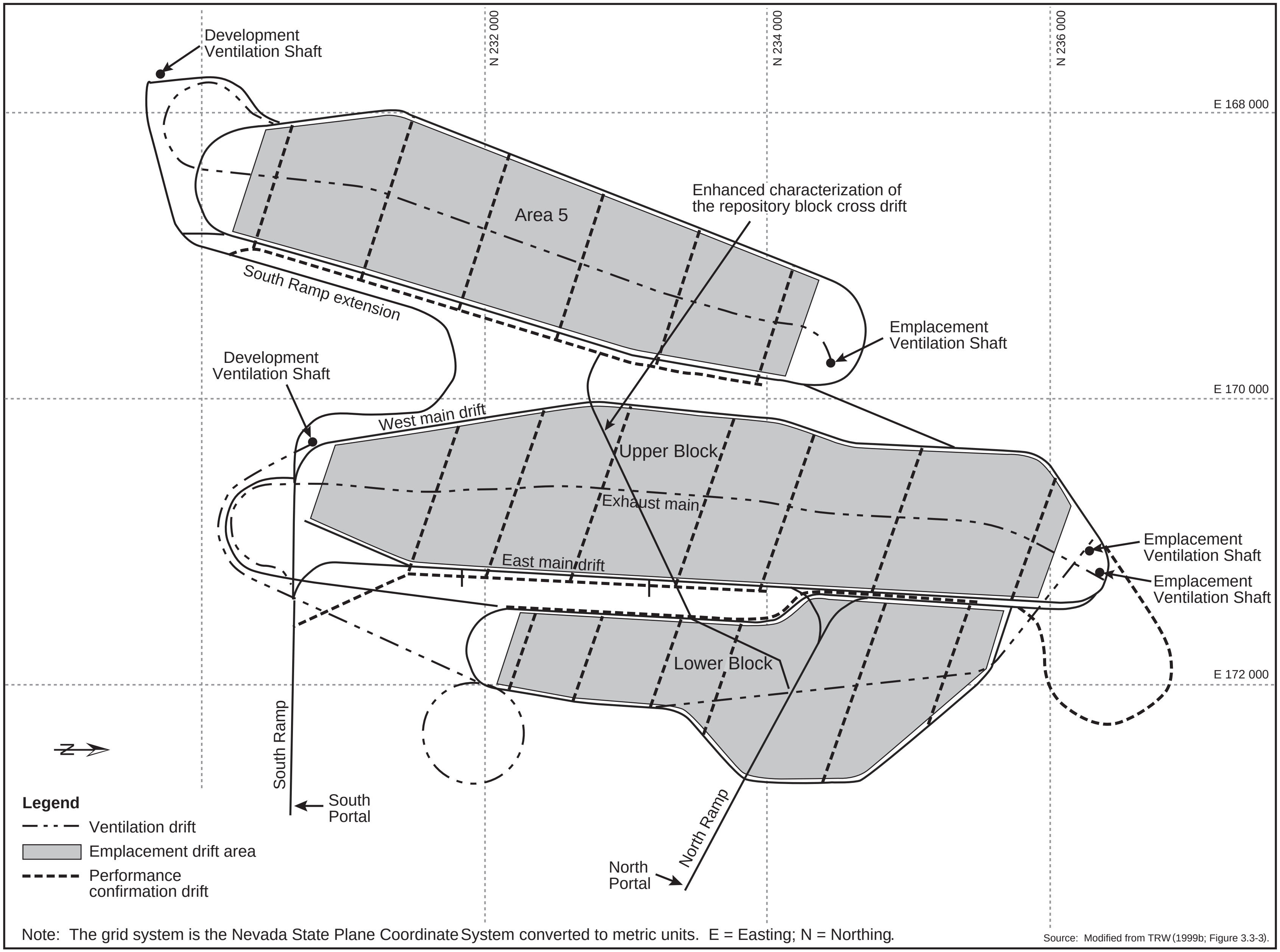
Figure 2-14. High thermal load repository layout.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999b; Figure 3.3-2).

Figure 2-15. Intermediate thermal load repository layout.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999b; Figure 3.3-3).

Figure 2-16. Low thermal load repository layout.

The following paragraphs describe the subsurface facility design and construction (including the ventilation system), the design of the waste packages, and waste package emplacement operations.

2.1.2.2.1 *Subsurface Facility Design and Construction*

The subsurface design would incorporate most of the drifts developed during the site characterization activities. Other areas would be excavated during the repository construction phase. Excavated openings would include gently sloping access ramps to enable rail-based movement of construction and waste package handling vehicles between the surface and subsurface, subsurface main drifts to enable the movement of construction and waste package handling vehicles, emplacement drifts for the placement of waste packages, exhaust mains to transfer air in the subsurface area, and ventilation shafts to transfer air between the surface and the subsurface. There would also be performance confirmation drifts for the placement of instrumentation to monitor emplaced waste packages (see Figures 2-14, 2-15, and 2-16).

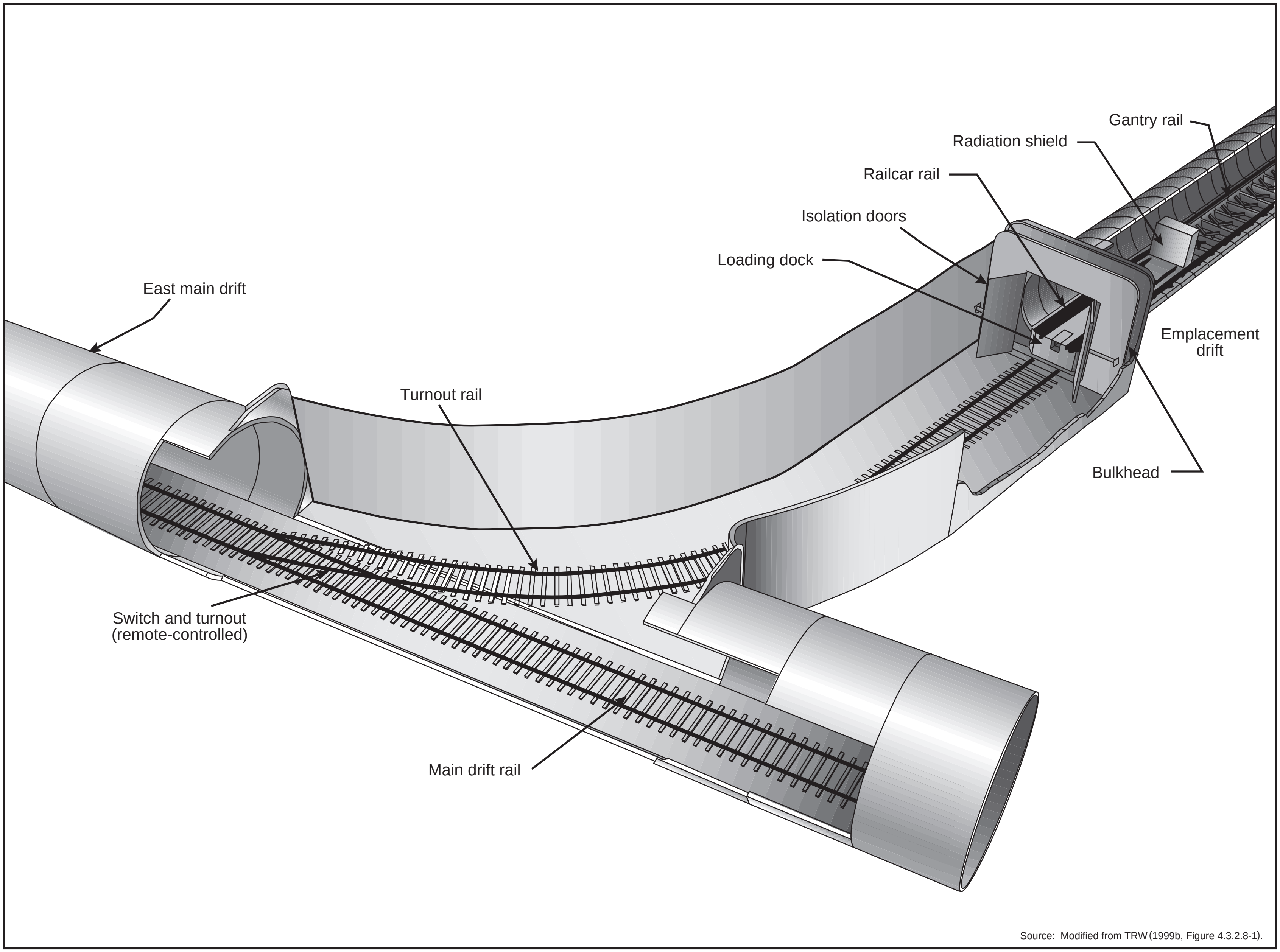
Access ramps connecting the surface and subsurface would be concrete-lined, 7.6-meter (25-foot)-diameter tunnels excavated by electric-powered tunnel boring machines (see Figure 2-17). Rail lines and an overhead trolley system would enable the movement of electric-powered construction and waste package handling vehicles. The North and South Ramps were developed during site characterization and would become part of the proposed repository. The North Ramp begins at the North Portal Operations Area on the surface (see Section 2.1.2.1) and extends through the subsurface to the edge of the repository area. It would support waste package emplacement operations. The South Ramp originates at the South Portal Operations Area on the surface (see Section 2.1.2.1) and extends through the subsurface to the edge of the repository area. It would support subsurface construction activities.

The main drifts for a high thermal load, shown in Figure 2-14, would include the East Main, the West Main, and the North Main. These drifts would be extended for the intermediate or low thermal load scenario. Additional main drifts would be excavated for the low thermal load scenario to provide access to other emplacement areas. Main drifts would be concrete-lined, 7.6-meter (25-foot)-diameter tunnels excavated by tunnel boring machines. Rail lines and an overhead trolley system in the main drifts would enable the movement of electric-powered construction and waste package handling vehicles. The East Main drift was excavated as part of site characterization activities but was not lined with concrete. During the operation and monitoring phase, the main drifts would support both subsurface construction and waste package emplacement, which would occur simultaneously. Ventilation barriers creating airlocks would separate the emplacement and development sides of the repository, and the ventilation system would be designed to maintain the emplacement side at a lower pressure than the development side. This would ensure that any air leakage would be from the development side to the emplacement side.

Emplacement drifts would be 5.5-meter (18-foot)-diameter tunnels connecting the main drifts; they could have steel ribbing or be lined with concrete. These drifts would be excavated by an electrically powered tunnel boring machine. An emplacement drift would be large enough to permit the movement of waste packages over emplaced packages in the drift. Steel isolation doors at the emplacement drift entrances would prevent unauthorized human access and reduce radiation exposure to personnel. In addition, radiation shields would be placed at the ends of emplacement drifts that contained waste packages. The isolation doors would be opened and closed remotely. Figure 2-18 shows an emplacement drift branching off the East Main drift.

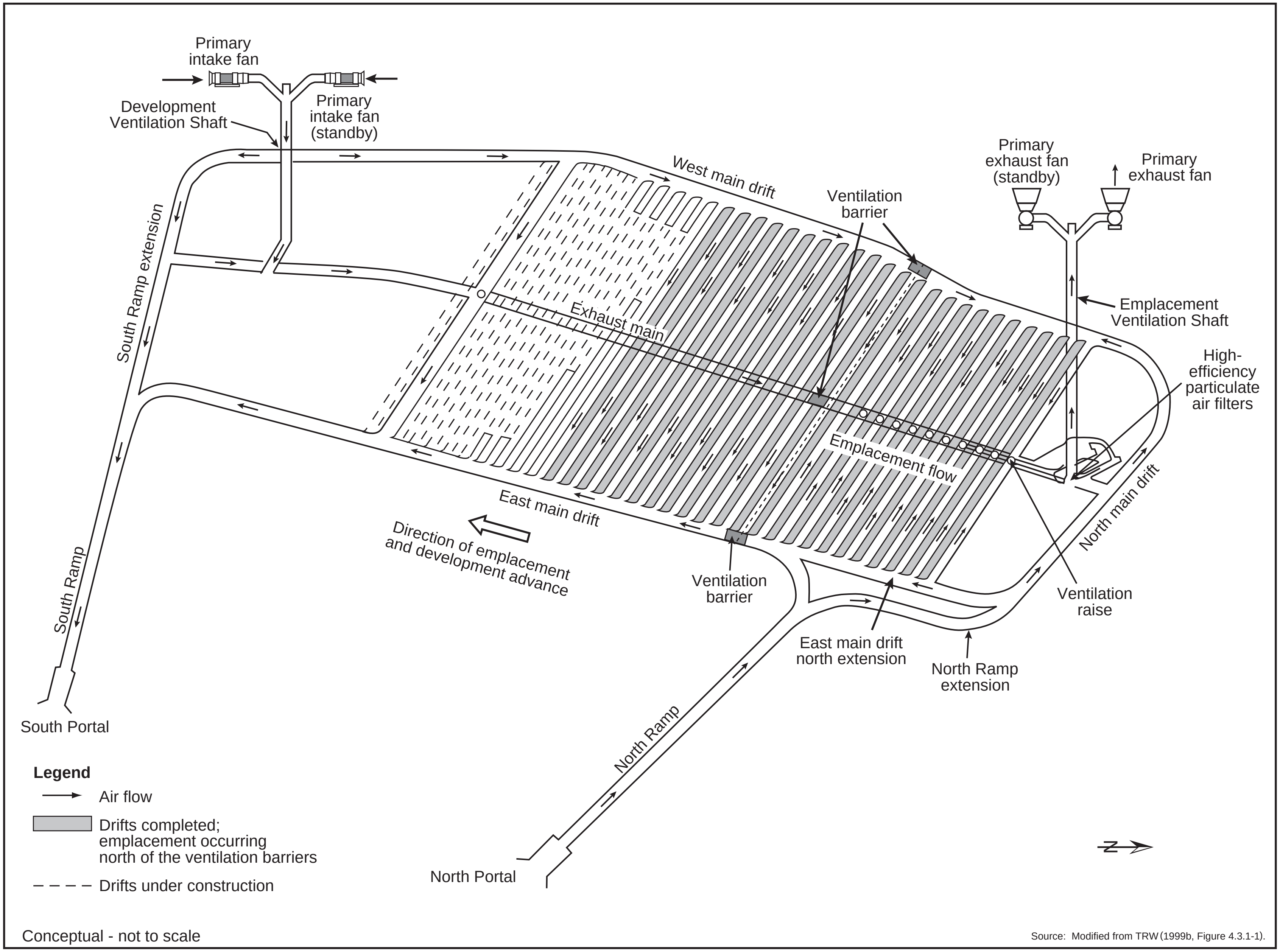
Exhaust main drifts would ventilate the emplacement side of the repository; they would be roughly perpendicular to and at a level below the emplacement drifts (see Figure 2-19). The exhaust main drift would connect with the emplacement drifts through a ventilation raise and would connect with an emplacement ventilation shaft. For a high thermal load configuration, a 6.7-meter (22-foot) exhaust main

Figure 2-17. Tunnel boring machine.



Source: Modified from TRW (1999b, Figure 4.3.2.8-1).

Figure 2-18. Artist’s conception of emplacement drift branching from main drift.



Source: Modified from TRW (1999b, Figure 4.3.1-1).

Figure 2-19. Subsurface conceptual design for ventilation air flow during construction and operations.

drift would be excavated approximately 10 meters (33 feet) below the emplacement drift. This drift would be extended for the intermediate and low thermal load scenarios. For the low thermal load scenario, other exhaust main drifts would be excavated to ventilate the additional emplacement areas. For a high thermal load configuration, DOE would excavate two 6.7-meter (22-foot)-diameter shafts for repository ventilation, an emplacement ventilation shaft at the north end and a development ventilation shaft at the south end of the upper emplacement block. An intermediate thermal load configuration would also require two shafts. These vertical shafts would extend from approximately 10 meters (33 feet) below the repository to the surface of the mountain. The emplacement ventilation shaft shown in Figure 2-19 would connect to the north end of the exhaust main drift and provide the only route for emplacement side air to leave the repository. It would be the primary ventilation exhaust airway for emplacement and monitoring activities before closure; as such, it would contain continuous radiation detection and monitoring equipment. During emplacement and monitoring operations, fans on the surface would pull air up the emplacement ventilation shaft. If the monitors detected a radioactive material leak from an emplacement drift, the exhaust air would be diverted automatically through the high-efficiency particulate air filters installed at the bottom of the emplacement ventilation shaft. Fresh air would be pulled into the repository through the North Ramp.

The development ventilation shaft, shown in Figure 2-19, would supply fresh air to the construction side of the repository. It would be the primary ventilation intake airway for subsurface development activities. Fans at the development ventilation shaft operations area would force air down to the development side of the repository. The South Ramp would be the exhaust path for air in the development side.

For a low thermal load configuration, DOE would excavate five ventilation shafts—three on the emplacement side of the repository and two on the development side. Two of the shafts on the emplacement side would contain fans to pull the air from the subsurface; the third would be an intake air shaft with no fans. Air would be pulled into the subsurface from this shaft and the North Ramp. An additional ventilation shaft would force air into the development side.

As noted above, electrically powered tunnel boring machines would excavate the emplacement drifts and most main drifts. DOE would use other mechanical excavators in areas where tunnel boring machines were impractical (for example, excavating turnouts and small alcoves) or industry-standard drill and blast techniques in limited applications where mechanical excavators were impractical. No drill and blast operations are currently envisioned, but if they were needed, care would be taken to ensure that the waste isolation properties of the mountain were not compromised. Ventilation shafts would be bored from the surface to the repository. Specialized equipment would move excavated rock in the subsurface to the conveyor system, which would move the rock from the subsurface to the excavated rock storage area on the surface. During drift excavation, water supplied to the subsurface in pipelines would be used for dust control at the excavation location and along the conveyor carrying excavated rock. Some of the water would be removed from the subsurface with the excavated rock, some would evaporate and be removed in the ventilation air, and the remainder would be collected in sumps near the point of use and pumped to the evaporation pond at the South Portal. DOE could recycle the water discharged to the evaporation pond for surface dust suppression activities. Controls would be established, as necessary, to ensure that water application for subsurface (and surface) dust control would not affect repository performance.

2.1.2.2.2 *Waste Package Design*

The function of the waste package changes over the repository lifetime. During the operation and monitoring phase, the disposal containers or waste packages would function as the vessels for safely handling, emplacing, and retrieving (if necessary) their contents. After closure, the waste packages would be the primary engineered barrier to inhibit the release of radioactive material to the environment.

DOE is developing specific waste package designs for uncanistered spent nuclear fuel assemblies, canistered spent nuclear fuel assemblies, and high-level radioactive waste canisters (Figure 2-20). The waste packages would be cylindrical containers and, in the preliminary conceptual design, range from 3.7 meters (12 feet) to 6.2 meters (20 feet) long and 1.25 to 2.0 meters (4.1 to 6.6 feet) in diameter. The waste packages of commercial spent nuclear fuel would hold as many as 21 pressurized-water reactor fuel assemblies or 44 boiling-water reactor fuel assemblies. There would be two general waste package designs for other types of spent nuclear fuel. These two designs would hold either a canister containing assemblies of naval spent nuclear fuel, or several canisters containing DOE spent nuclear fuel assemblies. There would be two general co-disposal waste package loading options, which would hold either five high-level radioactive waste canisters with an additional canister containing DOE spent nuclear fuel assemblies, or five canisters containing both high-level radioactive waste and immobilized plutonium waste forms. In addition, there would be waste packages that would contain only high-level radioactive waste.

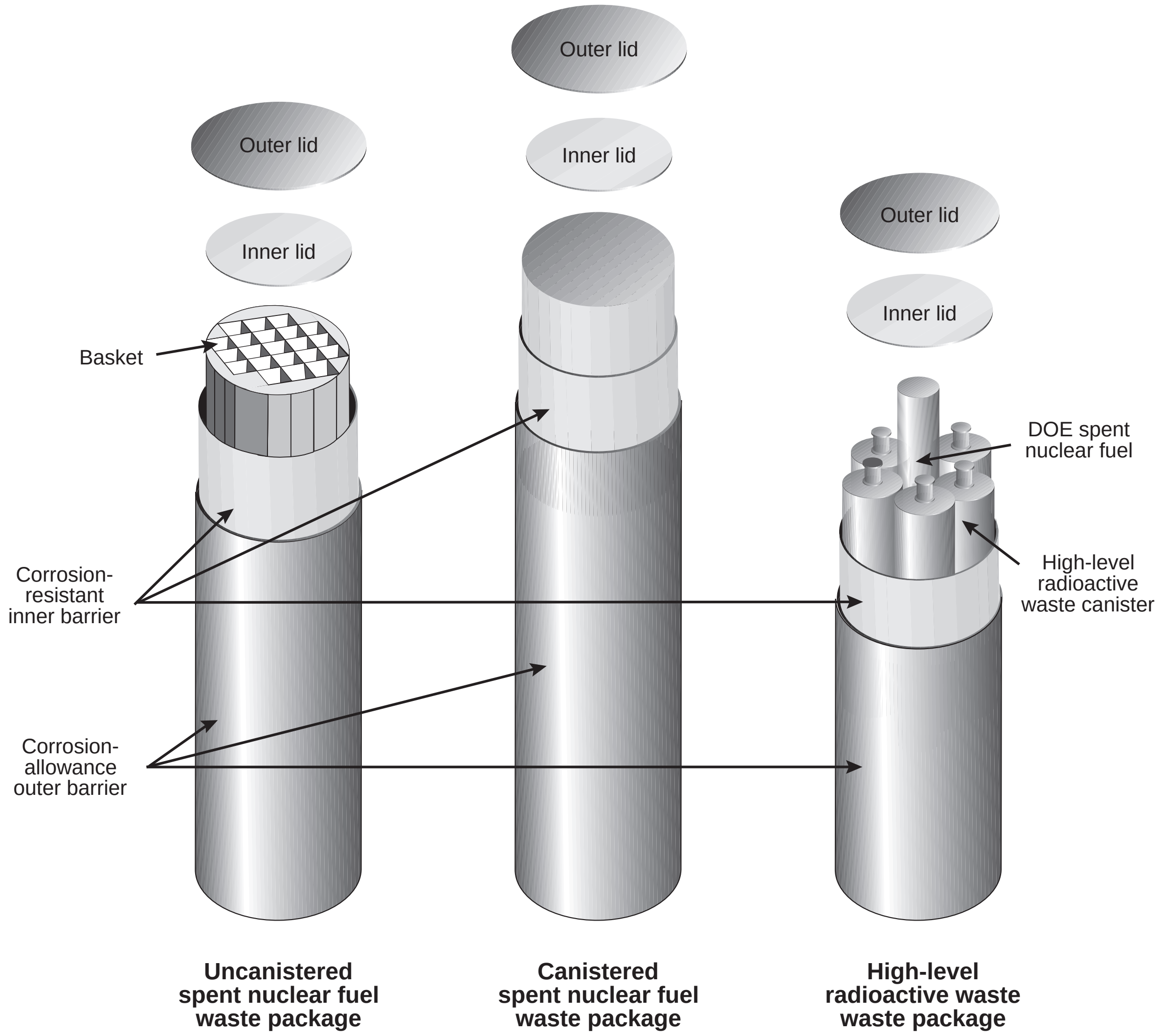
The preliminary conceptual design of the waste packages would have two layers: a structurally strong outer layer of carbon steel about 10 centimeters (4 inches) thick, and a corrosion-resistant inner layer of high-nickel alloy (Alloy 22) about 2 centimeters (0.79 inch) thick. These two layers would work together to preserve the integrity of the waste package for thousands of years.

Commercial spent nuclear fuel, DOE spent nuclear fuel, and immobilized plutonium contain *fissile material,* which is material capable, in principle, of sustaining a fission chain reaction. For a self-sustaining chain reaction to take place, a critical mass of fissile material—uranium-233 or -235 or one of several plutonium isotopes—must be arranged in a critical configuration. Waste packages are loaded with fissile material and neutron absorbers, if needed, so criticality cannot occur even in the unlikely event that the waste package somehow became full of water.

The waste packages would be placed horizontally on supports in the emplacement drifts (Figure 2-21). The supports would be steel and concrete structures that would hold the waste packages above the drift floor. DOE would place approximately 10,000 to 11,000 waste packages, which would include both spent nuclear fuel and high-level radioactive waste, in the repository. For the high thermal load scenario, the emplacement drifts would be spaced approximately 28 meters (92 feet) apart; for the intermediate thermal load scenario, they would be spaced approximately 28 to 40 meters (92 to 130 feet) apart; and for the low thermal load scenario, they would be spaced approximately 38 meters (125 feet) apart. In the emplacement drifts, DOE would then use the optimum spacing of waste packages based on their actual heat load; therefore, spacing would be greatest for the low thermal load scenario.

2.1.2.2.3 *Waste Package Emplacement Operations*

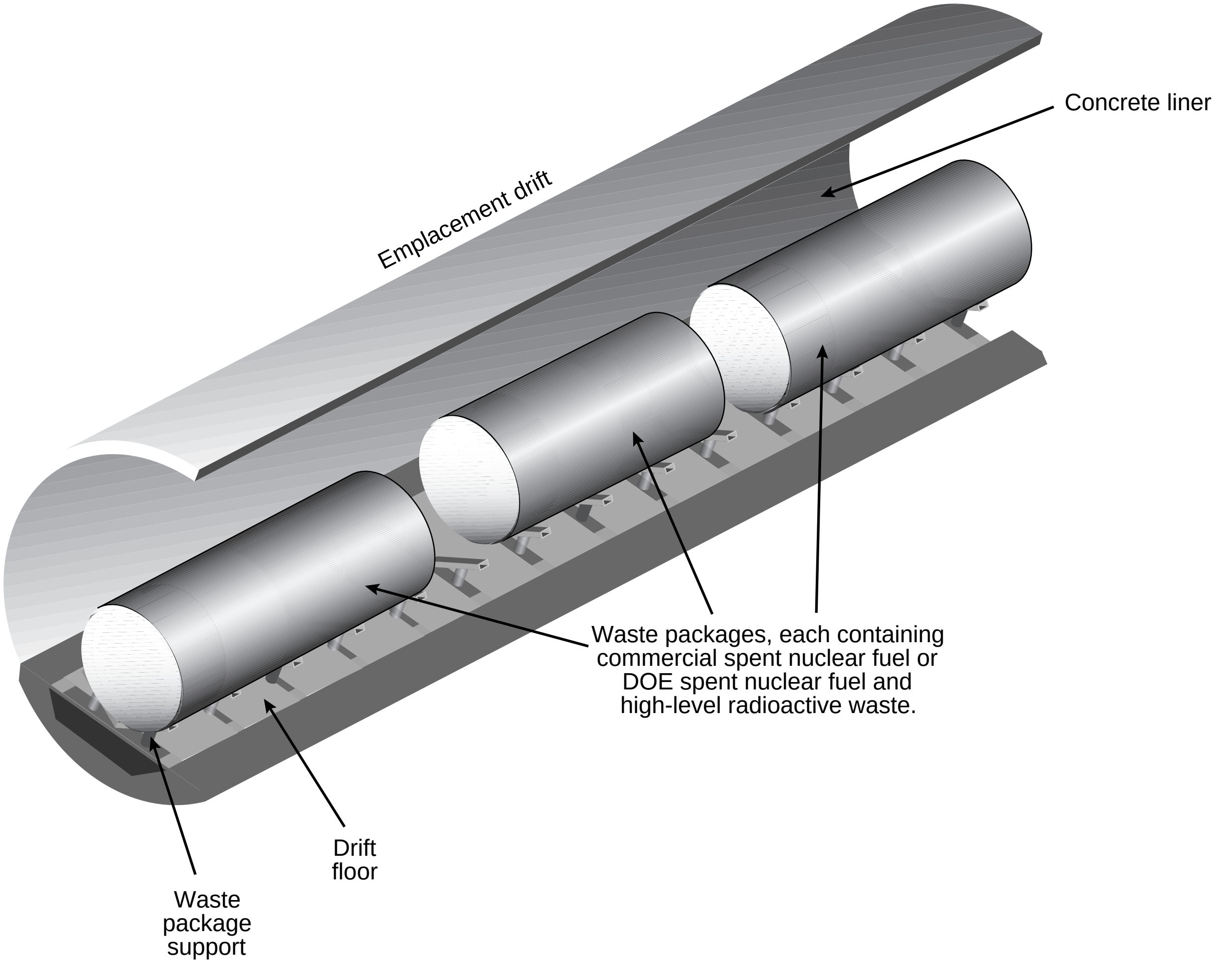
The transport of each waste package to the subsurface would start after the loading of a waste package on a reusable railcar and the loading of that railcar in a shielded waste package transporter in the Waste Handling Building (Figure 2-22). The transporter would be coupled at its closed end to a primary electric powered locomotive (trolley). A secondary electric powered locomotive would be coupled to the door end of the waste package transporter outside the Waste Handling Building. All waste packages would be transported underground through the North Ramp to the emplacement area main drift (Figure 2-23). On arrival at the emplacement drift, the secondary locomotive would be uncoupled from the transporter, and the transporter would be pushed into the emplacement drift turnout by the primary locomotive and stopped short of the isolation doors and loading dock. The doors would be opened remotely, as would the transporter doors. The transporter would be moved to align with the loading dock. The waste package would be moved on the railcar to the emplacement drift loading dock. The gantry would lift the waste package from the railcar and carry it to its emplacement location. The empty railcar would be returned to



Note: Waste packages would range in size from 3.7 to 6.2 meters (12 to 20 feet) long and 1.25 to 2.0 meters (4.1 to 6.6 feet) in diameter. They would range in weight from 35,000 kilograms (77,000 pounds) to 83,000 kilograms (183,000 pounds).

Source: Modified from DOE (1998a, Volume 3, Figure 2-3).

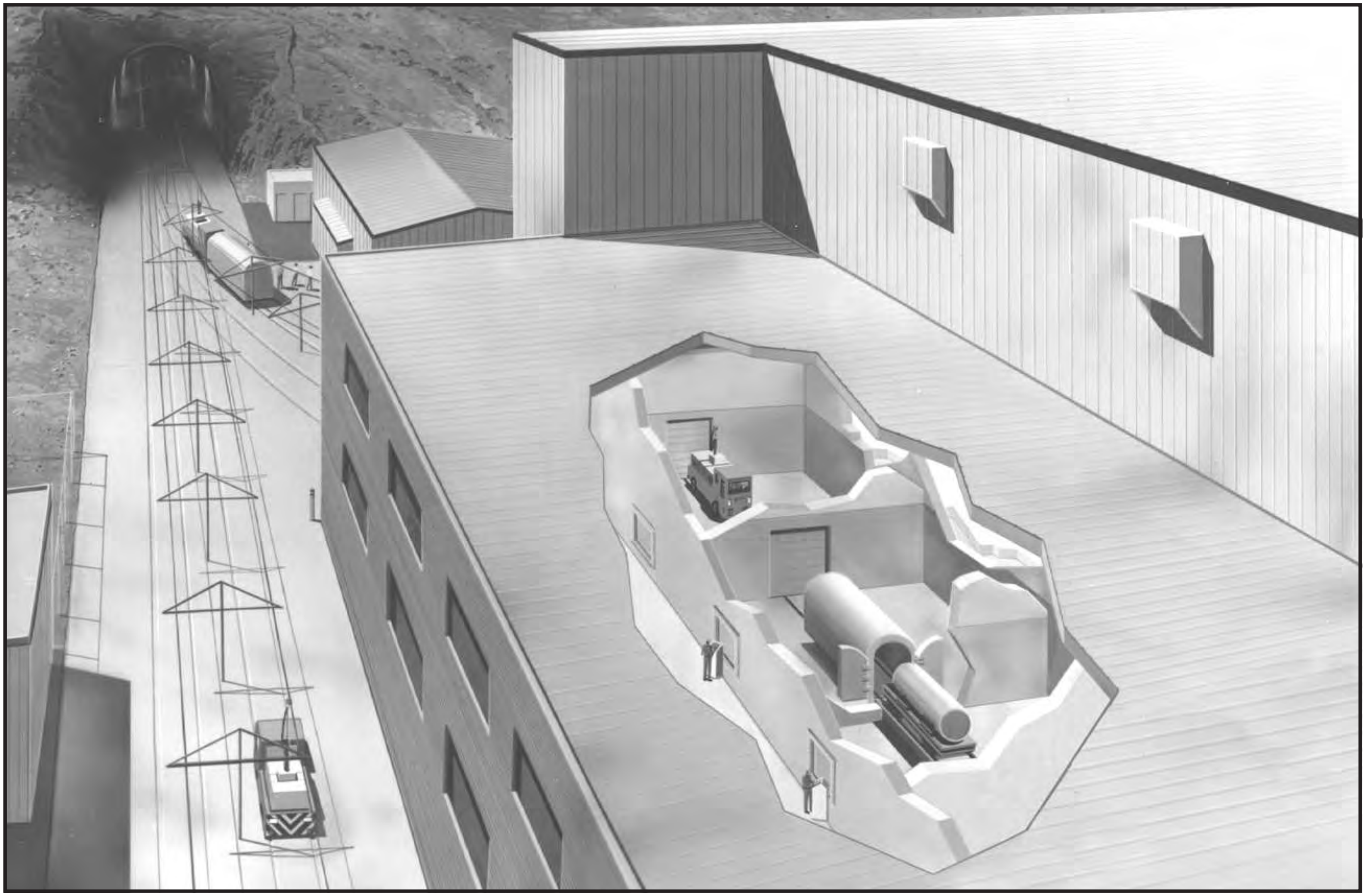
Figure 2-20. Potential waste package designs for spent nuclear fuel and high-level radioactive waste.



Note: Spacing between packages is for illustration only. The actual spacing would be determined as a function of the final repository thermal load design.

Sources: Modified from DOE (1998a, Volume 2, Figure 5-1).

Figure 2-21. Conceptual design of waste packages in emplacement drift.



Source: DOE (1998a, Overview, page 28).

Figure 2-22. Artist's conception of operations to move waste underground (view of Waste Handling Building and North Portal).

① Emplacement drift
② Emplacement drift isolation door
③ Waste package transporter (waste package waiting for gantry)
④ Electric-powered locomotive (trolley)
⑤ Turnout

Sources: Modified from DOE (1998a, Overview, page 14).

Figure 2-23. Artist's conception of repository underground facilities and operation.

the transporter, the isolation doors would be closed remotely, and the empty transporter with locomotives coupled front and rear would be returned to the surface for reuse.

2.1.2.3 Repository Closure

Permanent closure of the proposed repository would include closing the subsurface facilities, decontaminating and decommissioning the surface facilities, reclaiming the site, and establishing institutional barriers. This EIS assumes that repository closure would begin 100 years after the start of emplacement (76 years after the completion of emplacement). The time to complete repository closure would vary from about 6 years for the high and intermediate thermal load scenarios to about 15 years for the low thermal load scenario.

The closure of the subsurface repository facilities would include the removal and salvage of equipment and materials; filling of the main drifts, access ramps, and ventilation shafts; and sealing of openings, including ventilation shafts, access ramps, and boreholes. Filling operations would require surface operations to obtain fill material from the excavated rock pile or other source, and processing (screening, crushing, and possibly washing) the material to obtain the required particle size. Fill material would be transported on the surface in trucks and underground in open gondola railcars. A fill placement system would place the material in the underground main drifts and ramps. Seals for shafts, ramps, and boreholes would be strategically located to reduce radionuclide migration over extended periods, and so that they could not become pathways that could compromise the repository's postclosure performance. Seal materials and placement methods would be selected to reduce, to the extent practicable, the creation of preferential pathways for groundwater to contact the waste packages and the migration of radionuclides through existing pathways.

Decommissioning surface facilities would include decontamination activities, if required, and facility dismantlement and removal. Equipment and materials would be salvaged, recycled, or reused, if possible. Site reclamation would include restoring the site to as near its preconstruction condition as practicable. Reclamation could require the recontouring of disturbed surface areas, surface backfill, soil buildup and reconditioning, site revegetation, site water course configuration, and erosion control.

DOE would use institutional controls, including land records and warning systems, to limit or prevent intentional and unintentional activities in and around the closed repository. The repository area would be identified by monuments that would be designed, fabricated, and placed to be as permanent as practicable. Provisions could be added for postclosure monitoring.

2.1.2.4 Performance Confirmation Program

Performance confirmation refers to the program of tests, experiments, and analyses that DOE would conduct to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that long-term performance objectives have been met. The performance confirmation program, which would continue through the closure phase, would include elements of site testing, repository testing, repository subsurface support facilities construction, and waste package testing. Some of these activities would be a continuation of activities that began during site characterization. The data collection focus of the performance confirmation program initially would be to collect additional information to support enhanced confidence in the data used in the License Application. After the granting of licenses, the activities primarily would focus on monitoring and data collection for parameters important to terms and conditions of the license. The types of data important in the performance confirmation programs could include:

- Thermal response of the rock mass
- Air temperature and relative humidity in the emplacement drifts

- Possible emanation of radioactive gases from the emplacement drifts
- Condition of the waste packages and emplacement drifts
- Placement and recovery of test amounts of sample materials in the emplacement drifts
- Saturated zone monitoring
- Possible groundwater flow into the emplacement drifts and evidence of standing water accumulating in the emplacement drifts
- Air permeability, stress, and deformation and displacement of the rocks around the emplacement drifts
- Soil and rock temperature around the repository
- Moisture content, vapor content and humidity, fluid temperature, and air pressure in the rock adjacent to the emplacement drifts that would be most strongly affected by the presence of the emplaced waste

Performance confirmation drifts would be built about 15 meters (50 feet) above the emplacement drifts (see Figures 2-14, 2-15, and 2-16). DOE would drill boreholes from the performance confirmation drifts that would approach the rock mass near the emplacement drifts; instruments in these boreholes would gather data on the thermal, mechanical, hydrological, and chemical characteristics of the rock after waste emplacement. DOE would acquire performance confirmation data by sampling and mapping, from instruments in performance confirmation drifts or along the perimeter mains, ventilation exhaust monitoring, remote inspection systems in emplacement drifts, and possible recovery of waste packages for testing.

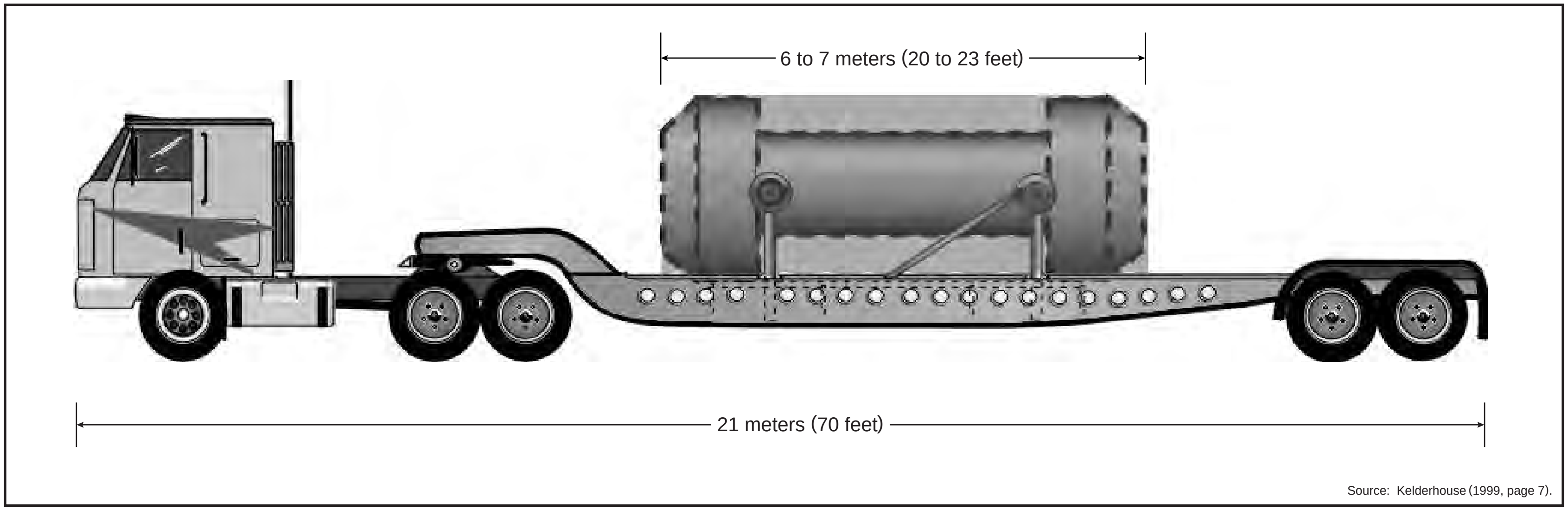
The performance confirmation program data would be used to evaluate total system performance and to confirm predicted system response. If the data determined that actual conditions differed from those predicted, the results could support further evaluation of the impacts of actual conditions on the long-term performance of the repository system.

2.1.3 TRANSPORTATION ACTIVITIES

Under the Proposed Action, DOE would transport spent nuclear fuel and high-level radioactive waste from commercial and DOE sites to the repository. The Naval Nuclear Propulsion Program would transport naval spent nuclear fuel from the Idaho National Engineering and Environmental Laboratory to the repository. Transportation activities would include the loading of these materials for shipment at generator sites (Section 2.1.3.1), transportation of the materials to the Yucca Mountain site by truck, rail, or possibly barge [see Sections 2.1.3.2 (National) and 2.1.3.3 (Nevada)], and shipping cask manufacturing, maintenance, and disposal (Section 2.1.3.4).

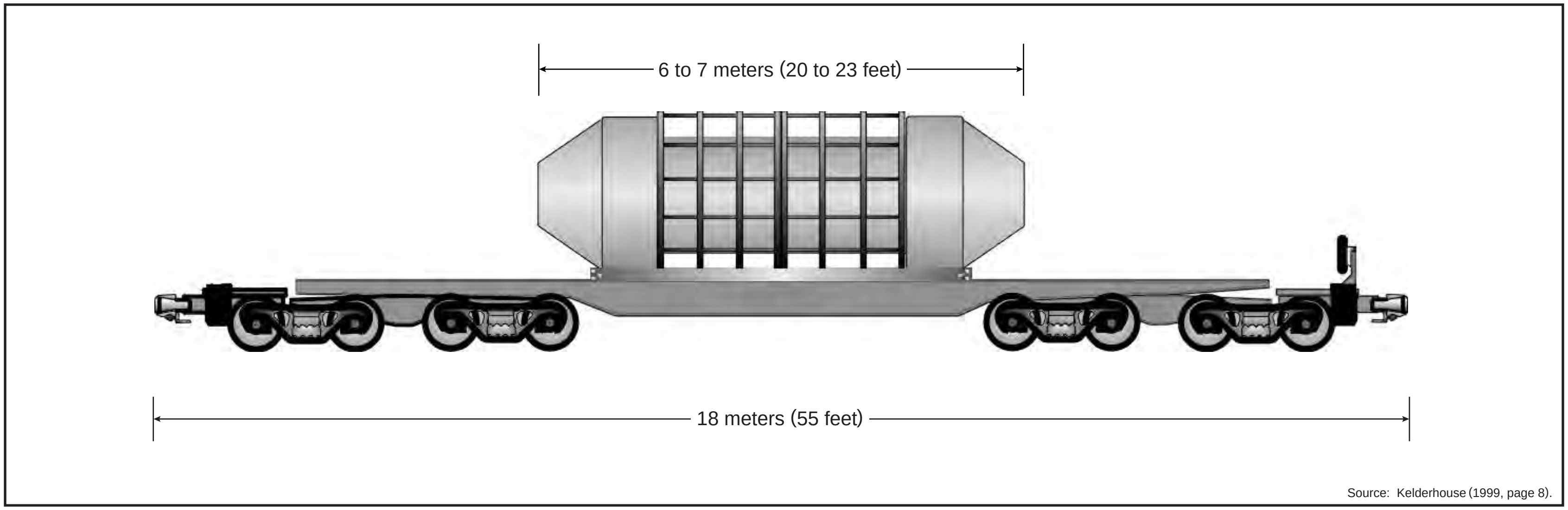
2.1.3.1 Loading Activities at Commercial and DOE Sites

This EIS evaluates the loading of spent nuclear fuel and high-level radioactive waste at commercial and DOE sites for transportation to the proposed repository at Yucca Mountain. Activities would include removing the spent nuclear fuel or high-level radioactive waste from storage, loading it in a shipping cask, and placing the cask on a vehicle (see Figures 2-24 and 2-25) for shipment to the repository. This EIS assumes that at the time of shipment the spent nuclear fuel and high-level radioactive waste would be in a form that met approved acceptance and disposal criteria for the repository.



Source: Kelderhouse (1999, page 7).

Figure 2-24. Artist's conception of a truck cask on a legal-weight tractor-trailer truck.



Source: Kelderhouse (1999, page 8).

Figure 2-25. Artist's conception of a large rail cask on a railcar.

2.1.3.2 National Transportation

National transportation includes the transport of spent nuclear fuel and high-level radioactive waste from the commercial and DOE sites to the Yucca Mountain site using existing highways (see Figure 2-26) and railroads (see Figure 2-27). Heavy-haul trucks could be used to transport spent nuclear fuel from commercial sites that did not have rail access to a nearby rail access point. Such sites on navigable waterways could use barges to deliver spent nuclear fuel to a nearby rail access point. The transportation of spent nuclear fuel and high-level radioactive waste to the repository would comply with applicable regulations of the U.S. Department of Transportation and the Nuclear Regulatory Commission, as well as applicable state and local regulations.

DOE has developed TRANSCOM, a satellite-based transportation tracking and communications system, to track current truck and rail shipments. Using the TRANSCOM system, DOE would monitor shipments of spent nuclear fuel and high-level radioactive waste to the repository at frequent intervals. This or a similar system could provide users (for example, DOE, the Nuclear Regulatory Commission, and state and tribal governments) with information about shipments to the repository and would enable communication between the vehicle operators and a central communication station. In heavily populated areas, armed escorts would be required for highway and rail shipments (10 CFR 73.37).

Section 180(c) of the Nuclear Waste Policy Act requires DOE to provide technical and financial assistance to states and tribes for training public safety officials in jurisdictions through which it plans to transport spent nuclear fuel and high-level radioactive waste. The training is to include procedures for the safe routine transportation of these materials and for emergency response situations. DOE is developing the policy and procedures for implementing this assistance and has started discussions with the appropriate organizations. The Department would institute these plans before beginning shipments to the repository. In the event of an incident involving a shipment of spent nuclear fuel or high-level radioactive waste, the transportation vehicle crew would notify local authorities and the central communications station monitoring the shipment. DOE would make resources available to local authorities as appropriate to mitigate such an incident.

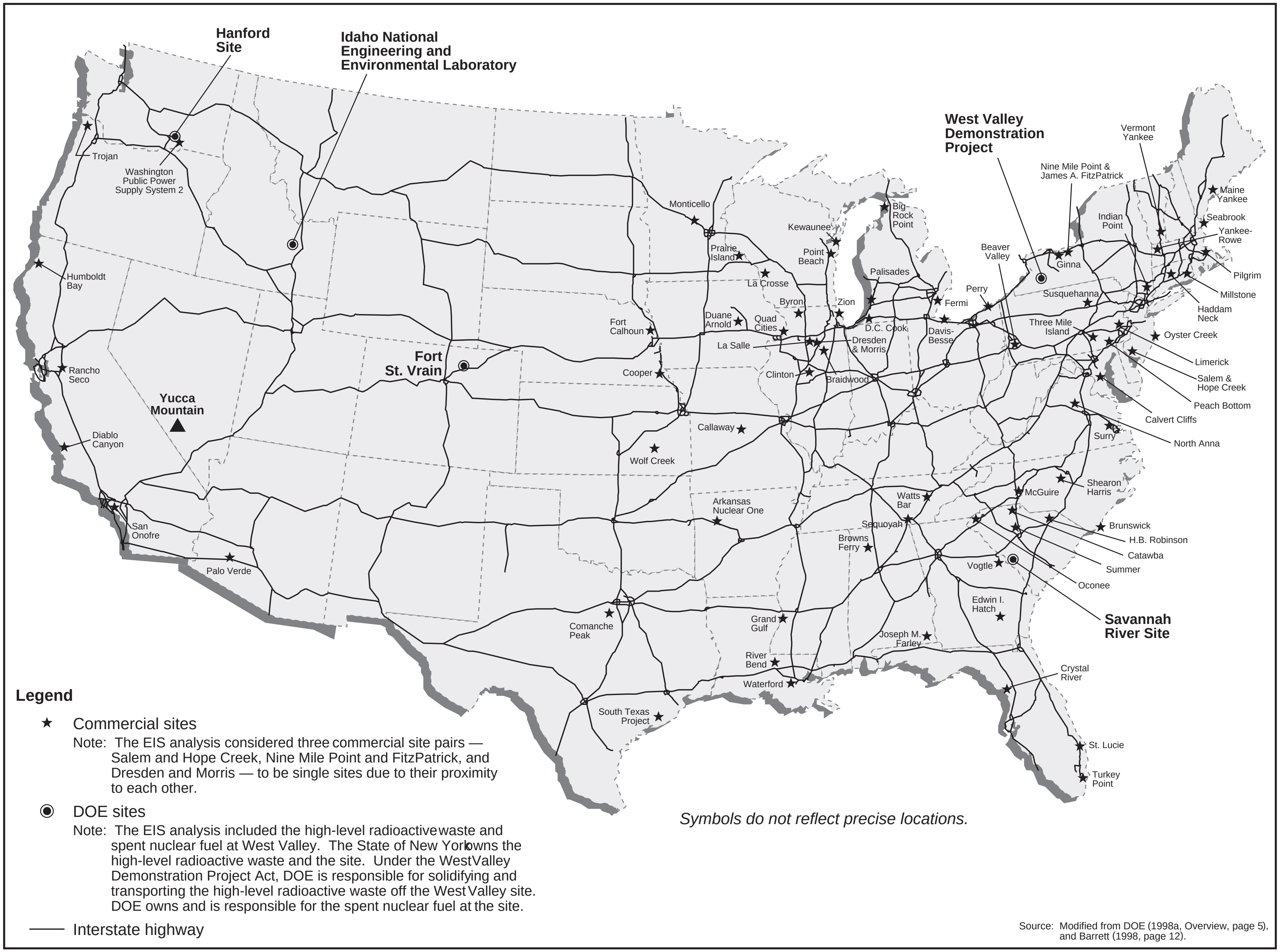
2.1.3.2.1 *National Transportation Shipping Scenarios*

DOE would ship spent nuclear fuel and high-level radioactive waste from commercial and DOE sites in some combination of legal-weight truck, rail, heavy-haul truck, and possibly barge. This EIS considers two national transportation scenarios, which for simplicity are referred to as the mostly legal-weight truck scenario and the mostly rail scenario. These scenarios illustrate the broadest range of operating conditions relevant to potential impacts to human health and the environment. Table 2-2 summarizes these scenarios, and Appendix J provides additional details.

Table 2-2. National transportation scenarios (percentage based on number of shipments).[a]

Material	Mostly legal-weight truck	Mostly rail
Commercial SNF	100% by legal-weight truck	About 80% by rail; about 20% by legal-weight truck
HLW	100% by legal-weight truck	100% by rail
DOE SNF	Mostly legal-weight truck; includes about 300 naval SNF shipments from INEEL to Nevada by rail	100% by rail

a. SNF = spent nuclear fuel; HLW = high-level radioactive waste; INEEL = Idaho National Engineering and Environmental Laboratory.



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New York owns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

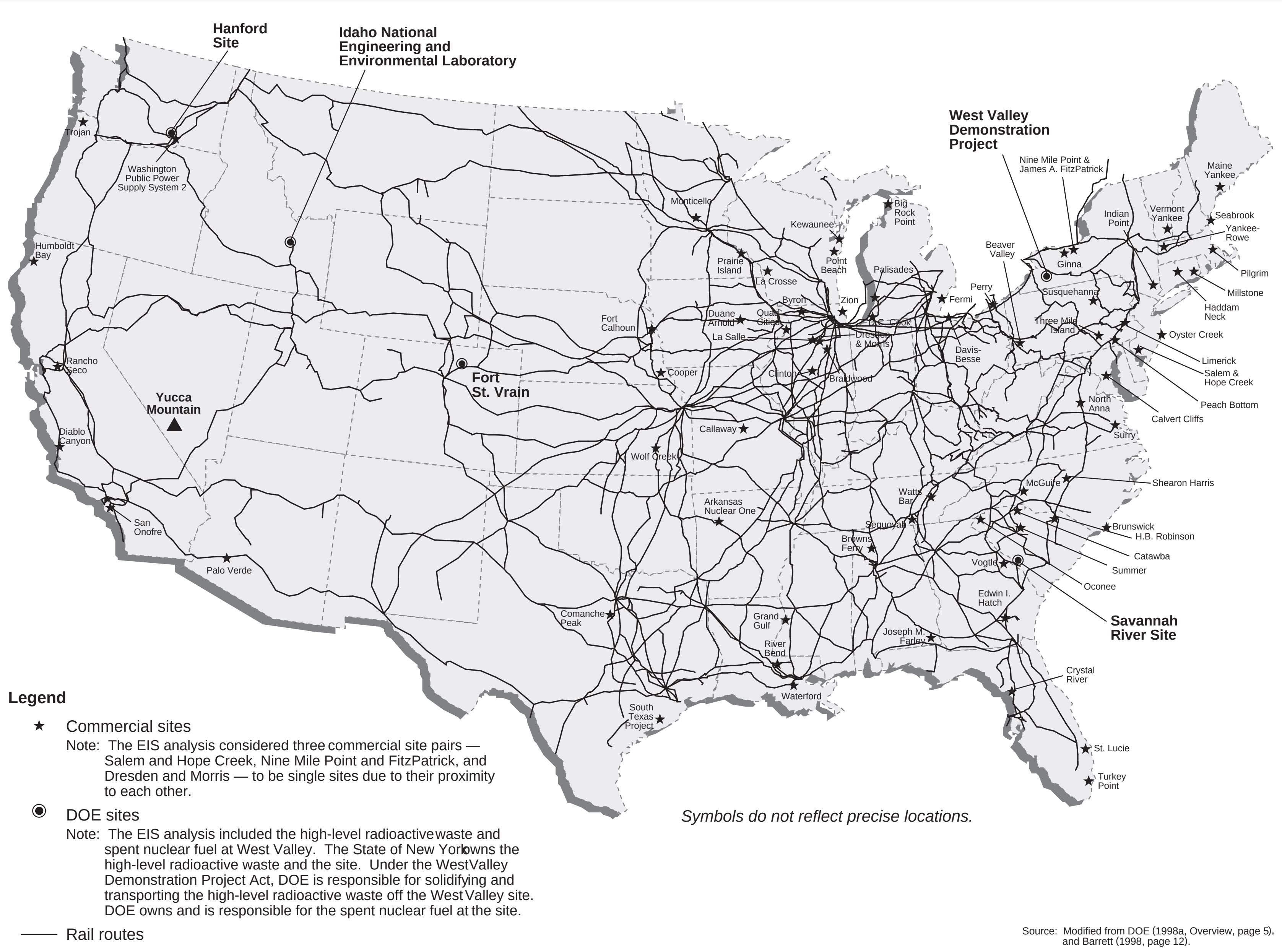
— Interstate highway

▲ Yucca Mountain

Symbols do not reflect precise locations.

Source: Modified from DOE (1998a, Overview, page 5), and Barrett (1998, page 12).

Figure 2-26. Commercial and DOE sites and Yucca Mountain in relation to the U.S. Interstate Highway System.



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New York owns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

—— Rail routes

Source: Modified from DOE (1998a, Overview, page 5), and Barrett (1998, page 12).

Figure 2-27. Commercial and DOE sites and Yucca Mountain in relation to the U.S. railroad system.

2.1.3.2.2 *Mostly Legal-Weight Truck Shipping Scenario*

Under this scenario, DOE would ship all high-level radioactive waste and most spent nuclear fuel from commercial and DOE sites to the Yucca Mountain site by legal-weight truck. About 50,000 shipments of these materials would travel on the Nation's Interstate Highway System during a 24-year period. There would be about 38,000 commercial spent nuclear fuel shipments and about 12,000 shipments of DOE spent nuclear fuel and high-level radioactive waste. The exception would be about 300 shipments of naval spent nuclear fuel that would travel from the Idaho National Engineering and Environmental Laboratory to Nevada by rail. [The Navy prepared an EIS (USN 1996a, all) and issued two Records of Decision (62 *FR* 1095, January 8, 1997; 62 *FR* 23770, May 1, 1997) on its spent nuclear fuel.]

Truck shipments would use Nuclear Regulatory Commission-certified, reusable shipping casks secured on legal-weight trucks (Figure 2-24). With proper labels and vehicle placards (hazard identification) and vehicle and cask inspections, a truck carrying a shipping cask of spent nuclear fuel or high-level radioactive waste would travel to the repository on highway routes selected in accordance with U.S. Department of Transportation regulations (49 CFR 397.101), which require the use of preferred routes. These routes include the Interstate Highway System, including beltways and bypasses. Alternative routes could be designated by states and tribes following Department of Transportation regulations (49 CFR 397.103) that require consideration of the overall risk to the public and prior consultation with affected local jurisdictions and with any other affected states.

Shipments of naval spent nuclear fuel would travel by rail in reusable shipping casks certified by the Nuclear Regulatory Commission. These shipments would use applicable and appropriate placards and inspection procedures.

2.1.3.2.3 *Mostly Rail Shipping Scenario*

Under this scenario, DOE would ship most spent nuclear fuel and high-level radioactive waste to Nevada by rail, with the exception of material from commercial nuclear sites that do not have the capability to load large-capacity rail shipping casks. Those sites would ship spent nuclear fuel to the repository by legal-weight truck. Commercial sites that have the capability to load large-capacity rail shipping casks but not rail access could use heavy-haul trucks or barges to transport their spent nuclear fuel to a nearby rail line. Under this scenario, about 11,000 railcars of spent nuclear fuel and high-level radioactive waste would travel on the nationwide rail network over a period of 24 years. Rail shipments would consist of Nuclear Regulatory Commission-certified, reusable shipping casks secured on railcars (see Figure 2-25). In addition, there would be about 2,600 legal-weight truck shipments. All shipments would be marked with the appropriate labels and placards and would be inspected in accordance with applicable regulations.

Some of the logistics of rail transportation to the repository would depend on whether DOE used general or dedicated freight service. General freight shipments of spent nuclear fuel and high-level radioactive waste would be part of larger trains carrying other commodities. A number of transfers between trains could occur as a railcar traveled to the repository. The basic infrastructure and activities would be similar between general freight and dedicated trains. However, dedicated train service would contain only railcars destined for the repository. In addition to railcars carrying spent nuclear fuel or high-level radioactive waste, there would be buffer and escort cars, in accordance with Federal regulations. DOE would use a satellite-based system to monitor all spent nuclear fuel shipments (see Section 2.1.3.2).

TERMS RELATED TO RAIL SHIPPING

General freight rail service: A train that handles a number of commodities. Railcars carrying spent nuclear fuel or high-level radioactive waste could switch in railyards or on sidings to a number of trains as they traveled from commercial and DOE sites to Nevada.

Dedicated freight rail service: A train that handles only one commodity (in this case, spent nuclear fuel or high-level radioactive waste). Use of a separate train with its own crew carrying spent nuclear fuel or high-level radioactive waste would avoid switching railcars between trains.

Buffer cars: Railcars placed in front and in back of those carrying spent nuclear fuel or high-level radioactive waste to provide additional distance from possibly occupied railcars. Federal regulations (49 CFR 174.85) require the separation of a railcar carrying spent nuclear fuel or high-level radioactive waste from a locomotive, occupied caboose, or carload of undeveloped film by at least one buffer car. These could be DOE railcars or, in the case of general freight service, commercial railcars.

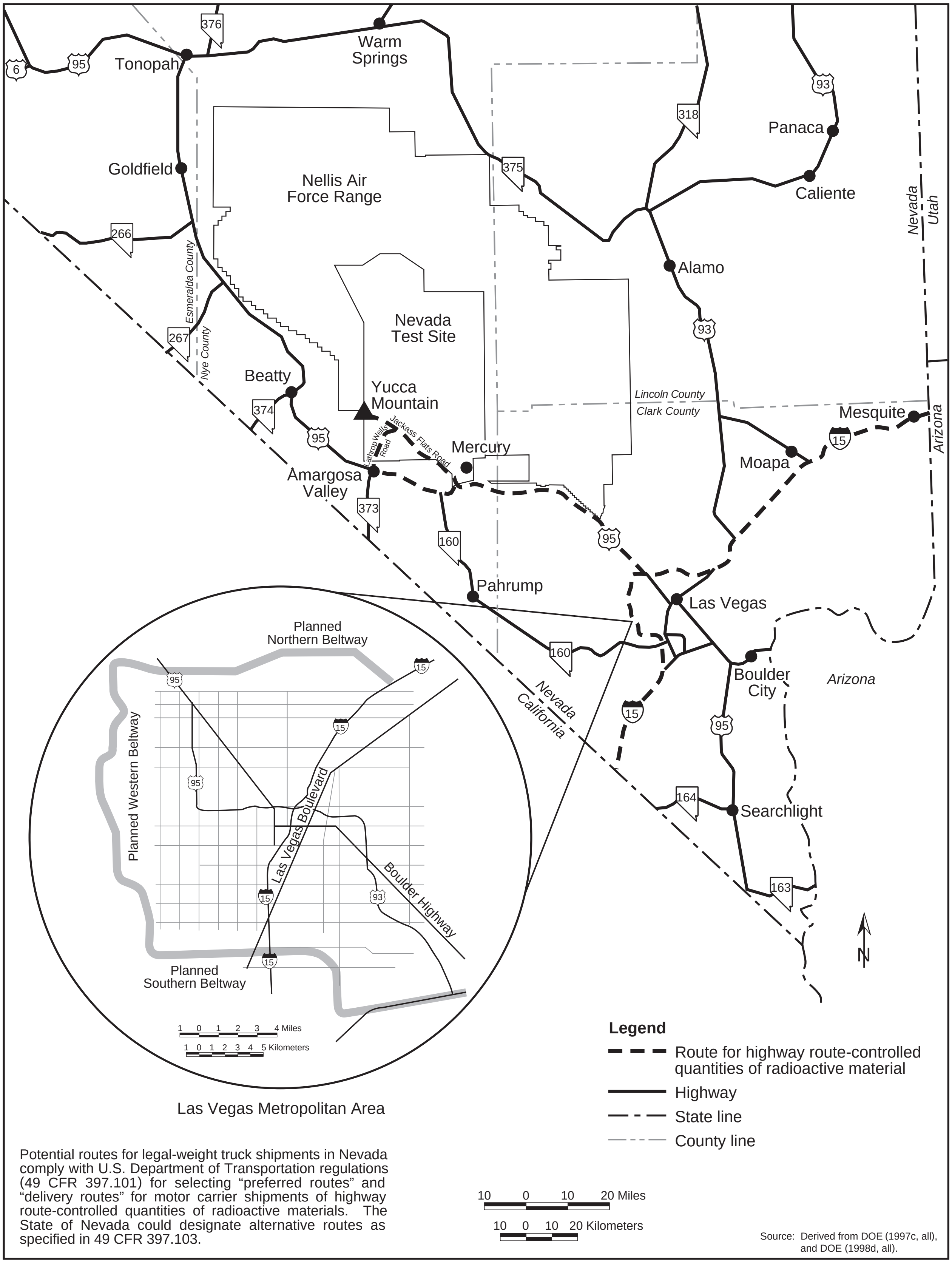
Escort cars: Railcars in which escort personnel (for example, security personnel) would reside on trains carrying spent nuclear fuel or high-level radioactive waste.

2.1.3.3 Nevada Transportation

Nevada transportation is part of national transportation, but the EIS also discusses it separately. Depending on how a shipment was transported, DOE could use one of three options or modes of transportation in Nevada: legal-weight trucks, rail, or heavy-haul trucks. Legal-weight truck shipments arriving in Nevada would travel directly to the Yucca Mountain site. Two Interstate highways cross Nevada—I-80 in the north and I-15 in the south. I-15, the closest Interstate highway to the proposed repository, travels through Salt Lake City, Utah, to southern California, passing through Las Vegas. Figure 2-28 shows the existing highway infrastructure in southern Nevada. The EIS analysis assumed that the proposed Interstate bypass around the urban core of Las Vegas (the Las Vegas Beltway) would be operational before 2010.

Shipments arriving in Nevada by rail would travel to the repository site by rail or heavy-haul truck (legal-weight trucks could not be used due to the size and weight of the rail shipping casks). Existing rail lines in the State include two northern routes and one southern route; the Southern Pacific Railroad owns one of the northern routes and the Union Pacific Railroad owns the other northern route and the southern route. The northern routes pass through or near the cities of Elko, Carlin, Battle Mountain, and Reno. The southern route runs through Salt Lake City, Utah, to Barstow, California, passing through Caliente, Las Vegas, and Jean, Nevada. Figure 2-29 shows the Nevada rail infrastructure. Rail access is not currently available to the Yucca Mountain site, so DOE would have to build a branch rail line from an existing mainline railroad to the site or transfer the rail cask to a heavy-haul truck at an intermodal transfer station for transport to the repository.

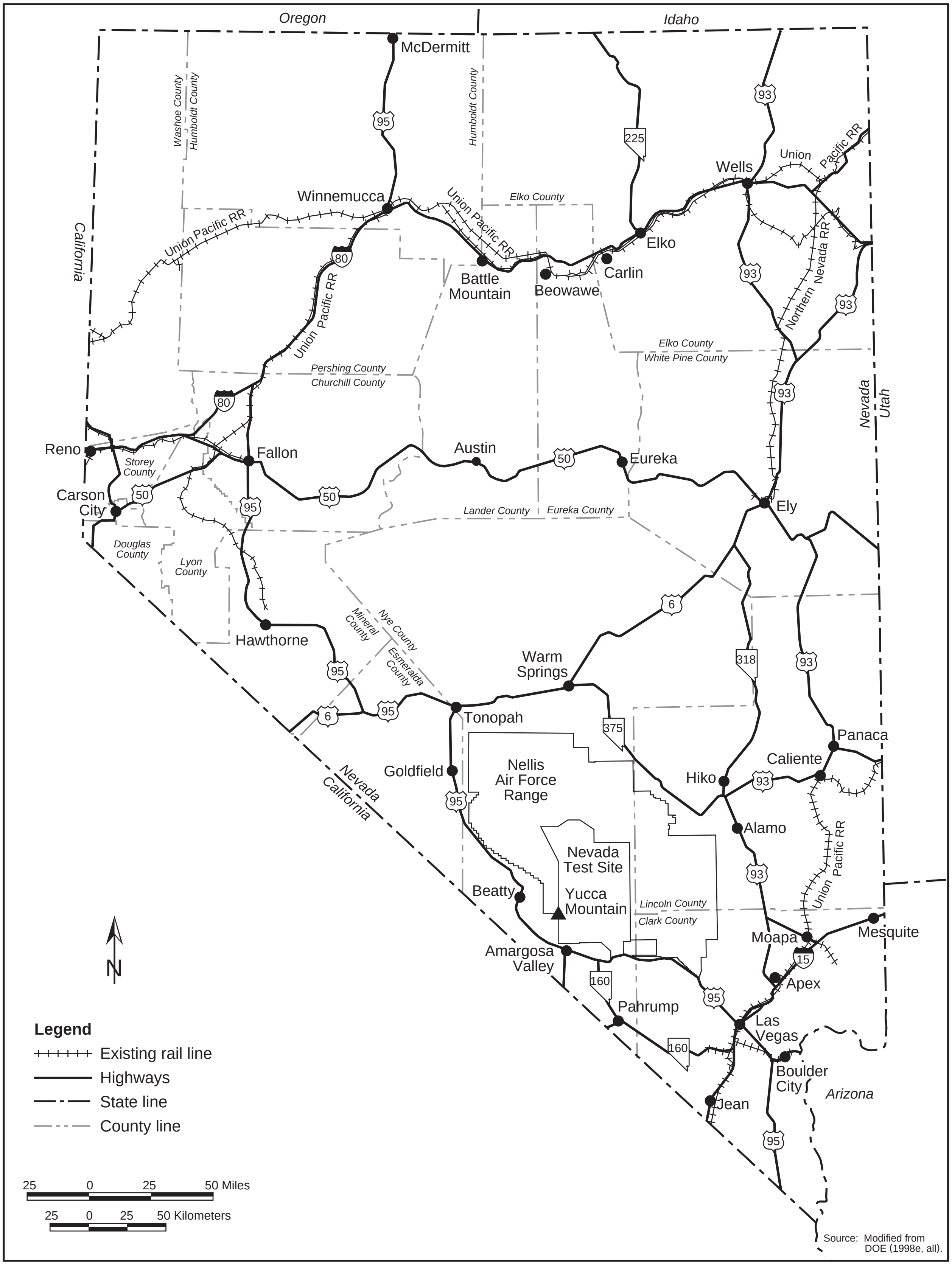
To indicate distinctions between available transportation options or modes in Nevada and to define the range of potential impacts associated with transportation in the State, this EIS analyzes three transportation scenarios: the first, associated with the national legal-weight truck scenario, is a Nevada legal-weight truck scenario; the second and third, both associated with the national rail scenario, are rail transport directly to the Yucca Mountain site, and an intermodal transfer from railcar to heavy-haul truck for travel to the site. Table 2-3 summarizes the Nevada transportation scenarios.



Potential routes for legal-weight truck shipments in Nevada comply with U.S. Department of Transportation regulations (49 CFR 397.101) for selecting "preferred routes" and "delivery routes" for motor carrier shipments of highway route-controlled quantities of radioactive materials. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

Source: Derived from DOE (1997c, all), and DOE (1998d, all).

Figure 2-28. Southern Nevada highways.



Source: Modified from DOE (1998e, all).

Figure 2-29. Existing Nevada rail lines.

Table 2-3. Nevada transportation shipping scenarios (percentage based on number of shipments).[a]

Material	Mostly legal-weight truck	Mostly rail	Mostly heavy-haul truck[b]
Commercial SNF	100% by legal-weight truck	About 80% by rail; about 20% by legal-weight truck	About 80% by heavy-haul truck; about 20% by legal-weight truck
HLW	100% by legal-weight truck	100% by rail	100% by heavy-haul truck
DOE SNF	Mostly by legal-weight truck; includes about 300 naval SNF shipments by rail and heavy-haul truck	100% by rail	100% by heavy-haul truck

a. SNF = spent nuclear fuel; HLW = high-level radioactive waste.

b. Rail shipment to intermodal transfer station, and heavy-haul truck shipment from intermodal transfer station to the repository.

The following sections describe the Nevada transportation scenarios and the implementing alternatives DOE is considering for a new branch rail line or a new intermodal transfer station and associated highway route for heavy-haul trucks. Detailed engineering descriptions are based on TRW (1999d, all), unless otherwise noted.

2.1.3.3.1 *Nevada Legal-Weight Truck Scenario*

Under this scenario, DOE would use legal-weight trucks in Nevada to transport spent nuclear fuel and high-level radioactive waste to the repository. Naval spent nuclear fuel would be transported to Nevada by rail. In Nevada, DOE would use heavy-haul trucks to transport these 300 shipments. DOE would establish an intermodal transfer capability and an associated heavy-haul shipment capability (see Section 2.1.3.3.3).

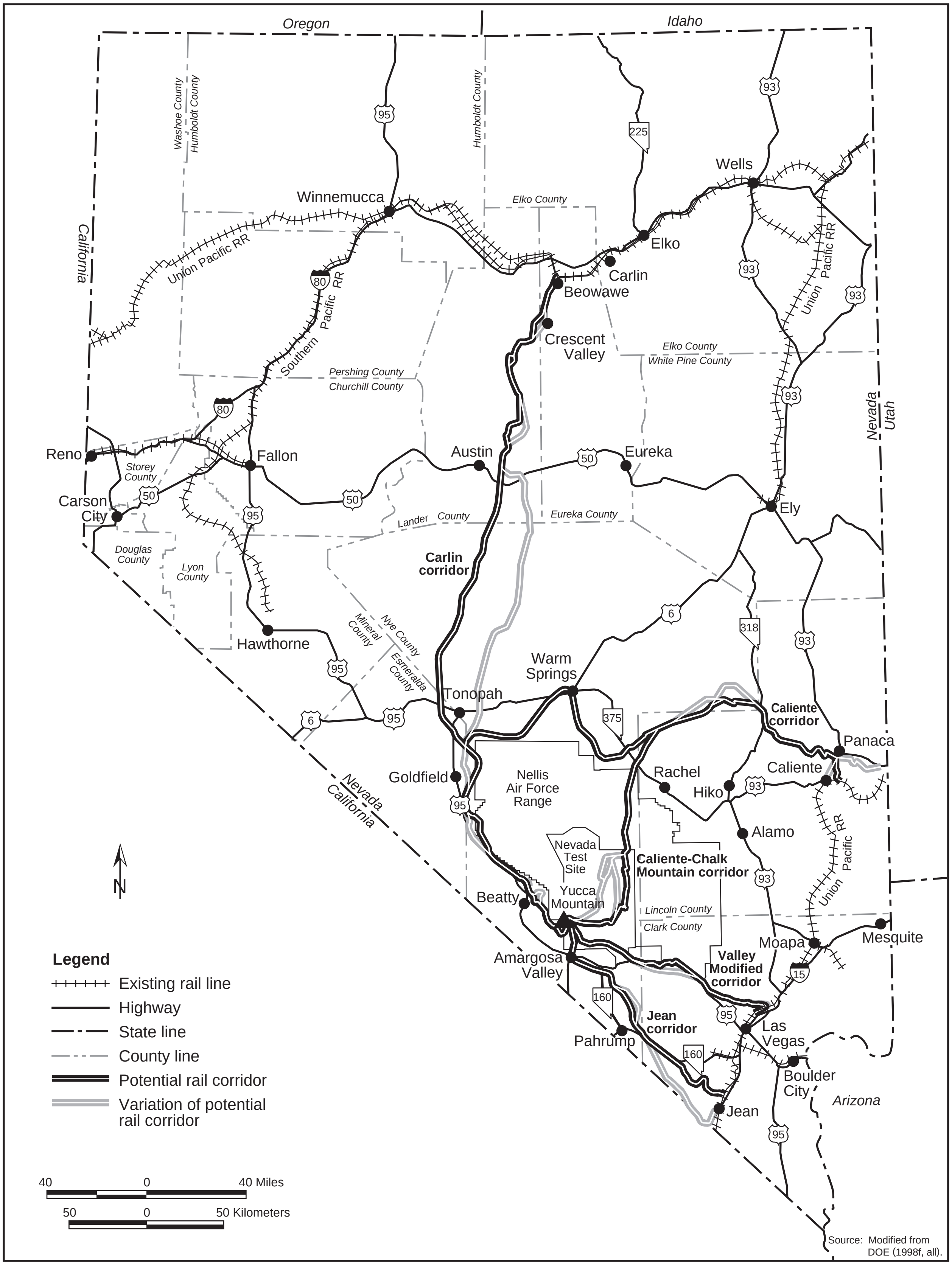
Legal-weight truck shipments would use existing routes that satisfy regulations of the U.S. Department of Transportation for the shipment of highway route-controlled quantities of radioactive materials (49 CFR 397.101). Legal-weight trucks would enter Nevada on I-15 from the north or south, bypass the Las Vegas area on the proposed beltway, and travel north on U.S. 95 to the Nevada Test Site and then to the Yucca Mountain site (Figure 2-28).

2.1.3.3.2 *Nevada Rail Scenario*

Under this scenario, DOE would construct and operate a branch rail line in Nevada. Based on previous studies (described in Section 2.3), DOE has narrowed its consideration for a new branch rail line to five potential rail corridors—Caliente, Carlin, Caliente-Chalk Mountain, Jean, and Valley Modified. These rail corridors are shown on Figure 2-30 and are described in the following paragraphs. DOE would need to obtain a 0.4-kilometer (0.25-mile)-wide right-of-way to construct a rail line and an associated access road. As shown in Figure 2-30, there are possible alignment variations, which are described further in Appendix J.

- *Caliente Rail Corridor Implementing Alternative.* The Caliente corridor originates at an existing siding to the Union Pacific mainline railroad near Caliente, Nevada (Figure 2-30). The corridor is 513 kilometers (319 miles) long from the Union Pacific line connection to the Yucca Mountain site.

- *Carlin Rail Corridor Implementing Alternative.* The Carlin corridor originates at the Union Pacific main line railroad near Beowawe in north-central Nevada (Figure 2-30). The Carlin and Caliente corridors converge near the northwest boundary of the Nellis Air Force Range (also known as the Nevada Test and Training Range). Past this point, they are identical. The corridor is 520 kilometers (323 miles) long from the tie-in point with the Union Pacific line to the Yucca Mountain site.



Source: Modified from DOE (1998f, all).

Figure 2-30. Potential Nevada rail routes to Yucca Mountatin.

- *Caliente-Chalk Mountain Rail Corridor Implementing Alternative.* The Caliente-Chalk Mountain corridor is identical to the Caliente corridor until it approaches the northern boundary of the Nellis Air Force Range. At that point the Caliente-Chalk Mountain corridor turns south through the Nellis Air Force Range and the Nevada Test Site to the Yucca Mountain site (Figure 2-30). The corridor is 345 kilometers (214 miles) long from the tie-in point at the Union Pacific line to the Yucca Mountain Site.

- *Jean Rail Corridor Implementing Alternative.* The Jean corridor originates at the existing Union Pacific mainline railroad near Jean, Nevada (Figure 2-30). The corridor is 181 kilometers (112 miles) long from the tie-in point at the Union Pacific line to the Yucca Mountain site.

- *Valley Modified Rail Corridor Implementing Alternative.* The Valley Modified corridor originates at an existing rail siding off the Union Pacific mainline railroad northeast of Las Vegas. The corridor is about 159 kilometers (98 miles) long from the tie-in point with the Union Pacific line to the Yucca Mountain site.

2.1.3.3.2.1 Rail Line Construction. The selected rail line would be designed and built in compliance with Federal Railroad Administration safety standards. In addition, a service road along the rail line would be built and maintained. Rail line construction along any of the corridors would take an estimated 2.5 years. Construction would start after the selection of a route, completion of engineering studies, completion of the rail line design, and land acquisition.

Construction activities would include the development of construction support areas; construction of access roads to the rail line construction initiation points and to major structures to be built, such as bridges; and movement of equipment to the construction initiation points. The number and location of construction initiation points would be based on such variables as the route selected, the length of the line, the construction schedule, the number of contractors used for construction, the number of structures to be built, and the locations of existing access roads adjacent to the rail line.

RAILROAD CONSTRUCTION TERMS

Borrow areas: Areas outside the rail corridor where construction personnel could obtain materials to be used in the establishment of a stable platform (subgrade) for the rail track. Aggregate crushing operations could occur in these areas.

Spoils areas: Areas outside the rail corridor for the deposition of excavated materials from rail line development.

Construction support areas: Areas along the rail route that could be used as temporary residences for construction crews, material and equipment storage areas, and concrete production areas. Such camps probably would be for the construction of routes far from population centers.

The construction of a rail line would require the clearing and excavation of previously undisturbed lands in the corridor and the establishment of borrow and spoils areas outside the corridor. To establish a stable platform for the rail track, construction crews would excavate some areas and fill (add more soil to) others, as determined by terrain features. To the extent possible, material excavated from one area would be used in areas that required fill material. However, if the distance to an area requiring fill material was excessive, the excavated material would be disposed of in adjacent low areas, and a borrow area would be established adjacent to the area requiring fill material. Access roads to spoils and borrow areas would be built during the track platform construction work.

Typical heavy-duty construction equipment (front-end loaders, power shovels, and other diesel-powered support equipment) would be used for clearing and excavation work. Trucks would spray water along graded areas for dust control and soil compaction. The fill material used along the rail line to establish a stable platform for the track would be compacted to meet design requirements. Water could be shipped from other locations or obtained from wells drilled along the route.

Railroad track construction would consist of the placement of railbed material, ties, rail, and ballast (support and stabilizing materials for the rail ties) over the completed railbed platform. Other activities would include the following:

- Installation of at-grade crossings (which would require rerouting existing utility lines in some areas)
- Installation of fences along the rail line, if requested by other agencies (for example, the Bureau of Land Management or the Fish and Wildlife Service)
- Installation of the train control system (monitoring equipment, signals, communications equipment)
- Final grading of slopes, installation of rock-fall protection devices, replacement of topsoil, revegetation and installation of other permanent erosion control systems, and completion of the adjacent maintenance road

2.1.3.3.2.2 Rail Line Operations. Branch rail line operations from the junction with the main line to the proposed repository at Yucca Mountain would meet Federal Railroad Administration standards for maintenance, operations, and safety. Current plans for the branch rail line anticipate a train with two 3,000-horsepower, diesel-electric locomotives; from one to five railcars containing spent nuclear fuel and high-level radioactive waste; buffer cars; and escort cars.

The operational interface between the Union Pacific and the branch rail line would be determined by whether the waste was shipped to Nevada by dedicated rail service or by general freight rail service. With dedicated rail service to Nevada, the railcars would be transferred to the branch rail line and shipped immediately to the repository. With general freight service, the railcars carrying spent nuclear fuel or high-level radioactive waste could be parked on a side track (off the main rail line) at the connection point until a train could be assembled to travel to the repository site. A small secure railyard off the main rail line would be established for switching operations. Railcars with spent nuclear fuel or high-level radioactive waste would have to be moved within 48 hours in accordance with U.S. Department of Transportation regulations (49 CFR 174.14).

This EIS assumes there would be about four trains per week for shipments of spent nuclear fuel and high-level radioactive waste to the repository. In addition, the rail line would enable the transport of other material to the repository, including empty disposal containers, bulk concrete materials, steel, large equipment, and general building materials. The EIS assumes one train per week for this other material for a total of about five trains per week to the repository from about 2010 to 2033.

2.1.3.3.3 *Nevada Heavy-Haul Truck Scenario*

Under this scenario, rail shipments to Nevada would go to an intermodal transfer station where the shipping cask would transfer from the railcar to a heavy-haul truck. The heavy-haul truck would travel on existing roads to the repository. The following sections describe the implementing alternatives (the intermodal transfer station locations and associated highway routes for heavy-haul trucks) that the EIS analyzes.

2.1.3.3.3.1 Intermodal Transfer Stations. To enable intermodal transfers and heavy-haul shipments to the repository, an intermodal transfer station would be built and operated in Nevada. DOE is considering three potential locations for intermodal transfer operations: near Caliente, northeast of Las Vegas (Apex/Dry Lake), and southwest of Las Vegas (Sloan/Jean) (Figure 2-31). DOE has identified general areas at these three locations where it could build and operate an intermodal transfer station:

- *Caliente Intermodal Transfer Station Implementing Alternative.* The Caliente siting areas are south of Caliente in the Meadow Valley Wash. DOE has identified two possible areas along the west side of the wash.

- *Apex/Dry Lake Intermodal Transfer Station Implementing Alternative.* The potential areas northeast of Las Vegas are between the Union Pacific rail sidings at Dry Lake and Apex. Two large contiguous areas are available for intermodal transfer station siting near the Apex/Dry Lake sidings. The first area is directly adjacent to the Dry Lake siding along the west side of the Union Pacific line. The second area is on the east side of I-15 adjacent to the Union Pacific line and south of where the main Union Pacific line crosses I-15. Because this area is between the Dry Lake and Apex sidings, the construction of an additional rail siding would be necessary.

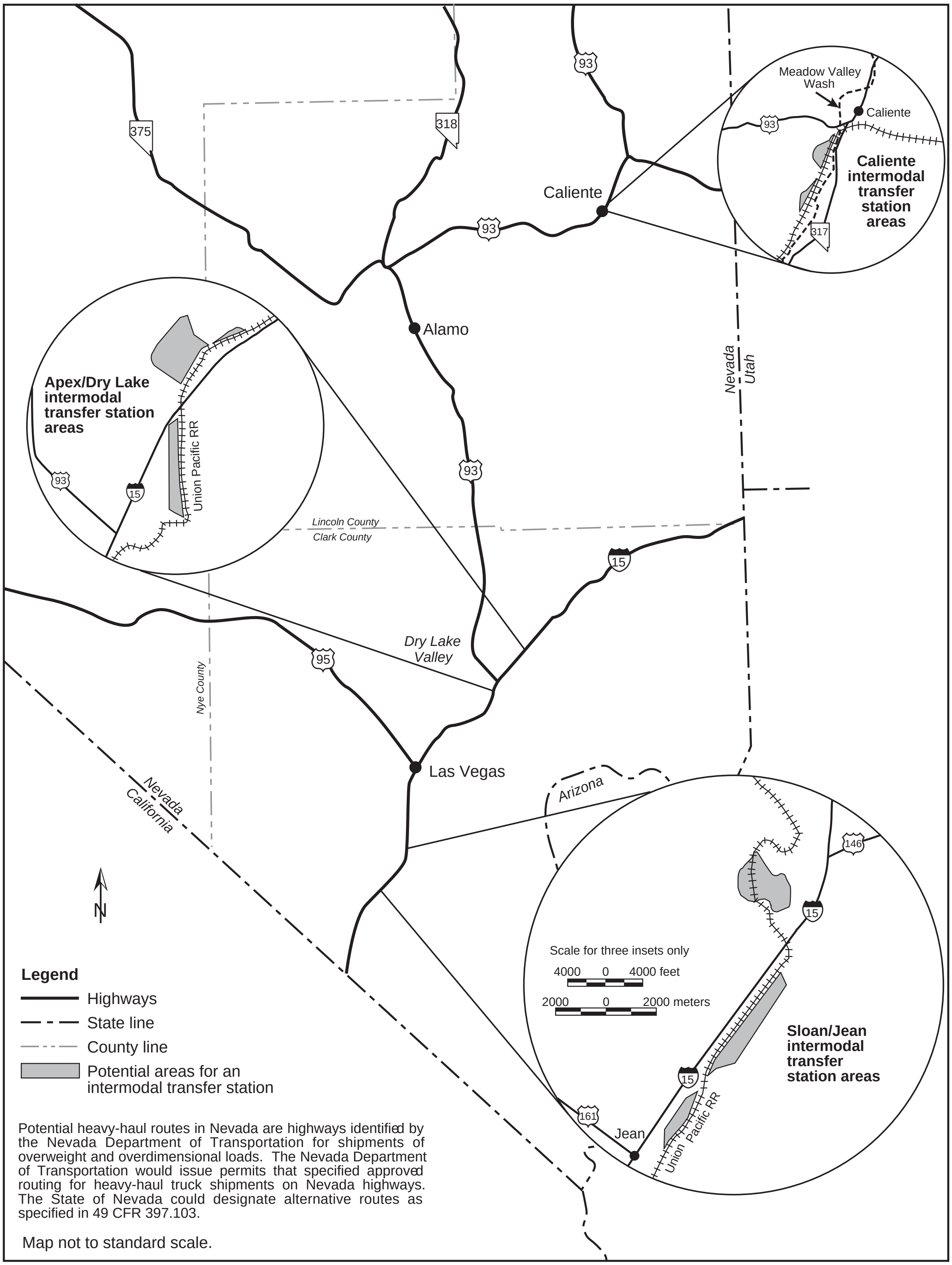
- *Sloan/Jean Intermodal Transfer Station Implementing Alternative.* The potential areas for an intermodal transfer station southwest of Las Vegas are between the existing Union Pacific rail sidings at Sloan and Jean. One area is on the west side of I-15, north of the Union Pacific rail underpass at I-15. The second is south of the Sloan rail siding along the east side of the rail line. A third area is south of the second, directly north of the Jean interchange on I-15.

The intermodal transfer station would be a fenced area of about 250 meters (820 feet) by 250 meters and a rail siding that would be about 2 kilometers (1.2 miles) long (see Figure 2-32). The estimated total area occupied by the facility and support areas would be about 0.2 square kilometer (50 acres). It would include rail tracks, two shipping cask transfer cranes (one on a gantry rail, and one on a backup rubber-tired vehicle), an office building, and a maintenance and security building. It would also have connection tracks to the existing Union Pacific line and storage and transfer tracks inside the station boundary. The maintenance building would provide space for routine service and minor repairs to the heavy-haul trailers and tractors. The station would have power, water, and other services. Diesel generators would provide a backup electric power source. Construction of an intermodal transfer station would take an estimated 1.5 years.

Intermodal transfer station operations would depend on whether the railcars that carried spent nuclear fuel and high-level radioactive waste arrived on dedicated or general freight trains. A dedicated train would enter the intermodal transfer station, passing the opened security gate and parking on a track for cask inspection. After inspection, the train would proceed to a loading and unloading track or a designated storage track (if the loading and unloading tracks were occupied).

General freight trains would switch from the main Union Pacific track to an existing or newly constructed passing track. The railcars carrying casks of spent nuclear fuel or high-level radioactive waste would be uncoupled from the freight train and switched to the intermodal transfer station track. The freight train would return to the main Union Pacific line and continue its trip. A railyard locomotive would move the cars containing the casks to the station.

The loading and unloading process would begin with the return of a heavy-haul truck from the repository. The empty cask returning from the repository would be lifted from the truck, loaded on an empty railcar, and secured. The gantry or mobile crane would then remove a loaded cask from another railcar and transfer it to the same truck, where it would be secured and inspected before shipment to the repository.



Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. The Nevada Department of Transportation would issue permits that specified approved routing for heavy-haul truck shipments on Nevada highways. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

Map not to standard scale.

Figure 2-31. Potential intermodal transfer station locations.

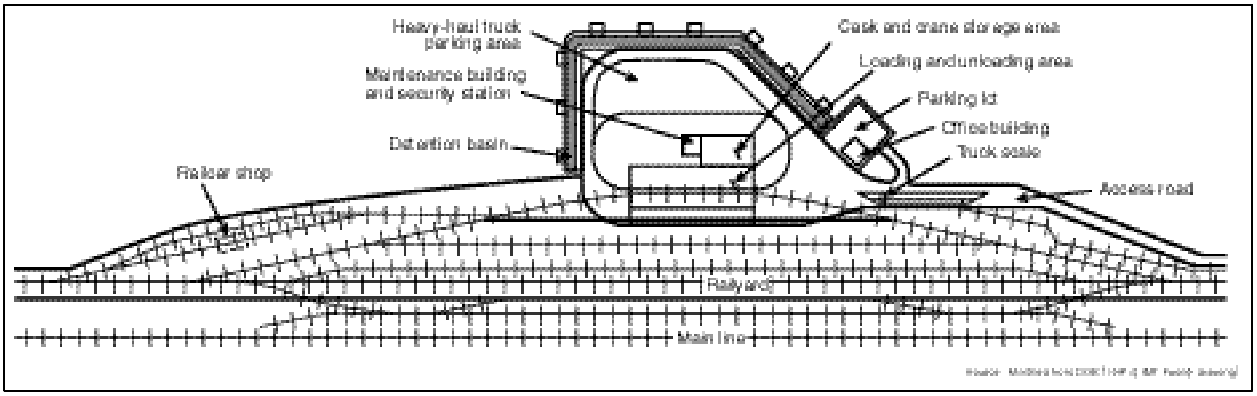
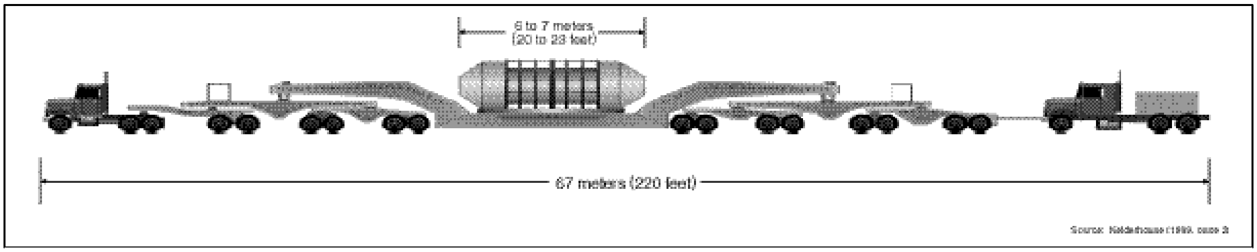


Figure 2-32. Conceptual diagram of intermodal transfer station layout.

The station would accept railcars as they arrived (24 hours a day, 7 days a week), but it would normally dispatch heavy-haul trucks during early morning daylight hours on weekdays, consistent with current Nevada heavy-haul shipment regulations.

At the completion of the 24 years of shipping, the intermodal transfer station would be decommissioned and, if possible, reused.

2.1.3.3.3.2 Highway Routes for Heavy-Haul Shipments. Figure 2-33 is an illustration of a heavy-haul truck that DOE could use to transport spent nuclear fuel and high-level radioactive waste to the repository. The heavy-haul truck would weigh about 91,000 kilograms (200,000 pounds) unloaded and would be up to 67 meters (220 feet) long. It would be custom-built for repository shipments. Average trip speeds would be 32 to 48 kilometers (20 to 30 miles) per hour.



Source: [illegible] (1999, page 3)

Figure 2-33. Artist’s conception of a heavy-haul truck carrying a rail shipping cask.

Heavy-haul truck shipments from an intermodal transfer station to the repository would comply with U.S. Department of Transportation requirements for shipments of highway route-controlled quantities of radioactive materials (49 CFR Part 177) and with State of Nevada permit requirements for heavy-haul shipments. Nevada permits heavy-haul shipments on Monday through Friday (excluding holidays) but only in daylight hours.

Road upgrades for candidate routes, if necessary, would involve four kinds of construction activities: (1) widening the shoulders and constructing turnouts and truck lanes, (2) upgrading intersections that are inadequate for heavy-haul truck traffic, (3) increasing the asphalt thickness (overlay) of some sections, and (4) upgrading engineered structures such as culverts and bridges. The overlay work would include upgrades needed to remove frost restrictions from some road sections.

Shoulder widening and the construction of turnouts and truck lanes would occur as needed along the side of the existing pavement. Shoulders would be widened from 0.33 or 0.66 meter (1 or 2 feet) to 1.2 meters (4 feet). Widening would build the existing shoulder up to pavement height. Truck lanes would be built on roadways with grades exceeding 4 percent. Turnout lanes would be built approximately every 8 to 32 kilometers (5 to 20 miles) depending on projected traffic. The truck lanes and turnouts would require land clearing and soil excavation or fill to establish the roadway. Culverts under the roadway would be lengthened. Most borrow material for construction could come from existing Nevada Department of Transportation borrow areas, if the State agreed. Asphalt could be produced at a portable plant in the borrow areas. Appendix J contains descriptions of the specific highway improvements for the five routes.

The following paragraphs describe the potential highway routes for heavy-haul trucks DOE is considering for the intermodal transfer station location and unique operational considerations for each route.

- *Caliente Intermodal Transfer Station Highway Routes.* Heavy-haul trucks leaving the Caliente intermodal transfer station could travel on one of three potential routes: (1) Caliente, (2) Caliente-Chalk Mountain, and (3) Caliente-Las Vegas (see Figure 2-34).

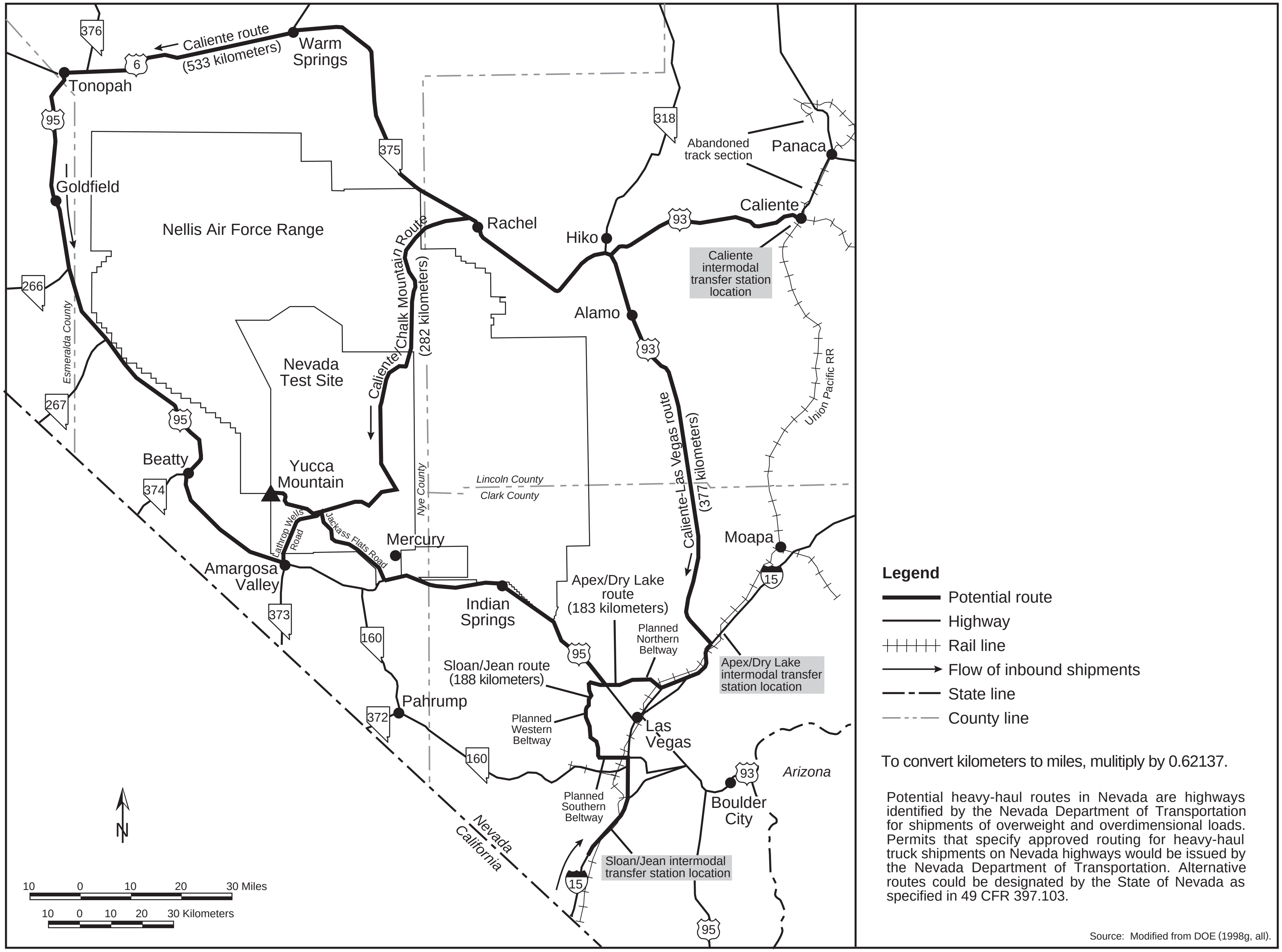
  The Caliente route would be approximately 533 kilometers (331 miles) long. Heavy-haul trucks leaving an intermodal transfer station in the Caliente area would travel directly from the station to U.S. Highway 93. The trucks would travel west on U.S. 93 to State Route 375, then on State Route 375 to the intersection with U.S. Highway 6. The trucks would continue on U.S. 6 to the intersection with U.S. 95 in Tonopah, then into Beatty on U.S. 95, where an alternate truck route would be built because the existing intersection is too constricted to allow a turn. Heavy-haul trucks would then travel south on U.S. 95 to the Lathrop Wells Road exit, which accesses the Yucca Mountain site. Because of the estimated travel time associated with the Caliente route and the restriction on nighttime travel for heavy-haul vehicles, DOE would construct a parking area along the route to enable these vehicles to park overnight. This parking area would be near the U.S. 6 and U.S. 95 interchange at Tonopah.

  The Caliente-Chalk Mountain route would be approximately 282 kilometers (175 miles) long. Heavy-haul trucks leaving an intermodal transfer station in the Caliente area would travel directly from the station to U.S. 93. The trucks would travel on U.S. 93 to State Route 375, on State Route 375 to Rachel, and head south through the Nellis Air Force Range to the Nevada Test Site.

  The Caliente-Las Vegas route would be approximately 377 kilometers (234 miles) long. Heavy-haul trucks leaving an intermodal transfer station in the Caliente area would travel directly from the station to U.S. 93. The trucks would travel south on U.S. 93 to the intersection with I-15, northeast of Las Vegas. The trucks would travel south on I-15 to the exit for the proposed northern Las Vegas Beltway, then would travel west on the beltway. They would leave the beltway at U.S. 95, and head north on U.S. 95 to the Nevada Test Site. The trucks would travel on Jackass Flats Road on the Nevada Test Site to the Yucca Mountain site.

- *Apex/Dry Lake Intermodal Transfer Station Highway Route.* Heavy-haul trucks would leave the intermodal transfer station at the Apex/Dry Lake location and enter I-15 at the Apex interchange. The trucks would travel south on I-15 to the exit to the proposed northern Las Vegas Beltway, and would travel west on the beltway. The trucks would leave the beltway at U.S. 95, and travel north on U.S. 95 to the Nevada Test Site. They would then travel on Jackass Flats Road on the Nevada Test Site to the Yucca Mountain site. This route is about 183 kilometers (114 miles) long (see Figure 2-34).

- *Sloan/Jean Intermodal Transfer Station Highway Route.* Heavy-haul trucks leaving a Sloan/Jean intermodal transfer station would enter I-15 at the Sloan interchange. The trucks would travel on I-15 to the exit to the southern portion of the proposed Las Vegas Beltway, and then travel northwest on the beltway. They would leave the beltway at U.S. 95, and travel to the Nevada Test Site. They would then travel on Jackass Flats Road to the Yucca Mountain site. This route would be approximately 188 kilometers (117 miles) long (see Figure 2-34).



To convert kilometers to miles, mulitiply by 0.62137.

Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. Permits that specify approved routing for heavy-haul truck shipments on Nevada highways would be issued by the Nevada Department of Transportation. Alternative routes could be designated by the State of Nevada as specified in 49 CFR 397.103.

Source: Modified from DOE (1998g, all).

Figure 2-34. Potential routes in Nevada for heavy-haul trucks.

2.1.3.4 Shipping Cask Manufacturing, Maintenance, and Disposal

To transport spent nuclear fuel and high-level radioactive waste to the repository, DOE would use existing or new shipping casks that met Nuclear Regulatory Commission regulations (10 CFR Part 71). One or more qualified companies that provide specialized metal structures, tanks, and other heavy equipment would manufacture new shipping casks. The number and type of shipping casks required would depend on the predominant mode of transportation.

DOE would remove casks from service periodically for maintenance and inspection. These activities would occur at a cask maintenance facility(s) where cask functions and components would be checked and inspected in compliance with Nuclear Regulatory Commission requirements and preventive maintenance procedures. The major operations involved in cask maintenance would include decontamination, replacement of limited-life components such as O-rings, and verification of radiation shielding integrity, structural integrity, and heat transfer efficiency.

The large number of repository shipments would require new facilities for cask maintenance. DOE has not decided where in the United States it would locate a cask maintenance facility(s), but this EIS assumes that such a facility would be at the repository inside the Restricted Area at the North Portal on approximately 0.01 square kilometer (2.5 acres). Minor cask maintenance activities could occur at commercial or DOE sites.

2.1.4 ALTERNATIVE DESIGN CONCEPTS AND DESIGN FEATURES

The EIS analyzed thermal load and packaging scenarios to identify the range of potential short- and long-term impacts of a repository at Yucca Mountain. This analysis used conceptual designs, which is typical for an EIS. However, the level of design is insufficient to meet information needs for a License Application to the Nuclear Regulatory Commission. Therefore, the repository design will continue to evolve through the submittal of the License Application.

As part of this evolving design process, DOE is evaluating various design features and alternatives. The purpose of the evaluation is to determine if these features and alternatives would reduce uncertainties in the long-term performance of the repository, reduce costs, or improve operations. Other construction materials could be evaluated in the future. The License Application Design Selection project is considering a variety of design alternatives and features, as described in Appendix E. In addition, DOE has made preliminary identification of five combinations of design features and alternatives, called Enhanced Design Alternatives, as part of this process (Table 2-4). The EIS analysis categorized the design features and alternatives into three groups, based on their primary function, which are intended to:

- Limit the release and transport of radionuclides
- Control the thermal/moisture environment in the repository
- Support operational and cost considerations

The following sections summarize the design approaches for the three groups DOE is considering within the scope of the design features and alternatives.

2.1.4.1 Design Features and Alternatives To Limit Release and Transport of Radionuclides

The features related to improving the barriers that limit the release and transport of radioactive material focus on two areas of the design. Some of the features focus on improvements in the long-term integrity

Table 2-4. Design features and alternatives used to form Enhanced Design Alternatives.

	Enhanced Design Alternative				
Category	I	II	III	IV	V
Barriers to limit release and transport of radionuclides					
Drip shields	X[a]	X	X	X	X
Backfill to protect waste package and drip shield from rockfall		X		X	
Waste package corrosion-resistant barrier	X	X	X		X
Additives and fillers				X	
Ground support options			X		
Repository design to control thermal/moisture environment					
Low thermal alternative evaluation	X	X			
Aging and blending of waste	X	X			X
Continuous postclosure ventilation	X	X	X	X	X
Drift diameter	X				
Waste package spacing and drift spacing	X	X	X	X	X
Higher thermal load					X
Repository designs to support operational and cost considerations					
Enhanced access design	X	X	X	X	X
Timing of repository closure	X	X	X	X	X
Maintenance of underground design features and ground support			X		

a. X specifies what is used in each Enhanced Design Alternative.

of the waste packages; others focus on limiting the transport of radioactive material released from a waste package to the environment. Examples of designs include the following:

- Designs to improve the long-term integrity of waste packages, including coating the package with a ceramic or using multiple types of corrosion-resistant materials, which should directly reduce waste package failure due to corrosion.

- Designs to reduce the potential of structural damage to waste packages from rockfall, such as backfilling the drifts or providing mechanical support to the drift wall (concrete or steel liner).

- Designs to limit the transport of radionuclides, including additives and fillers to the waste packages or getters under the waste packages; these substances would capture radionuclides chemically to limit transport.

Some features provide the potential to limit both the release and transport of radionuclides, and to modify the temperature environment. For instance, backfill could protect against the release and transport of contaminants by capturing corrosive salts in the water and retarding flow and by increasing the emplacement drift temperature to decrease the relative humidity. For convenience of presentation, each feature is listed in only one category.

2.1.4.2 Design Features and Alternatives To Control the Thermal/Moisture Environment in the Repository

Potentially the most effective repository design would provide an environment in the emplacement drifts that would accommodate the heat discharge from the waste packages, maintain the materials and contents of the packages at low temperatures, and maintain low ambient moisture. Several alternatives and features focus on these goals. An example of a design to control the repository drift environment would be continuous postclosure ventilation of the drifts to provide both heat and moisture removal.

Many designs use an integrated approach to control the drift environment. The high thermal load designs, for example, provide ambient temperatures above 100°C (212°F) through portions of the repository so moisture would vaporize and disperse. Designs involving the diameter and spacing of drifts and the loading of waste packages consider similar integrated effects to control the heat load. Some designs focus only on moisture control, such as those that involve surface modifications directly above the repository to retard or eliminate any infiltration of moisture.

2.1.4.3 Design Features and Alternatives To Support Operational and Cost Considerations

In general, these design features and alternatives focus on repository operation and cost, so they would not usually affect long-term (postclosure) performance but could have short-term (preclosure) impacts. Designs to enhance access to the drifts and to facilitate performance monitoring incorporate approaches that would reduce occupational exposure. Modular design and phased construction would result in slightly increased short-term impacts but would accommodate incremental funding of repository construction.

The final design of the repository is likely to evolve from the current design (as described in Section 2.1 and analyzed in this EIS), combinations of the design features and alternatives, and other design concepts that evolve from the DOE License Application Design Selection process (that is, Enhanced Design Alternatives). The identification and evolution of the features and alternatives was underway as DOE was preparing the Draft EIS. The evolution of the repository design is likely to incorporate some of the features and alternatives discussed in this section and Appendix E. After incorporating modifications in the design, DOE will evaluate the environmental impacts associated with the updated design in the Final EIS.

The design features and alternatives are functionally equivalent to potential mitigation measures because they have the potential to improve long-term (postclosure) performance (that is, they would reduce risk), reduce operational impacts, or reduce costs. Chapter 9 summarizes the mitigation aspects of these design features and alternatives and Appendix E describes them more fully. However, there are tradeoffs associated with many of these features and alternatives that could have negative short-term (preclosure) or long-term impacts that could be greater than the impacts associated with the basic design under the thermal load and packaging scenarios evaluated as part of the Proposed Action. Appendix E contains qualitative descriptions of the features and alternatives, including the reasons for their consideration (potential benefits) and potential negative environmental considerations.

2.1.5 ESTIMATED COSTS ASSOCIATED WITH THE PROPOSED ACTION

DOE has estimated the total cost of the Proposed Action to construct, operate and monitor, and close a geologic repository at Yucca Mountain, including the transportation of spent nuclear fuel and high-level radioactive waste to the repository (TRW 1999e, all). The estimate is based on acceptance and disposal of about 63,000 MTHM of commercial spent nuclear fuel, 2,333 MTHM of DOE spent nuclear fuel, and 8,315 canisters of solidified high-level radioactive waste (4,667 MTHM). Table 2-5 lists the estimated costs. The costs would total about $29 billion. This is representative and would vary

Table 2-5. Proposed Action costs.[a,b]

Description	Costs
Monitored geologic repository	$18.7
Waste acceptance, storage, and transportation	4.5
Nevada transportation	0.8
Program integration	2.1
Institutional	2.7
Total	**$28.8**

a. Source: TRW (1999e, all).

b. Adjusted to constant 1998 dollars, in billions.

somewhat, depending on the thermal load, packaging, and transportation scenarios and on the Nevada transportation implementing alternative selected.

2.2 No-Action Alternative

This section describes the No-Action Alternative, which provides a baseline for comparison with the Proposed Action. Under the No-Action Alternative and consistent with the Nuclear Waste Policy Act, as amended [Section 113(c)(3) (the EIS refers to the amended Act as the NWPA)], DOE would end site characterization activities at Yucca Mountain and undertake site reclamation to mitigate adverse environmental impacts from characterization activities. Commercial nuclear power utilities and DOE would continue to manage spent nuclear fuel and high-level radioactive waste at 77 sites in the United States (see Figure 2-35).

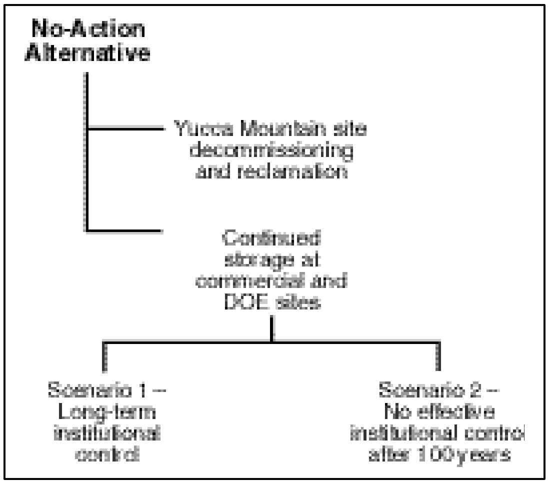


Figure 2-35. No-Action Alternative activities and analytical scenarios.

Under the NWPA, if DOE decided not to proceed with the development of a repository at Yucca Mountain, it would prepare a report to Congress with its recommendations for further action to ensure the safe permanent disposal of spent nuclear fuel and high-level radioactive waste, including the need for new legislative authority. Furthermore, DOE intends to comply with the terms of existing consent orders and compliance agreements regarding the management of spent nuclear fuel and high-level radioactive waste. However, the future course that Congress, DOE, and the commercial nuclear power utilities would take if Yucca Mountain were not recommended as a repository remains uncertain. A number of possibilities could be pursued, including continued storage of the material at its current locations or at one or more centralized location(s); the study and selection of another location for a deep geologic repository (Chapter 1 discusses alternative sites previously selected by DOE for technical study); development of new technologies (for example, transmutation); or reconsideration of other disposal alternatives to deep geologic disposal (Section 2.3.1 discusses other disposal options previously evaluated by DOE). The environmental considerations related to continued storage at current locations or at one or more centralized location(s) have been analyzed in other contexts for both commercial and DOE spent nuclear fuel and high-level radioactive waste in several documents (see Chapter 7, Table 7-1 for a description of representative studies). Under any future course that would include continued storage, both commercial and DOE sites would have an obligation to continue managing spent nuclear fuel and high-level radioactive waste in a manner that protected public health and safety and the environment.

In light of the uncertainties described above, DOE decided to illustrate one set of possibilities by focusing its analysis of the No-Action Alternative on the potential impacts of two scenarios:

- Long-term storage of spent nuclear fuel and high-level radioactive waste at the current storage sites with effective institutional control for at least 10,000 years (Scenario 1)

- Long-term storage at the current storage sites with no effective institutional control after approximately 100 years (Scenario 2)

DOE recognizes that neither of these scenarios is likely to occur in the event there is a decision not to develop a repository at Yucca Mountain. However, these two scenarios were chosen for analysis because they provide a baseline for comparison to the impacts from the Proposed Action and they reflect a range of the impacts that could occur. Scenario 1, which includes an analysis of impacts under effective institutional controls for at least 10,000 years, is consistent with the portion of the analysis of the Proposed Action that includes an analysis of effective institutional controls for the first 100 years after closure. Scenario 2, in which the analyses do not consider institutional controls after approximately 100 years, is consistent with the portion of the analysis of the Proposed Action in which long-term performance after 100 years also does not include institutional controls.

The following sections describe expected Yucca Mountain site decommissioning and reclamation activities (Section 2.2.1), and further describe the scenarios for continued spent nuclear fuel and high-level radioactive waste management at the commercial and DOE sites (Section 2.2.2). Chapter 7 describes the potential environmental impacts of the No-Action Alternative.

2.2.1 YUCCA MOUNTAIN SITE DECOMMISSIONING AND RECLAMATION

Under the No-Action Alternative, site characterization activities would end at Yucca Mountain and decommissioning and reclamation would begin as soon as practicable and could take several years to complete. Decommissioning and reclamation would include removing or shutting down surface and subsurface facilities, and restoring lands disturbed during site characterization.

INSTITUTIONAL CONTROL

Monitoring and maintenance of storage facilities to ensure that radiological releases to the environment and radiation doses to workers and the public remain within Federal limits and DOE Order requirements.

Portable and prefabricated buildings would be emptied of their contents, dismantled, and removed from the site. Other facilities could be shut down without being removed from the site. DOE would remove and salvage such equipment as electric generators and tunneling, ventilation, meteorological, and communications equipment. Foundations and similar materials would remain in place.

DOE would remove equipment and materials from the underground drifts and test rooms. Horizontal and vertical drill holes extending from the subsurface would be sealed. Subsurface drifts and rooms would not be backfilled, but would be left with the concrete inverts in place. The North and South Portals would be gated to prohibit entry to the subsurface.

Excavated rock piles would be stabilized. Topsoil previously removed from the excavated rock pile area and stored in a stockpile would be returned and the areas would be revegetated. Areas disturbed by surface studies (drilling, trenching, fault mapping) or used during site characterization (borrow areas, laydown pads, etc.) would be restored. Fluid impoundments (mud pits, evaporation ponds) would be backfilled or capped as appropriate and reclaimed. Access roads throughout the site (paved or graveled) and parking areas would be left in place and would not be restored.

2.2.2 CONTINUED STORAGE OF SPENT NUCLEAR FUEL AND HIGH-LEVEL RADIOACTIVE WASTE AT COMMERCIAL AND DOE SITES

Under the No-Action Alternative, spent nuclear fuel and high-level radioactive waste would be managed at the 72 commercial and 5 DOE sites (the Hanford Site, the Idaho National Engineering and Environmental Laboratory, the Savannah River Site, Fort St. Vrain, and the West Valley Demonstration Project) (see Figure 1-1). The No-Action Alternative assumes that the spent nuclear fuel and high-level radioactive waste would be treated, packaged, and stored. The amount of spent nuclear fuel and high-level radioactive waste considered in this analysis is the same as that in the Proposed Action—70,000 MTHM, including 63,000 MTHM of commercial spent nuclear fuel, 2,333 MTHM of DOE spent nuclear fuel, and 8,315 canisters of solidified high-level radioactive waste (4,667 MTHM). This EIS assumes that the No-Action Alternative would start in 2002.

2.2.2.1 Storage Packages and Facilities at Commercial and DOE Sites

A number of designs for storage packages and facilities at the commercial and DOE sites would provide adequate protection to the environment from spent nuclear fuel and high-level radioactive waste. Because specific designs have not been identified for most locations, DOE selected a representative range of commercial and DOE designs for analysis as described in the following paragraphs.

Spent Nuclear Fuel Storage Facilities

Most commercial nuclear utilities currently store their spent nuclear fuel in water-filled basins (fuel pools) at the reactor site. Some utilities have built *independent spent fuel storage installations* in which they store spent nuclear fuel dry, above ground, in metal casks or in weld-sealed canisters inside reinforced concrete storage modules. Some utilities are planning to build independent spent fuel storage installations so they can proceed with decommissioning their nuclear plants and terminating their operating licenses (for example, the Rancho Seco and Trojan plants). Because utilities could elect to continue operations until their fuel pools are full and then cease operations, the EIS analysis originally considered ongoing wet storage in existing fuel pools to be a potentially viable option for spent nuclear fuel storage. However, dry storage is the preferred option for long-term spent nuclear fuel storage at commercial sites for the following reasons (NRC 1996, pages 6-76 and 6-85):

- Dry storage is a safe economical method of storage.
- Fuel rods in dry storage are likely to be environmentally secure for long periods.
- Dry storage generates minimal, if any, amounts of low-level radioactive waste.
- Dry storage units are simpler and easier to maintain.

Accordingly, this EIS assumes that all commercial spent nuclear fuel would be in dry storage at independent spent fuel storage installations at existing locations. This includes spent nuclear fuel at sites that no longer have operating nuclear reactors. Figure 2-36 shows a photograph of the independent spent fuel storage installation at the Calvert Cliffs commercial nuclear site. Although most utilities and DOE have not constructed independent spent fuel storage installations or designed dry storage containers, this analysis evaluated the impacts of storing all commercial and most DOE spent nuclear fuel in horizontal concrete storage modules (see Figure 2-37) on a concrete pad at the ground surface. Concrete storage modules have openings that allow outside air to circulate and remove the heat of radioactive decay. The analysis assumed that both pressurized-water reactor and boiling-water reactor spent nuclear fuel would have been loaded into a dry storage canister that would be placed inside the concrete storage module. Figure 2-38 shows a typical dry storage canister, which would consist of a stainless-steel outer shell, welded end plugs, pressurized helium internal environment, and criticality-safe geometry for 24 pressurized-water or 52 boiling-water reactor fuel assemblies.

The combination of the dry storage canister and the concrete storage module would provide safe storage of spent nuclear fuel as long as the fuel and storage facilities were properly maintained. The reinforced concrete storage module would provide shielding against the radiation emitted by the spent nuclear fuel. The concrete storage module would also provide protection from damage from such occurrences as aircraft crashes, earthquakes, and tornadoes.

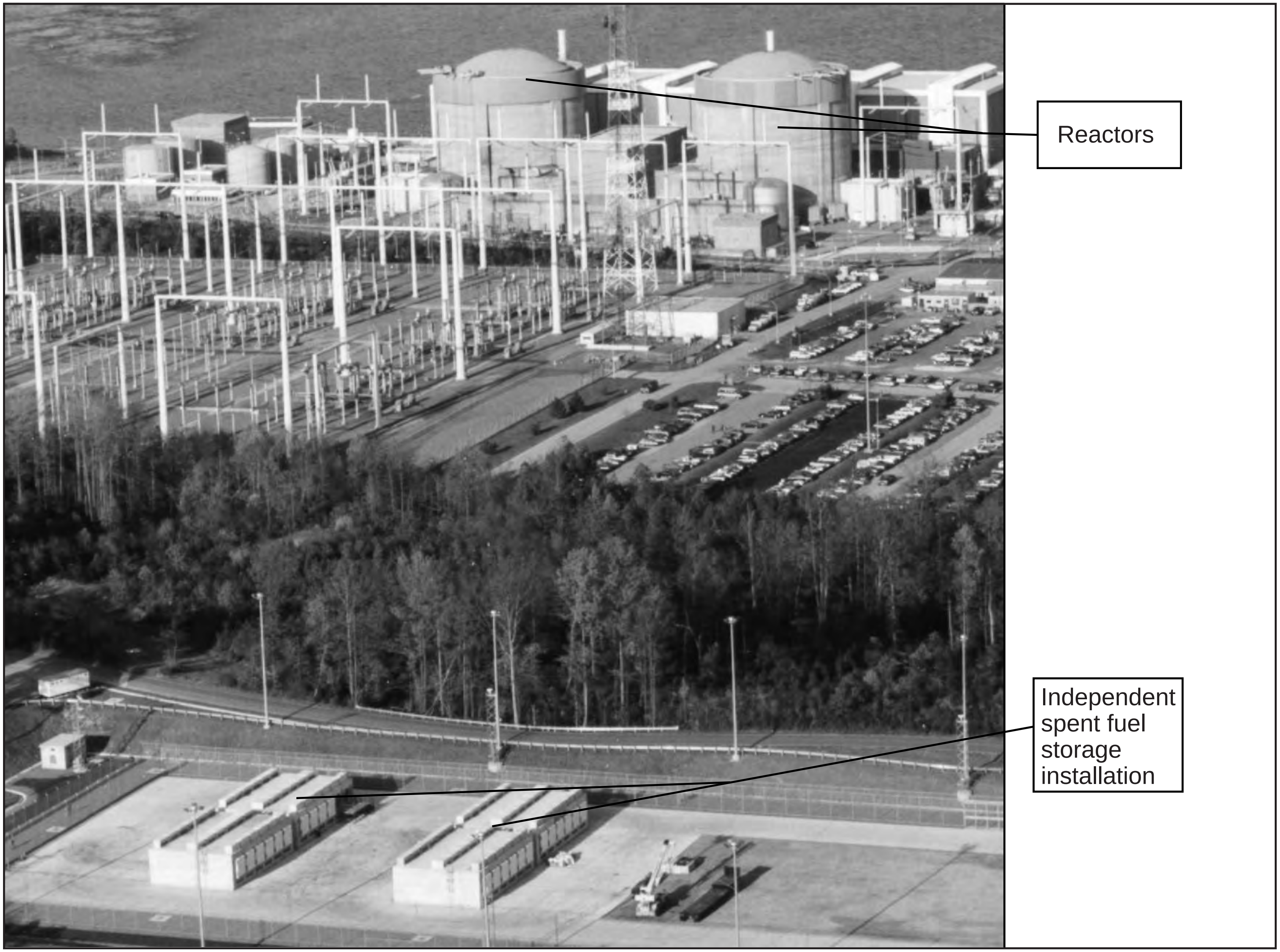
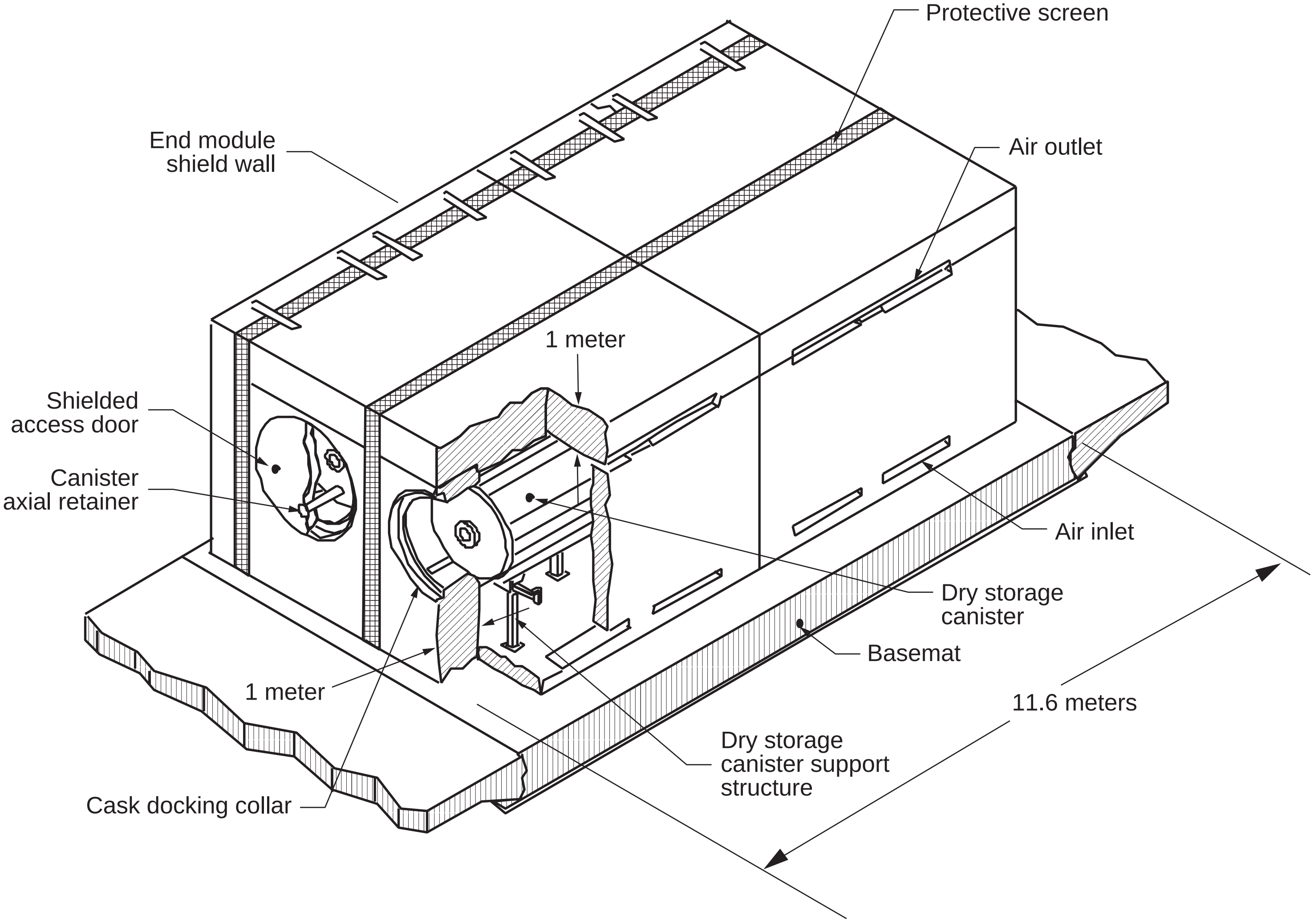


Figure 2-36. Calvert Cliffs independent spent fuel storage installation and reactors.

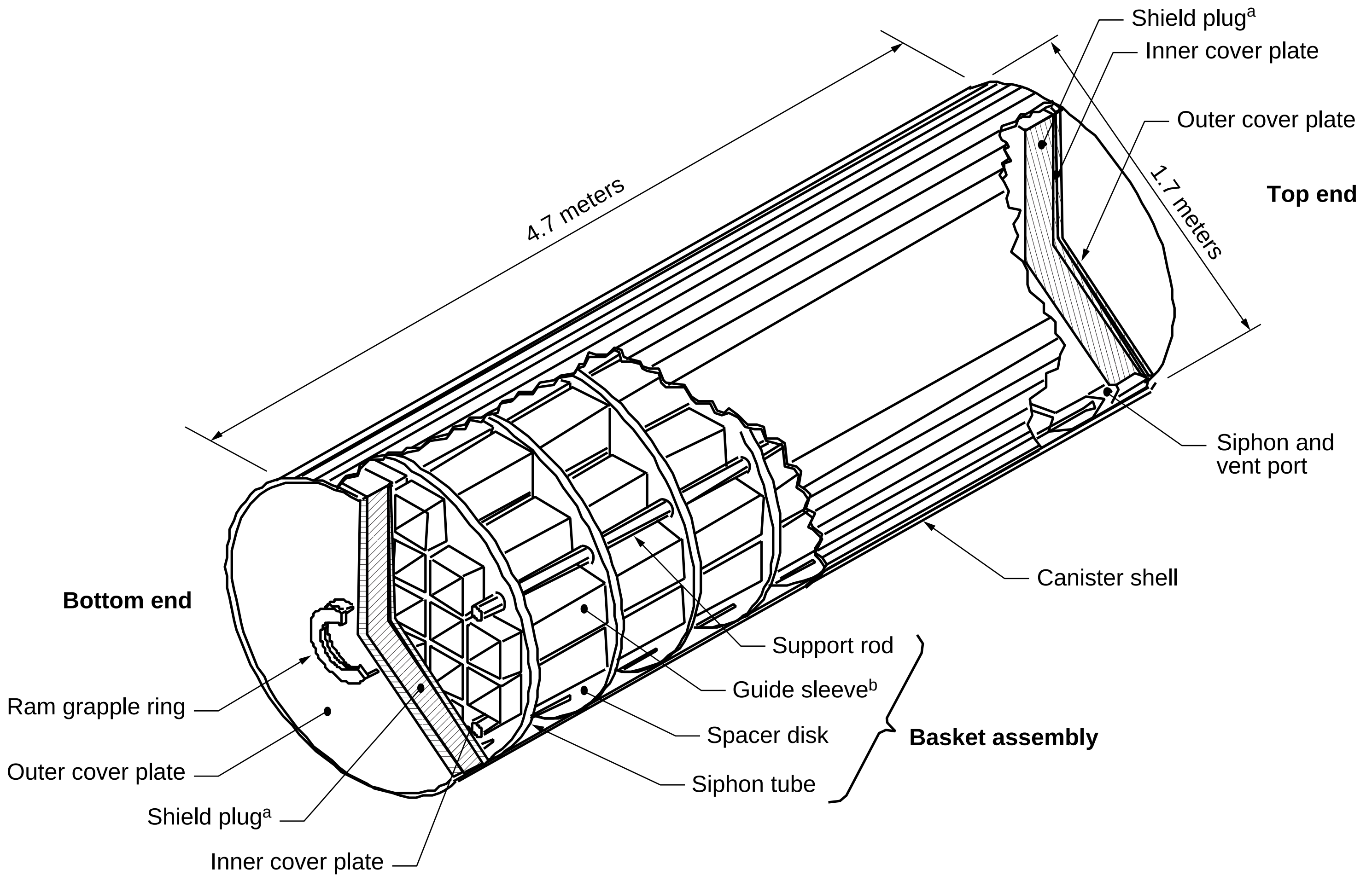


To convert meters to feet, multiply by 3.2808.

Note: Arrangement shown is a row of two storage modules with two canisters in each module.

Source: Modified from Poe (1998a, page 1-2).

Figure 2-37. Spent nuclear fuel concrete storage module.



All materials 304 stainless steel except as noted.

a. Shield plug would be lead.

b. Borated neutron absorber plate
for boiling-water reactor spent nuclear fuel assemblies.

To convert meters to feet, multiply by 3.2808.

Source: Modified from Poe (1998a, page 1-5).

Figure 2-38. Spent nuclear fuel dry storage canister.

This analysis assumed that DOE spent nuclear fuel at the Savannah River Site, Idaho National Engineering and Environmental Laboratory, and Fort St. Vrain would be stored dry, above ground in stainless-steel canisters inside concrete casks. In addition, it assumed that the design of DOE above-ground spent nuclear fuel storage facilities would be similar to the independent spent fuel storage installations at commercial nuclear sites.

The analysis assumed that DOE spent nuclear fuel at Hanford would be stored dry in below-grade storage facilities. The Hanford N-Reactor fuel would be stored in the Canister Storage Building, which would consist of three below-grade concrete vaults with air plenums for natural convective cooling. Storage tubes of carbon steel would be installed vertically in the vaults. Each storage tube, which would be able to accommodate two spent nuclear fuel canisters, would be closed and sealed with a shield plug. The vaults would be covered by a structural steel shelter.

High-Level Radioactive Waste Storage Facilities

With one exception, this analysis assumed that high-level radioactive waste would be stored in a below-grade solidified high-level radioactive waste storage facility (Figure 2-39). At the West Valley Demonstration Project, it was assumed that DOE would use a dry storage system similar to a commercial spent nuclear fuel storage installation for high-level radioactive waste storage.

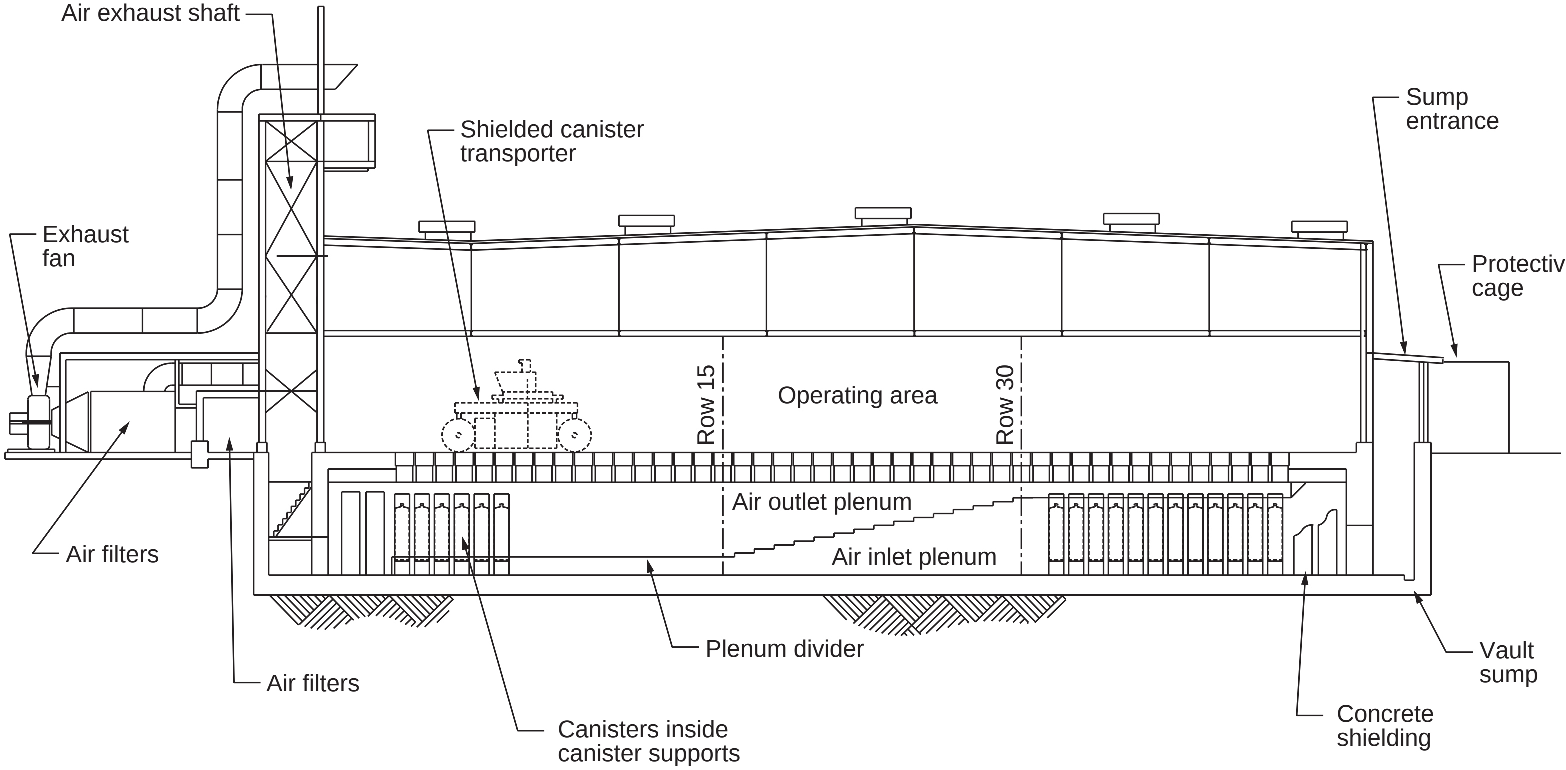
The high-level radioactive waste storage facility has four areas: below-grade storage vaults, an operating area above the vaults, air inlet shafts, and air exhaust shafts. The canister cavities are galvanized-steel large-diameter pipe sections arranged in a grid. Canister casings are supported by a concrete base mat. Space between the pipes is filled with overlapping horizontally stepped steel plates that direct most of the ventilation air through the storage cavities.

The below-grade storage vault would be below the operating floor, which would be slightly above grade. The storage vault would be designed to withstand earthquakes and tornadoes. In addition, the operating area would be enclosed by a metal building, which would provide weather protection and prevent the infiltration of precipitation. The storage vault would be designed to store the canisters and protect the operating personnel, the public, and the environment as long as the facilities were maintained. Radiation shielding would be provided by the surrounding earth, concrete walls, and a concrete deck that would form the floor of the operating area. Canister cavities would have individual precast concrete plugs.

Each vault would have an air inlet, air exhaust, and air passage cells. The heat of radioactive decay would be removed from around the canisters by the facility’s forced air exhaust system. The exhaust air could be filtered with high-efficiency particulate air filters before it was discharged to the atmosphere through a stack, or natural convection cooling could be used with no filter. The oversize diameter of the pipe storage cavities would allow air passage around each cavity.

2.2.2.2 No-Action Scenario 1

In No-Action Scenario 1, DOE would continue to manage its spent nuclear fuel and high-level radioactive waste in above- or below-grade dry storage facilities at five sites around the country. Commercial utilities would continue to manage their spent nuclear fuel at 72 sites. The commercial and DOE sites would remain under effective institutional control for at least 10,000 years. Under institutional control, these facilities would be maintained to ensure that workers and the public were protected adequately in accordance with current Federal regulations (10 CFR Parts 20 and 835) and the requirements in DOE Order 5400.5, *Radiation Protection of the Public and the Environment*. DOE based the 10,000-year analysis period on the generally applicable Environmental Protection Agency regulation for the disposal of spent nuclear fuel and high-level radioactive waste (40 CFR Part 191), even though the regulation would not apply to disposal at Yucca Mountain.



Source: Derived from Poe (1998a, pages 4-7, 4-8, and 4-11).

Figure 2-39. Conceptual design for solidified high-level radioactive waste storage facility.

Under Scenario 1, the storage facilities would be completely replaced every 100 years. They would undergo one major repair during the first 100 years, because this scenario assumes that the design of the first storage facilities at a site would include a facility life of less than 100 years. The 100-year lifespan of future storage facilities is based on analysis of concrete degradation and failure in regions throughout the United States (Poe 1998a, all). The facility replacement period of 100 years represents the assumed useful lifetime of the structures. Replacement facilities would be built on land adjacent to the existing facilities. After the spent nuclear fuel and high-level radioactive waste had been transferred to the replacement facility, the older facility would be demolished and the land prepared for the next replacement facility, thereby minimizing land-use impacts. The top portion of Figure 2-40 shows the conceptual timeline for activities at the storage facilities for Scenario 1. Only the relative periods shown on this figure, not the exact dates, are important to the analysis.

2.2.2.3 No-Action Scenario 2

In No-Action Scenario 2, spent nuclear fuel and high-level radioactive waste would remain in dry storage at commercial and DOE sites and would be under effective institutional control for approximately 100 years (the same as Scenario 1). Beyond that time, the scenario assumes no effective institutional control. Therefore, after about 100 years and up to 10,000 years, the analysis assumed that the spent nuclear fuel and high-level radioactive waste storage facilities at 72 commercial and 5 DOE sites would begin to deteriorate and that the radioactive materials in them could eventually be released to the environment. DOE based the choice of 100 years on a review of generally applicable Environmental Protection Agency regulations for the disposal of spent nuclear fuel and high-level radioactive waste (40 CFR Part 191, Subpart B), Nuclear Regulatory Commission regulations for the disposal of low-level radioactive material (10 CFR Part 61), and a National Research Council report on standards for the proposed Yucca Mountain Repository that generally discounts the consideration of institutional control for longer periods in performance assessments for geologic repositories (National Research Council 1995, Chapter 4). The lower portion of Figure 2-40 shows the conceptual timeline for activities at the storage facilities for Scenario 2.

2.2.3 NO-ACTION ALTERNATIVE COSTS

The total estimated cost of the No-Action Alternative includes costs for the decommissioning and reclamation of the Yucca Mountain site, and for the storage of spent nuclear fuel at 72 commercial sites (63,000 MTHM), storage of DOE spent nuclear fuel (2,333 MTHM) at 4 sites (there would be no spent nuclear fuel at the West Valley Demonstration Project), and storage of solidified high-level radioactive waste (8,315 canisters) at 4 sites (there is no high-level radioactive waste at Fort St. Vrain). As listed in Table 2-6, the estimated cost of both Scenarios 1 and 2 for the first 100 years ranges from $51.5 billion to $56.7 billion, depending on whether the dry storage canisters have to be replaced every 100 years. The estimated cost for the remaining 9,900 years of Scenario 1 ranges from $480 million to $529 million per year. There are no costs for Scenario 2 after the first 100 years because the scenario assumes no effective institutional control.

2.3 Alternatives Considered but Eliminated from Detailed Study

This section addresses alternatives that DOE considered but eliminated from detailed study in this EIS. These include alternatives that the NWPA states this EIS need not consider (Section 2.3.1); design alternatives that DOE considered but eliminated during the evolution of the repository design analyzed in this EIS (Section 2.3.2); and alternative rail corridors and highway routes for heavy-haul trucks and associated intermodal transfer station locations that DOE considered but eliminated during the transportation studies that identified the 10 Nevada implementing rail and intermodal alternatives analyzed in this EIS (Section 2.3.3).

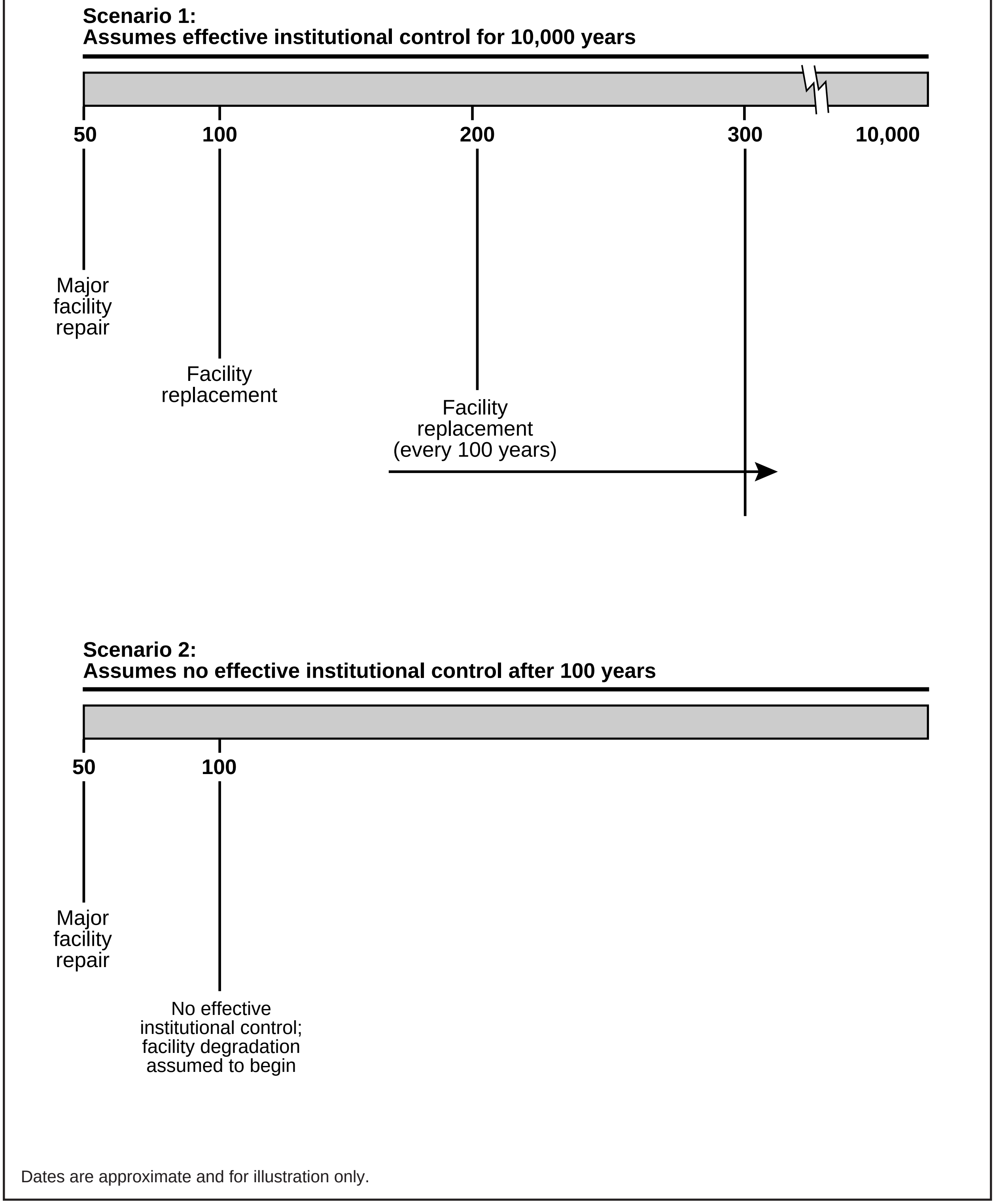


Figure 2-40. Facility timeline assumptions for No-Action Scenarios 1 and 2.

Table 2-6. No-Action Alternative life-cycle costs (in billions of 1998 dollars).[a]

Factor	First 100 years Scenarios 1 and 2[b]	Remaining 9,900 years (per year) Scenario 1[b,c]	Remaining 9,900 years (per year) Scenario 2[d]
72 commercial sites (63,000 MTHM)	$40.3 - 45.5	$0.376 - 0.425	$0
DOE spent nuclear fuel storage sites (2,333 MTHM)	7.4	0.069	0
High-level radioactive waste storage sites (8,315 canisters)	3.8	0.035	0
Decommissioning and reclamation of the Yucca Mountain site	(e)	NA[f]	0
Totals	**$51.5 - 56.7**	**$0.480 - 0.529**	**$0**

a. Source: TRW (1999e, all).

b. The range of costs for commercial sites is based on the assumption that the spent nuclear fuel would either be placed in dry storage canisters that would not need to be replaced over the 10,000-year period (low cost) or would have to be placed in new dry storage canisters every 100 years (high cost).

c. Stewardship costs are expressed in average annual disbursement costs (constant year 1998 dollars) only.

d. Costs are not applicable.

e. The costs for decommissioning and reclamation of the Yucca Mountain site would contribute less than 0.1 percent to the total life-cycle cost of continued storage.

f. NA = not applicable.

2.3.1 ALTERNATIVES ADDRESSED UNDER THE NUCLEAR WASTE POLICY ACT

The NWPA states that, with respect to the requirements imposed by the National Environmental Policy Act, compliance with the procedures and requirements of the NWPA shall be deemed adequate consideration of the need for a repository, the time of the initial availability of a repository, and all alternatives to the isolation of spent nuclear fuel and high-level radioactive waste in a repository [Section 114(f)(2)]. The geologic disposal of radioactive waste has been the focus of scientific research for more than 40 years. Starting in the 1950s, the Atomic Energy Commission and the Energy Research and Development Administration (both predecessor agencies to DOE) investigated different geologic formations as potential hosts for repositories and considered different disposal concepts, including deep-seabed disposal, disposal in the polar ice sheets, and rocketing waste into the sun. After extensive discussion of the options in an EIS (DOE 1980, all), DOE decided in 1981 to pursue disposal in an underground mined geologic repository (46 *FR* 26677, May 14, 1981). A panel of the National Academy of Sciences noted in 1990 that there is a worldwide scientific consensus that deep geologic disposal, the approach being followed by the United States, is the best option for disposing of high-level radioactive waste (National Research Council 1990, all).

Chapter 1 of this EIS summarizes the process that led to the 1987 amendments to the Nuclear Waste Policy Act of 1982, in which Congress directed DOE to study only Yucca Mountain to determine if it is suitable for a repository. Consistent with this approach, the NWPA states that, for purposes of complying with the requirements of the National Environmental Policy Act, DOE need not consider alternative sites to Yucca Mountain for the repository [Section 114(f)(3)].

Under the Proposed Action, this EIS does not consider alternatives for the emplacement of more than 70,000 MTHM of spent nuclear fuel and high-level radioactive waste in a repository at Yucca Mountain because the NWPA prohibits the Nuclear Regulatory Commission from approving the emplacement in the first repository of a quantity of spent nuclear fuel containing more than 70,000 MTHM or a quantity of solidified high-level radioactive waste resulting from the reprocessing of such a quantity of spent nuclear fuel until a second repository is in operation [Section 114(d)]. However, Chapter 8 of this EIS analyzes the cumulative impacts from the disposal of all projected spent nuclear fuel and high-level radioactive waste, as well as Greater-Than-Class-C waste and Special-Performance-Assessment-Required waste in the proposed Yucca Mountain Repository.

2.3.2 REPOSITORY DESIGN ALTERNATIVES ELIMINATED FROM DETAILED STUDY

The preliminary design concept for the proposed Yucca Mountain Repository analyzed in this EIS is the result of a design process that began with early site characterization activities. The design process identified design alternatives (options) that DOE considered. Some of the design options were eliminated from further detailed study during the design evolution. Examples include placement of the emplacement drifts in the saturated zone (rather than the unsaturated zone); vertical shafts (rather than the gently sloping North and South Ramps); use of drilling and blasting methods for emplacement drift construction (rather than mechanical excavation methods such as tunnel-boring machines); and use of diesel-powered vehicles for waste package emplacement (rather than electrically powered, rail-based vehicles).

DOE recently undertook a comprehensive review and examination of possible design options to provide information for use in support of the suitability recommendation and License Application. Appendix E discusses the design options that DOE considered in this review, and Section 2.1.1 discusses their consideration in this EIS.

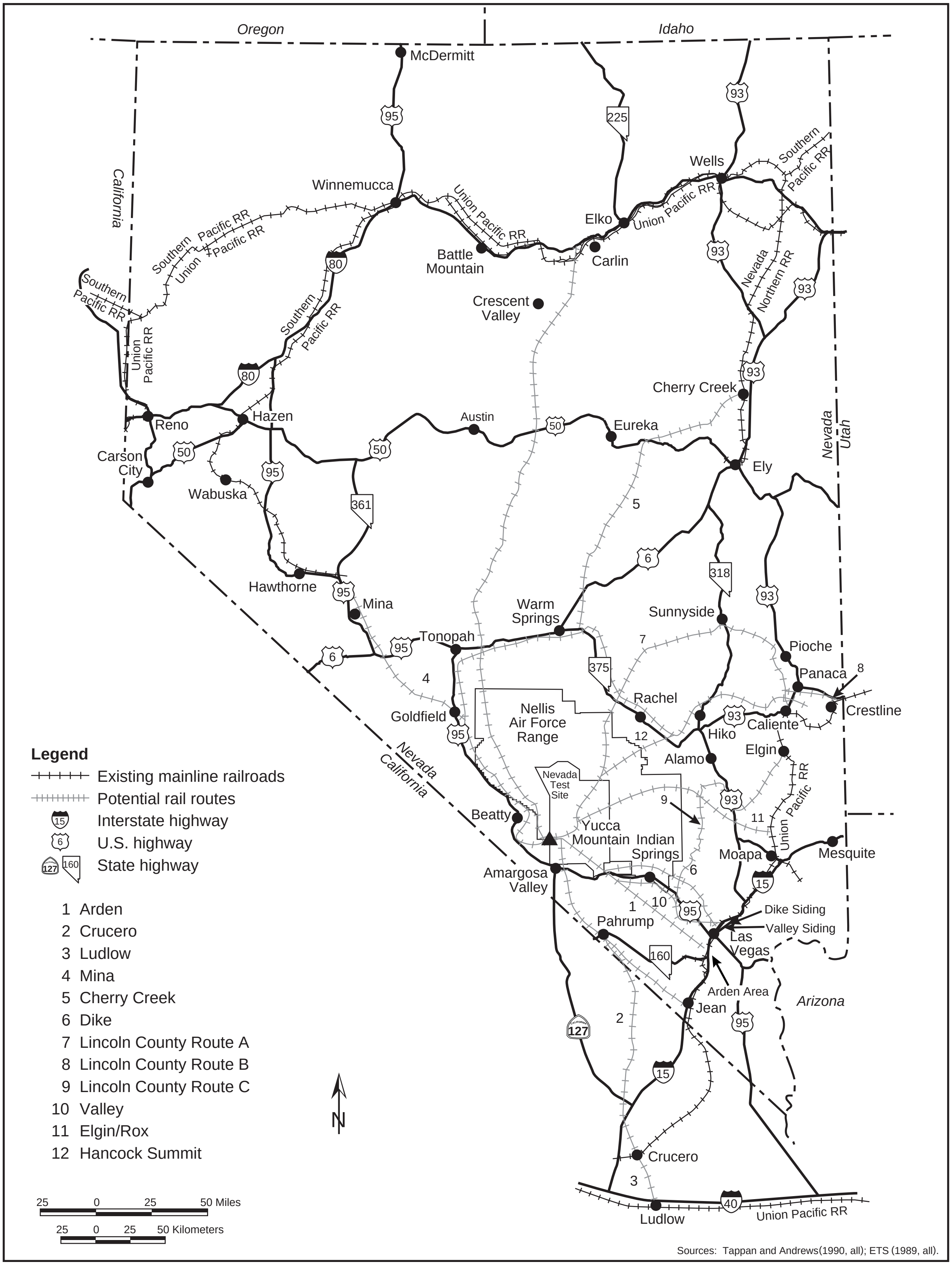
2.3.3 NEVADA TRANSPORTATION ALTERNATIVES ELIMINATED FROM DETAILED STUDY

Because rail access is not currently available to the Yucca Mountain site, DOE would have to build a branch rail line from an existing mainline railroad to the repository or transfer rail shipping casks to heavy-haul trucks at an intermodal transfer station to make effective use of rail transportation for shipping spent nuclear fuel and high-level radioactive waste to the repository. Section 2.1.3 describes the 10 implementing rail and intermodal alternatives for Nevada transportation that this EIS evaluates. DOE selected these implementing alternatives based on transportation studies that identified, evaluated, and eliminated other potential Nevada transportation rail and intermodal alternatives (Tappen and Andrews 1990, all; TRW 1995a, all; TRW 1996, all). This section identifies the potential rail and highway routes for heavy-haul trucks and associated intermodal transfer station locations that DOE considered but eliminated from further detailed study.

2.3.3.1 Potential Rail Routes Considered but Eliminated from Further Detailed Study

In the *Preliminary Rail Access Study* (Tappen and Andrews 1990, all), DOE identified 10 potential branch rail line routes to the Yucca Mountain site (Valley, Arden, Jean, Crucero, Ludlow, Mina, Caliente, Carlin, Cherry Creek, and Dike). Figure 2-41 shows these potential rail routes, each named for the area where it would connect to the mainline railroad. Alternatives within each route were developed wherever possible. The routes were chosen to maximize the use of Federal lands, provide access to regional rail carriers, avoid obvious land-use conflicts, and meet current railroad engineering practices. After the development of these rail routes, Lincoln County and the City of Caliente identified three additional routes (identified as Lincoln County Routes A, B, and C).

DOE evaluated these 13 potential rail routes in Tappen and Andrews (1990, all) and reevaluated them in the *Nevada Potential Repository Preliminary Transportation Strategy, Study 1* (TRW 1995a, all). One new route, Valley Modified, was added in the 1995 study based on updated information from the Bureau of Land Management on the status of two Wilderness Study Areas that represent possible land-use conflicts for the Valley route in the original evaluation. Three additional alignments—Caliente-Chalk Mountain, Elgin/Rox, and Hancock Summit—were evaluated in the Nevada Potential Repository Preliminary Assessment of the Caliente-Chalk Mountain Rail Corridor. The evaluations reviewed each potential rail corridor to identify land-use compatibility issues (the presence or absence of land-use conflicts, and the potential for mitigation of a conflict if one exists) and for access to regional rail carriers. The evaluations also compared other factors of the routes, including favorable topography (gently sloping rather than rugged terrain) and avoidance of lands withdrawn from public use by Federal action. Based



Sources: Tappan and Andrews(1990, all); ETS (1989, all).

Figure 2-41. Potential rail routes to Yucca Mountain, Nevada, considered but eliminated from detailed study.

on these evaluations, DOE eliminated the Valley, Arden, Crucero, Ludlow, Mina, Cherry Creek, Dike, Elgin/Rox, Hancock Summit, and Lincoln County A, B, and C rail routes from further study.

2.3.3.2 Potential Highway Routes for Heavy-Haul Trucks and Associated Intermodal Transfer Station Locations Considered but Eliminated from Further Detailed Study

DOE identified and evaluated potential highway routes for heavy-haul trucks from existing mainline railroads to the Yucca Mountain site (TRW 1995a, all; TRW 1996, all; TRW 1999d, all). The Department identified highway routes for heavy-haul trucks and associated intermodal transfer station locations to provide reasonable access to existing mainline railroads, to minimize transport length from an existing mainline rail interchange point, and to maximize the use of roads identified by the Nevada Department of Transportation for the highest allowable axle load limits. In addition to the five implementing intermodal alternatives selected for analysis in this EIS (see Section 2.1.3), Figure 2-42 shows highway routes for heavy-haul trucks and associated intermodal transfer station locations that DOE considered but eliminated from further detailed study. The eliminated alternatives include four routes named for the location of the intermodal transfer station—Apex, Arden, Baker, and Apex/Dry Lake (Las Vegas Bypass)—and three that are representative of routes from the northern Union Pacific mainline railroad (Northern Routes 1, 2, and 3).

DOE considered the development of new roads for dedicated heavy-haul truck shipments. The analysis assumed those routes would be within the corridors identified for potential rail routes, because the selection criteria for heavy-haul routes and rail routes (land-use compatibility issues, access to regional rail carriers, etc.) would be similar (TRW 1996, page 6-3). DOE also considered routes for heavy-haul trucks in the potential rail corridors that could use portions of the existing road system for part of the route length. DOE eliminated the development of a new road for heavy-haul trucks from further detailed evaluation, because the construction of a new branch rail line would be only slightly more expensive and transportation by rail would be safer (no intermodal transfers) and more efficient (TRW 1996, page 6-7).

2.4 Summary of Findings and Comparison of the Proposed Action and the No-Action Alternative

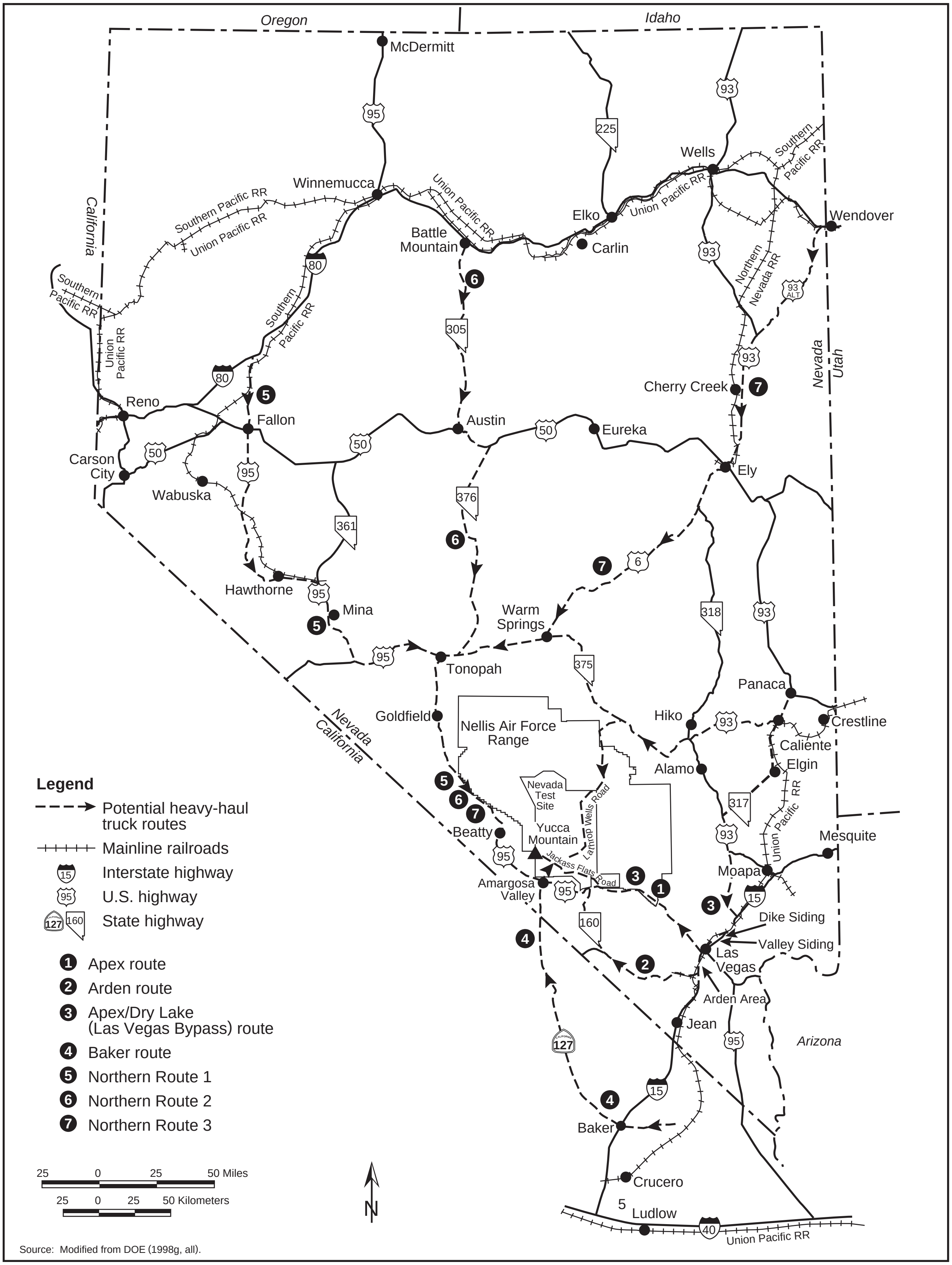
This section summarizes and compares the potential environmental impacts of the Proposed Action and the No-Action Alternative (Section 2.2). Detailed descriptions of the impact analyses are contained in the following chapters:

- Chapter 4 describes the short-term environmental impacts associated with construction, operation and monitoring, and closure of the repository and includes the manufacture of waste disposal containers and shipping casks.

- Chapter 5 describes long-term (postclosure) environmental impacts from the disposal of spent nuclear fuel and high-level radioactive waste in the repository.

- Chapter 6 describes the impacts associated with the transportation of spent nuclear fuel, high-level radioactive waste, other materials, and personnel to and from the repository.

- Chapter 7 describes the short-term and long-term impacts associated with the No-Action Alternative.



Source: Modified from DOE (1998g, all).

Figure 2-42. Potential highway routes for heavy-haul trucks to Yucca Mountain, Nevada, considered but eliminated from detailed study.

This EIS defines *short-term impacts* as those that would occur until and during the closure of the repository (approximately 100 years following the start of emplacement) and *long-term impacts* as those that would occur after repository closure (after 100 years) and for as long as 10,000 years.

This section summarizes the findings of the EIS analyses and contains a general comparison of the Proposed Action and No-Action Alternative (Section 2.4.1), potential short-term impacts (Section 2.4.2), long-term impacts (Section 2.4.3), and transportation impacts (Section 2.4.4).

2.4.1 PROPOSED ACTION AND NO-ACTION ALTERNATIVE

In general, the EIS analyses showed that the environmental impacts associated with the Proposed Action would be small, as described in Chapters 4, 5, 6, and 8. For some of the resource areas specifically analyzed in this study, there would be no impacts. Table 2-7 provides an overview approach to comparing the Proposed Action and the No-Action Alternative.

Although generally small, environmental impacts would occur under the Proposed Action. DOE would reduce or eliminate many such impacts with mitigation measures or implementation of standard Best Management Practices. Under the No-Action Alternative, the short-term impacts would be the same under Scenarios 1 or 2. Under Scenario 1, DOE would continue to manage spent nuclear fuel and high-level radioactive waste facilities at 5 DOE sites, and commercial utilities would continue to manage their spent nuclear fuel at 72 sites on a long-term basis and to isolate the material from human access with institutional control. Under Scenario 2, with the assumption of no effective institutional control after 100 years, the spent nuclear fuel and high-level radioactive waste storage facilities would begin to deteriorate and radioactive materials could escape to the environment, contaminating the local atmosphere, soils, surface water, and groundwater, thereby representing a considerable human health risk.

2.4.2 SHORT-TERM IMPACTS OF REPOSITORY CONSTRUCTION, OPERATION AND MONITORING, AND CLOSURE

DOE analyzed short-term impacts (about 100 years) for the Proposed Action and No-Action Alternative in various resource areas. The information presented in Table 2-7 shows that the short-term environmental impacts for the Proposed Action and the No-Action Alternative would generally be small and do not differentiate dramatically between the two alternatives. The analyses also included cost estimates for the two alternatives. Estimated short-term (to 100 years) costs for the Proposed Action would be about $29 billion, and those for the No-Action Alternative would be as much as $57 billion for the same period.

2.4.3 LONG-TERM IMPACTS OF THE PROPOSED ACTION AND THE NO-ACTION ALTERNATIVE

In addition to the short-term impacts described above, DOE assessed the impacts from radiological and nonradiological hazardous materials released over a much longer period (100 years to as long as 10,000 years) after the closure of the repository. Because these projections are based essentially on best available scientific techniques, DOE focused the assessment of long-term impacts on human health, biological resources, surface-water and groundwater resources, and other resource areas for which the analysis determined the information was particularly important and could establish estimates of impacts.

The EIS also examined possible biological impacts from the long-term production of heat by the radioactive materials disposed of in Yucca Mountain. Because there would be no repository activity after approximately 100 years, there would be no changes in land use, employment of workers, and use of water or utilities. The analysis determined that there would be no impacts to land use, noise, socioeconomic resources, cultural resources, surface-water resources, aesthetics, utilities, or site services

Table 2-7. Impacts associated with the Proposed Action and No-Action Alternative (page 1 of 4).

	Proposed Action			No-Action Alternative		
	Short-term (through closure, about 100 years)		Long-term (after closure, about 100 to 10,000 years)	Short -term	Long-term (100 to 10,000 years)	
Resource area	Repository	Transportation		(100 years)	Scenario 1	Scenario 2
Land use and ownership	Withdraw about 600 km^{2}(a) of land now under Federal control; active use of about 3.5 km^{2}	0 to about 20 km^{2} of land disturbed for new transportation routes; Air Force identified conflicts for some routes; Valley Modified rail corridor would pass near the Las Vegas Paiute Indian Reservation; some rail corridors could overlap with potential Las Vegas growth; heavy-haul trucks could slow traffic flow; some heavy-haul routes would pass near or through the Moapa and Las Vegas Paiute Indian Reservations	Potential for limited access into the area; the only surface features remaining would be markers	Small; storage would continue at existing sites	Small; storage would continue at existing sites	Potential contamination of 0.04 to 0.4 km^{2} surrounding each of the 72 commercial and 5 DOE sites
Air quality	Releases and exposures well below regulatory limits (less than 5 percent of limits)	Releases and exposures below regulatory limits; pollutants from vehicle traffic and trains would be small in comparison to other national vehicle and train traffic	No air releases	Releases and exposures well below regulatory limits	Releases and exposures well below regulatory limits	Increases in airborne radiological releases and exposures (potentially exceeding current regulatory limits)
Hydrology (groundwater and surface water)	Water demand well below Nevada State Engineer's ruling on perennial yield (250 to 480 acre-feet[b] per year)	Withdrawal of up to 710 acre-feet[b] from multiple wells and hydrographic areas over 2.5 years	Low-level contamination of groundwater in Amargosa Valley after a few thousand years (estimated concentration would be below drinking water standards)	Small; usage would be small in comparison to other site use	Small; usage would be small in comparison to other site use	Potential for radiological contamination of groundwater around 72 commercial and 5 DOE sites
	Small; minor changes to runoff and infiltration rates; floodplain assessment concluded impacts would be small	Small; minor changes to runoff and infiltration rates; additional floodplain assessments would be performed in the future as necessary	Small; minor changes to runoff and infiltration rates	Small; minor changes to runoff and infiltration rates	Small; minor changes to runoff and infiltration rates	Potential for radiological releases and contamination of drainage basins downstream of 72 commercial and 5 DOE sites (concentrations potentially exceeding current regulatory limits)

Table 2-7. Impacts associated with the Proposed Action and No-Action Alternative (page 2 of 4).

	Proposed Action			No-Action Alternative		
	Short-term (through closure, about 100 years)		Long-term (after closure, about 100 to 10,000 years)	Short -term (100 years)	Long-term (100 to 10,000 years)	
Resource area	Repository	Transportation			Scenario 1	Scenario 2
Biological resources and soils	Loss of about 3.5 km^2 of desert soil, habitat, and vegetation; adverse impacts to threatened desert tortoise (individuals, not the species as a whole); reasonable and prudent measures to minimize impacts; impacts to other plants and animals and habitat small; wetlands assessment concluded impacts would be small	Loss of 0 to about 20 km^2 of desert soil, habitat, and vegetation for heavy-haul routes and rail corridors; adverse impacts to threatened desert tortoise (individuals, not the species as a whole); reasonable and prudent measures to minimize impacts; impacts to other plants and animals and habitat small; additional wetlands assessments would be performed in the future as necessary	Slight increase in temperature of surface soil directly over the repository for 10,000 years resulting in a potential temporary shift in plant and animal communities in this small area (about 8 km^2)	Small; storage would continue at existing sites	Small; storage would continue at existing sites	Potential adverse impacts at each of the 77 sites from subsurface contamination of 0.04 to 0.4 km^2
Cultural resources	Repository development would disturb about 3.5 km^2; damage to and illicit collecting at archaeological sites; programs in place to minimize impacts; opposing Native American viewpoint	Loss of 0 to about 20 km^2 of land disturbed for new transportation routes; damage to and illicit collecting at archaeological sites; programs in place to minimize impacts; opposing Native American viewpoint	Potential for limited access into the area; opposing Native American viewpoint	Small; storage would continue at existing sites; limited potential of disturbing sites	Small; storage would continue at existing sites; limited potential of disturbing sites	No construction or operation activities; no impacts
Socioeconomics	Estimated peak employment of 1,800 occurring in 2006 would result in less than a 1 percent increase in direct and indirect regional employment; therefore, impacts would be low	Employment increases would range from less than 1 percent to 5.7 percent (use of intermodal transfer station or rail line in Lincoln County, Nevada) of total employment by county; therefore, impacts would be low	No workers, no impacts	Small; population and employment changes would be small compared to totals in the regions	Small; population and employment changes would be small compared to totals in the regions	No workers; no impacts
Occupational and public health and safety						
Public						
Radiological (LCFs[c])						
MEI[c]	1.9×10^{-5} to 5.1×10^{-5}	1.6×10^{4} to 1.2×10^{3}	1.9×10^{8} to 4.4×10^{5}	4.3×10^{6}	1.3×10^{6}	(d)
Population	0.14 to 0.41	3 to 18	5.5×10^{-5} to 5.3×10^{4}	0.41	3	3,300[e]
Nonradiological	Exposures well below regulatory limits	Exposures below regulatory limits; pollutants from vehicle traffic and trains	Exposures well below regulatory limits or guidelines	Exposures well below regulatory limits or guidelines	Exposures well below regulatory limits or guidelines	Increases in releases of hazardous substances in the spent nuclear fuel and high-level radioactive waste and exposures to the public

Table 2-7. Impacts associated with the Proposed Action and No-Action Alternative (page 3 of 4).

	Proposed Action			No-Action Alternative		
	Short-term (through closure, about 100 years)		Long-term (after closure, about 100 to 10,000 years)	Short -term (100 years)	Long-term (100 to 10,000 years)	
Resource area	Repository	Transportation			Scenario 1	Scenario 2
Occupational and public health and safety (continued)						
Workers (involved and noninvolved)						
Radiological (LCFs)	3 to 4	3 to 11	No workers, no impacts	16	12	No workers, no impacts
Nonradiological fatalities (includes commuting traffic fatalities)	1 to 2	11 to 16[f]	No workers, no impacts	9	1,080	No workers, no impacts
Accidents						
Probability (frequency per year)	8.6×10^{-7} to 1.1×10^{-2}	1.4×10^{-7} to 1.9×10^{-7}	No credible accidents	3.2×10^{-6}	3.2×10^{-6}	3.2×10^{-6}
Public						
Radiological (LCFs)						
MEI	2.9×10^{-13} to 2.1×10^{-6}	0.002 to 0.013	Not applicable	No impacts	No impacts	Not applicable
Population	1.0×10^{-11} to 7.8×10^{-5}	0.02 to 0.07	Not applicable	No impacts	No impacts	3 to 13
Workers	For some accident scenarios workers would likely be severely injured or killed	For some accident scenarios workers would likely be severely injured or killed	No workers; no impacts	For some accident scenarios workers would likely be severely injured or killed	For some accident scenarios workers would likely be severely injured or killed	No workers; no impacts
Noise	Impacts to public would be low due to large distances to residences; workers exposed to elevated noise levels – controls and protection used as necessary	Transient and not excessive, less than 90 dBA[g]	No activities, therefore, no noise	Transient and not excessive, less than 90 dBA	Transient and not excessive, less than 90 dBA	No activities, therefore, no noise
Aesthetics	Low adverse impacts to aesthetic or visual resources in the region	Low, temporary, and transient; possible conflict with visual resource management goals for Jean rail corridor	Small; only surface features remaining would be markers	Small; storage would continue at existing sites; expansion as needed	Small; storage would continue at existing sites; expansion as needed	Small; aesthetic value decreases as facilities degrade
Utilities, energy, materials, and site services	Use of materials would be very small in comparison to amounts used in the region; electric power delivery system to the Yucca Mountain site would have to be enhanced.	Use of materials and energy would be small in comparison to amounts used nationally	No use of materials or energy	Small; materials and energy use would be small compared to total site use	Small; materials and energy use would be small compared to total site use	No use of materials or energy

Table 2-7. Impacts associated with the Proposed Action and No-Action Alternative (page 4 of 4).

	Proposed Action			No-Action Alternative		
	Short-term (through closure, about 100 years)		Long-term (after closure, about 100 to 10,000 years)	Short -term	Long-term (100 to 10,000 years)	
Resource area	Repository	Transportation		(100 years)	Scenario 1	Scenario 2
Management of site-generated waste and hazardous materials	Radioactive and hazardous waste generated would be a few percent of existing offsite capacity; other wastes would be managed offsite and some waste potentially at an onsite landfill	Radioactive and hazardous waste generated would be a few percent of existing offsite capacity; other wastes would be managed offsite and some waste potentially at an onsite landfill	No waste generated or hazardous materials used	Small; waste generated and materials used would be small compared to total site generation and use	Small; waste generated and materials used would be small compared to total site generation and use	No waste generated or hazardous materials used
Environmental justice	No disproportionately high and adverse impacts to minority or low-income populations; opposing Native American viewpoint	No disproportionately high and adverse impacts to minority or low-income populations; opposing Native American viewpoint	No disproportionately high and adverse impacts to minority or low-income populations; opposing Native American viewpoint	No disproportionately high and adverse impacts to minority or low-income populations	No disproportionately high and adverse impacts to minority or low-income populations	Potential for disproportionately high and adverse impacts to minority or low-income populations

a. km^2 = square kilometers; to covert to acres, multiply by 247.1.

b. To convert acre-feet to cubic meters, multiply by 1233.49.

c. LCF = latent cancer fatality; MEI = maximally exposed individual.

d. The maximally exposed individual could receive a fatal dose of radiation within a few weeks to months. Death would be caused by acute direct radiation exposure.

e. Downstream exposed population of approximately 3.9 billion over 10,000 years.

f. As many as 8 of these fatalities could be members of the public; fatalities include commuting traffic fatalities.

g. dBA = A-weighted decibels, a common sound measurement. A-weighting accounts for the fact that the human ear responds more effectively to some pitches than to others. Higher pitches receive less weighting than lower ones.

from the Proposed Action and limited impacts from the No-Action Alternative, depending on the scenario. The analysis led to the following conclusions:

- From 0.04 to 0.4 square kilometer (10 to 100 acres) of land could be contaminated to the extent it would not be usable for long periods near each of the 77 sites for No-Action Scenario 2. There could be accompanying impacts on biological resources, socioeconomic conditions, cultural resources, and aesthetic resources for long periods. Such impacts for the Proposed Action and No-Action Scenario 1 would be very small.

- For No-Action Scenario 2, there could be low levels of contamination in the surface watershed and high concentrations of contaminants in the groundwater downstream of the 77 sites for long periods. There would be no such impacts for No-Action Scenario 1. For the Proposed Action, there could be low levels of contamination in the groundwater in the Amargosa Desert for a long period.

- Projected radiological impacts to the public for the first 10,000 years for the Proposed Action would be low (0.000055 to 0.00053 latent cancer fatality per year) compared to No-Action Scenario 2 (3,300 latent cancer fatalities).

- Radionuclides would be released for a long period of time under the Proposed Action and peak doses would occur hundreds of thousand years after closure of the repository.

- Projected long-term fatalities associated with No-Action Scenario 1 would be about 1,000, primarily to the workforce at the storage sites.

- Risks associated with sabotage and materials diversion in relation to the fissionable material stored at the 77 sites would be much greater than they would be if the fissionable material were in a monitored deep geologic repository.

The projected cost associated with No-Action Scenario 1 would be approximately $600 million a year (1998 dollars) for 9,900 years. Projected long-term costs for the Proposed Action would be very low while there would be none for No-Action Scenario 2 due to the lack of institutional control.

2.4.4 IMPACTS OF TRANSPORTATION SCENARIOS

2.4.4.1 National Transportation

This section summarizes and compares transportation-related environmental impacts for the movement of spent nuclear fuel and high-level radioactive waste from the 77 sites to the Yucca Mountain site. Table 2-8 compares the environmental impacts for the two national transportation scenarios analyzed, mostly rail and mostly legal-weight truck (see Section 2.1.3.2). Because DOE does not know the actual mix for these potential national transportation modes, the analyses used these two scenarios to bound the impacts from transportation activities that would move spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site. In addition, Table 2-8 lists estimates of the environmental impacts associated with transportation activities in Nevada.

The values listed in Table 2-8 are limited to radiological impacts. As discussed in more detail in Chapter 6, shipments of spent nuclear fuel and high-level radioactive waste to Yucca Mountain would be a small fraction of the overall railroad and highway shipping activity in the United States. Thus, the incremental impacts from shipments to Yucca Mountain for the resource areas would be small in comparison to background impacts from all shipping activities, with the exception of potential radiological impacts.

Table 2-8. National transportation impacts for the transportation of spent nuclear fuel and high-level radioactive waste for the mostly rail and mostly legal-weight truck scenarios.

Group	Impact	Mostly legal-weight truck scenario	Mostly rail scenario
Worker	*Incident-free health impacts, radiological*		
	Maximally exposed individual (rem)	48	48
	Individual latent cancer fatality probability	0.02	0.02
	Collective dose (person-rem)	11,000	1,900 - 2,300[a]
	Latent cancer fatality incidence	4.5	0.8 - 0.9[a]
Public	*Incident-free health impacts, radiological*		
	Maximally exposed individual (rem)	2.4	0.31
	Individual latent cancer fatality probability	0.001	0.00016
	Collective dose (person-rem)	35,000	3,300 - 5,000[a]
	Latent cancer fatality incidence	18	1.6 - 2.5[a]
	Incident-free vehicle emissions impacts		
	Fatalities	0.6	0.3
Public	*Radiological impacts from maximum reasonably foreseeable accident scenario*		
	Probability (per year)	1.9 in 10,000,000	1.4 in 10,000,000
	Maximally exposed individual (rem)	3.9	26
	Individual latent cancer fatality probability	0.002	0.013
	Collective dose (person-rem)	9,400	61,000
	Latent cancer fatality incidence	4.7	31
Public and transportation workers	*Fatalities from vehicular accidents*	3.9	3.6

a. Range for the 10 rail and heavy-haul truck implementing alternatives in Nevada.

The following conclusions can be drawn from the analysis results summarized in Table 2-8:

- Radiological impacts from maximum foreseeable accident scenarios during the transportation of spent nuclear fuel and high-level radioactive waste would be lower for the mostly legal-weight truck case.

- Impacts from the transportation of spent nuclear fuel and high-level radioactive waste from the commercial and DOE sites to the Yucca Mountain site would be low for either national shipping mode.

- Radiological impacts to the public and to workers for normal transportation activities would be lower for the mostly rail scenario.

Most of the occupational and public health and safety impacts to the public and to workers would occur during the repository operating and monitoring phase.

Incremental differences in short-term impacts for the thermal load scenarios would be small, generally by less than a factor of about 2. Short-term impacts would generally be largest for the low thermal load and lowest for the high thermal load.

2.4.4.2 Nevada Transportation

For shipments coming into the State of Nevada by rail, there is no rail line to connect the national rail routes with the Yucca Mountain site (see Section 2.1.3.3). As a consequence, DOE evaluated the impacts in Nevada of moving spent nuclear fuel and high-level radioactive waste to the site using 10 implementing alternatives. These included five potential corridors for a new branch rail line (see Section 2.1.3.3.2) and five potential combinations of intermodal transfer stations and highway routes for heavy-haul trucks (see Section 2.1.3.3.3).

Tables 2-9 and 2-10 compare the impacts from transportation activities in potential Nevada rail corridors and heavy-haul truck corridors, respectively. In addition, they list impacts associated with engineering attributes for each implementing alternative. These engineering factors include cost, institutional acceptability of the route, construction and schedule risk, and operational compatibility. Additional attributes could affect a decision on the choice of a transportation mode or route in Nevada.

The following conclusions can be drawn from the information in Tables 2-9 and 2-10:

- Environmental impacts for each of the 10 implementing alternatives would be small.
- With the exception of collective dose, the environmental impacts for shipment by legal-weight truck in Nevada would be smaller than those from the 10 implementing alternatives associated with incoming shipments by rail. However, even for shipment by rail or heavy-haul truck in Nevada, the projected collective dose impacts would be small (approximately 2 latent cancer fatalities to both the public and transportation workers).
- With the exception of land use, differences in environmental impacts for the 10 implementing alternatives related to incoming shipments by rail would be small, so environmental impacts do not appear to be a major factor in the selection of transportation mode, route, or corridor in Nevada for incoming rail shipments.
- For land use, the Caliente-Chalk Mountain routes for a rail corridor and for a highway route for heavy-haul trucks would have conflicts with ongoing national defense activities at the Nellis Air Force Range.
- Impacts to cultural resources for any of the potential implementing alternative routes or corridors cannot be fully assessed until more detailed archaeological and ethnographic studies are conducted, but they are likely to be similar to one another. Impacts to Native American values could occur from the use of any of the routes including the use of highways in Nevada by legal-weight trucks that would pass through the Moapa and Las Vegas Paiute Indian reservations.

2.5 Collection of Information and Analyses

DOE conducted a broad range of studies to obtain or evaluate the information needed for the assessment of Yucca Mountain as a monitored geologic repository for spent nuclear fuel and high-level radioactive waste. The Department used the information from these studies in the analyses described in this EIS. Because some of these studies are ongoing, some of the information is incomplete.

The complexity and variability of the natural system at Yucca Mountain, the long periods evaluated, and factors such as the use of incomplete information or the unavailability of information have resulted in a certain degree of uncertainty associated with the analyses and findings in this EIS. DOE believes that it is important that the EIS identify the use of incomplete and unavailable information and uncertainty to enable an understanding of its findings. It is also important to understand that research can produce results or conclusions that might disagree with other research. The interpretation of results and conclusions has resulted in the development of views that differ from those that DOE presents in this EIS. DOE has received input from a number of organizations interested in the Proposed Action or No-Action Alternative or from potential recipients of impacts from those actions. These organizations include among others the State of Nevada, local governments, and Native American groups. Their input includes documents that present research or information that in some cases disagrees with the views that DOE presents in this EIS. The Department reviewed these documents and evaluated their findings for inclusion as part of the EIS analyses. If the information represents a substantive view, DOE has made every effort to incorporate that view in the EIS and to identify its source.

Table 2-9. Comparison of impacts for Nevada rail implementing alternatives and for legal-weight truck shipments (page 1 of 2).

Impact	Caliente	Carlin	Caliente-Chalk Mountain	Jean	Valley Modified	Mostly legal-weight truck
Land use and ownership						
Disturbed land (square kilometers)[a]	18	19	12	9	5	None
Private land (square kilometers)	0.9	7	0.8	3.6	0	None
Nellis Air Force Base land (square kilometers)	20	19	22	0	10	None
Air quality						
PM_{10} (construction)	Areas in attainment of air quality standards - branch rail line construction not a significant source of pollution	Areas in attainment of air quality standards - branch rail line construction not a significant source of pollution	Areas in attainment of air quality standards - branch rail line construction not a significant source of pollution	Except in Clark County, areas in attainment of air quality standards - branch rail line construction would not be a significant source of pollution	Clark County is in nonattainment of air quality standards for PM_{10} - branch rail line construction would not be a significant source of pollution	No construction
CO (operations)	93% of General Conformity Rule threshold	93% of General Conformity Rule threshold	93% of General Conformity Rule threshold	93% of General Conformity Rule threshold	93% of General Conformity Rule threshold	93% of General Conformity Rule threshold
Hydrology						
Surface water	Low	Low	Low	Low	Low	None
Groundwater						
Water use (acre-feet)[b]	710	660	480	410	320	None
Water use (number of wells)	64	67	43	23	20	None
Biological resources and soils	Low	Low	Low	Low	Low	None
Cultural resources	None identified to archaeological, historical, or cultural resources	None identified to archaeological, historical, or cultural resources	None identified to archaeological, historical, or cultural resources	None identified to archaeological, historical, or cultural resources	None identified to archaeological or historical resources. Route passes close to the Las Vegas Paiute Indian Reservation	Since shipments would use existing highways, none to archaeological or historical resources. Shipments from the northeast would pass through the Moapa Indian Reservation. All shipments would pass through the Las Vegas Paiute Indian Reservation
Noise	Moderate	Low	Moderate	Moderate	Moderate	Low
Utilities and resources						
Diesel (million liters)[c]	42	39	33	26	13	Low
Steel (thousand metric tons)[d]	71	72	48	26	22	None

Table 2-9. Comparison of impacts for Nevada rail implementing alternatives and for legal-weight truck shipments (page 2 of 2).

Impact	Caliente	Carlin	Caliente-Chalk Mountain	Jean	Valley Modified	Mostly legal-weight truck
Concrete (thousand metric tons)[e]	420	400	280	150	130	None
Aesthetics	Very low	Very low	Very low	Potential small area of conflict	Very low	None
Socioeconomics						
New jobs (percent of workforce in affected counties	1,200 (< 1% to 4%)	1,100 (< 1%)	910 (< 1% to 5.7%)	720 (< 1%)	350 (< 1%)	Low
Peak real disposable income (million dollars)	27	25	19	16	7	Low
Peak incremental Gross Regional Product (million dollars)	49	44	35	29	14	NA[f]
Waste management	Limited quantity	Limited quantity	Limited quantity	Limited quantity	Limited quantity	None
Environmental justice (disproportionately high and adverse impacts)	None	None	None	None	None	None
Incident-free health and safety						
Industrial hazards						
Total recordable incidents	250	240	220	170	130	NA
Lost workday cases	130	120	110	90	70	NA
Fatalities	1.3	1.2	1	0.9	0.5	NA
Collective dose (person-rem [LCFs])						
Workers	430 [0.17]	470 [0.19]	390 [0.16]	400 [0.16]	380 [0.15]	1,600 [0.63]
Public	390 [0.20]	420 [0.21]	380 [0.19]	430 [0.21]	380 [0.19]	2,800 [1.4]
Fatalities from vehicle emissions	0.0019	0.0025	0.0017	0.014	0.0018	0.005
Traffic accident fatalities						
Construction and operations workforce	1.9	1.8	1.5	1.2	0.9	NA[f]
SNF[g] and HLW[h] shipping	0.13	0.15	0.11	0.11	0.1	0.5
Radiological impacts, accident scenarios						
Maximum exposed individual (rem)	26	26	26	26	26	3.9
Individual latent cancer fatality probability	0.02	0.02	0.02	0.02	0.02	0.002
Collective dose	0.09	0.1	0.09	0.15	0.09	0.5
Latent cancer fatalities	0.00005	0.00005	0.00004	0.00008	0.00004	0.0002

a. To convert square kilometers to acres, multiply by 247.1.

b. To convert acre-feet to gallons, multiply by 325,850.1.

c. To convert liters to gallons, multiply by 0.26418.

d. To convert metric tons to tons, multiply by 1.1023.

e. To convert cubic feet to cubic meters, multiply by 0.028317.

f. NA = not applicable.

g. SNF = spent nuclear fuel.

h. HLW = high-level radioactive waste.

Table 2-10. Comparison of impacts for Nevada heavy-haul truck implementing alternatives and for legal-weight truck shipments (page 1 of 2).

Impact	Caliente	Caliente-Chalk Mountain	Caliente-Las Vegas	Sloan/Jean	Apex/Dry Lake	Mostly legal-weight truck
Land use and ownership						
Disturbed land (square kilometers)[a]	0.28	0.24	0.24	0.2	0.2	None
Private land (square kilometers)	0	0	0	0	0	None
Nellis Air Force Base land (square kilometers)	0	0	0	0	0	None
Air quality						
PM_{10} (construction)	Areas in attainment of air quality standards - highway upgrades not a significant source of pollution	Areas in attainment of air quality standards - highway upgrades not a significant source of pollution	Except Clark County, areas in attainment of air quality standards - highway upgrades not a significant source of pollution	48% of GCR Threshold for IMT construction	48% of GCR Threshold for IMT construction	No construction
CO (operations)	93% of General Conformity Rule threshold	93% of General Conformity Rule threshold	93% of General Conformity Rule threshold	93% of General Conformity Rule threshold	93% of General Conformity Rule threshold	
Hydrology						
Surface water	Low	Low	Low	Low	Low	None
Groundwater						
Water use (acre-feet)[b]	100	60	44	8	8	None
Water use (number of wells)	16	5	7	Truck water	Truck water	None
Biological resources and soils	Low	Low	Low	Low	Low	None
Cultural resources	None identified to archaeological, historical, or cultural resources	None identified to archaeological, historical, or cultural resources	None identified to archaeological, historical, or cultural resources; route near Moapa Indian Reservation and passes across 1.6-kilometer (1-mile) corner of the Las Vegas Paiute Indian Reservation	None identified to archaeological, historical, or cultural resources; route passes across 1.6-kilometer (1-mile) corner of the Las Vegas Paiute Indian Reservation	None identified to archaeological, historical, or cultural resources; IMT[c] and route near the Moapa Indian Reservation and passes across 1.6-kilometer (1-mile) corner of the Las Vegas Paiute Indian Reservation	Since shipments would use existing highways, none to archaeological or historical resources. Shipments from the northeast would pass through the Moapa Indian Reservation. All shipments would pass through the Las Vegas Paiute Indian Reservation
Noise	Low	Low	Low	Low	Low	Low
Utilities and resources						
Diesel (million liters)[d]	13	4.7	5.5	1.7	1.6	Low
Steel (metric tons)[e]	49	14	21	2.3	2.3	None
Concrete (thousand metric tons)[f]	1.8	0.5	0.8	0.1	0.1	None
Aesthetics	Some potential near Caliente	Some potential near Caliente	Some potential near Caliente	Very low	Very low	None

Table 2-10. Comparison of impacts for Nevada heavy-haul truck implementing alternatives and for legal-weight truck shipments (page 2 of 2).

Impact	Caliente	Caliente-Chalk Mountain	Caliente-Las Vegas	Sloan/Jean	Apex/Dry Lake	Mostly legal-weight truck
Socioeconomics						
New jobs (percent of workforce in affected counties)	1,000 (< 1% to 2.3%)	830 (< 1% to 2.6%)	810 (< 1% to 2%)	720 (< 1%)	540 (< 1%)	Low
Peak real disposable personal income (million dollars)	25	20	20	20	15	Low
Peak incremental Gross Regional Product (million dollars)	42	35	35	34	26	Low
Waste management	Limited quantity	Limited quantity	Limited quantity	Limited quantity	Limited quantity	None
Environmental justice (disproportionately high and adverse impacts)	None	None	None	None	None	None
Incident-free health and safety						
Industrial hazards						
Total recordable incidents	340	330	300	180	180	NA[g]
Lost workday cases	190	180	160	100	100	NA
Fatalities	0.7	0.6	0.6	0.4	0.4	NA
Incident-free health and safety (continued)						
Collective dose (person-rem [LCFs])						
Workers	780 [0.31]	710 [0.29]	740 [0.30]	710 [0.29]	690 [0.28]	1,600 [0.63]
Public	2,100 [1.0]	1,200 [0.62]	1,600 [0.77]	1,000 [0.51]	940 [0.47]	2,800 [1.4]
Fatalities from vehicle emissions	0.0016	0.0012	0.0013	0.012	0.0012	0.005
Traffic accident fatalities						
Construction and operations workforce	5.6	2.9	3.4	2.0	2.0	NA[g]
SNF[h] and HLW[i] shipping	0.73	0.42	0.54	0.33	0.31	0.5
Radiological impacts, accident scenarios						
Maximum exposed individual (rem)	26	26	26	26	26	3.9
Individual latent cancer fatality probability	0.02	0.02	0.02	0.02	0.02	0.002
Collective dose	0.29	0.26	0.72	4.1	0.67	0.5
Latent cancer fatalities	0.0001	0.0001	0.0004	0.002	0.0003	0.0002

a. To convert square kilometers to acres, multiply by 247.1.

b. To convert acre-feet to gallons, multiply by 325,850.1.

c. IMT = intermodal transfer.

d. To convert liters to gallons, multiply by 0.26418.

e. To convert metric tons to tons, multiply by 1.1023.

f. To convert cubic feet to cubic meters, multiply by 0.028317.

g. NA = not applicable.

h. SNF = spent nuclear fuel.

i. HLW = high-level radioactive waste.

2.5.1 INCOMPLETE OR UNAVAILABLE INFORMATION

Some of the analyses in this EIS had to use incomplete information. To ensure an understanding of the status of its information, DOE has identified the use of incomplete information or the unavailability of information in the EIS in accordance with the Council on Environmental Quality regulations pertaining to incomplete and unavailable information (40 CFR 1502.22). Such cases describe the basis for the analyses, including assumptions, the use of preliminary information, or conclusions from draft or incomplete studies. DOE continues to study issues relevant to understanding what could happen in the future at Yucca Mountain and the potential impacts associated with its use as a repository. As a result, the Final EIS will include information that was not available for the Draft EIS. In addition, DOE might not complete some of the studies and design development for the repository until after it has issued the Final EIS. DOE believes, however, that sufficient information is currently available to assess the range of impacts that could result from either the Proposed Action or the No-Action Alternative.

2.5.2 UNCERTAINTY

The results and conclusions of analyses often have some associated uncertainty. The uncertainty could be the result of the assumptions used, the complexity and variability of the process being analyzed, the use of incomplete information, or the unavailability of information. To enable an understanding of the status of its findings, this EIS contains descriptions of the uncertainties, if any, associated with the results and conclusions presented.

2.5.3 OPPOSING VIEWS

In this EIS, opposing views are defined as differing views or opinions currently held by organizations or individuals outside DOE. These views are considered to be opposing if they include or rely on data or methods that DOE is not currently using in its own impact analysis. In addition, these views are reasonably based on scientific, regulatory, or other information supported by credible data or methods that relate to the impacts analyzed in the EIS.

DOE has attempted to identify and address the range of opposing views in this EIS. The Department identified potential opposing views by reviewing published or other information in the public domain. Sources of information included reports from universities, other Federal agencies, the State of Nevada, counties, municipalities, other local governments, and Native American groups. DOE reviewed the potential opposing views to determine if they:

- Address issues analyzed in the EIS
- Differ from the DOE position
- Are based on scientific, regulatory, or other information supported by credible data or methods that relate to the impacts analyzed in the EIS
- Have significant basic differences in the data or methods used in the analysis or to the impacts described in the EIS

DOE has included potential opposing views that met the above criteria in the EIS where it discusses the particular subject. For example, opposing views on the groundwater system are discussed in the sections on groundwater.

2.6 Preferred Alternative

DOE's preferred alternative is to proceed with the Proposed Action to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. The analyses in this EIS did not identify any potential environmental impacts that would be a basis for not proceeding with the Proposed Action. DOE has not chosen any transportation mode, corridor, or route as preferred at this time.

DOE recognizes that implementation of the preferred alternative would require the completion of a number of actions. As part of this process, the Secretary of Energy is to:

- Undertake (and complete) site characterization activities at Yucca Mountain to provide information and data required to evaluate the site.

- Prepare an EIS.

- Decide whether to recommend approval of the development of a geologic repository at Yucca Mountain to the President.

The NWPA also requires DOE to hold hearings to provide the public in the vicinity of Yucca Mountain with opportunities to comment on the Secretary's possible recommendation of the Yucca Mountain site to the President. If, after completing the hearings and site characterization activities, the Secretary decides to recommend that the President approve the site, the Secretary will notify the Governor and legislature of the State of Nevada accordingly. No sooner than 30 days after the notification, the Secretary may submit the recommendation to the President to approve the site for development of a repository.

If the Secretary recommends the Yucca Mountain site to the President, a comprehensive statement of the basis for the recommendation, including the Final EIS, will accompany the recommendation. This Draft EIS has been prepared now so that DOE can consider the Final EIS, including the public input on the Draft EIS, in making a decision on whether to recommend the site to the President.

If, after a recommendation by the Secretary, the President considers the site qualified for application to the Nuclear Regulatory Commission for a construction authorization, the President will submit a recommendation of the site to Congress. The Governor or legislature of Nevada may object to the site by submitting a notice of disapproval to Congress within 60 days of the President's action. If neither the Governor nor the legislature submits a notice within the 60-day period, the site designation would become effective without further action by the President or Congress. If, however, the Governor or the legislature did submit such a notice, the site would be disapproved unless, during the first 90 days of continuous session of Congress after the notice of disapproval, Congress passed a joint resolution of repository siting approval and the President signed it into law.

In determining whether to recommend the Yucca Mountain site to the President, DOE would consider not only the potential environmental impacts identified in this EIS, but also other factors. Those factors could include those identified through public input, as well as other available information. Examples of such other possible factors include the following:

- Ability to obtain necessary approvals, license and permits
- Ability to fulfill stakeholder agreements
- Consistency with DOE mission
- Assurance of safety
- Facility construction and operation flexibility

- Cost of implementation
- Ability to mitigate adverse impacts

As part of the Proposed Action, the EIS analyzes the impacts of transporting spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site from 77 sites across the United States. As part of this analysis, the EIS includes information, such as the comparative impacts of truck and rail transportation, alternative intermodal (rail to truck) transfer station locations, associated heavy-haul truck routes, and alternative rail transport corridors in Nevada, that might not lead to near-term decisions. It is uncertain at this time when DOE would make these transportation-related decisions. If and when it is appropriate to make such decisions, DOE believes that the EIS provides the information necessary to make these decisions. However, measures to implement those decisions, such as selection of a specific rail alignment within a corridor, or the specific location of an intermodal transfer station, or the need to upgrade the associated heavy-haul routes, would require additional field surveys, state and local government consultations, environmental and engineering analyses, and National Environmental Policy Act reviews.

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3

Affected Environment

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3. AFFECTED ENVIRONMENT

To analyze potential environmental impacts that could result from the implementation of the Proposed Action, the U.S. Department of Energy (DOE) has compiled extensive information about the environments that could be affected. The Department used this information to establish the baseline against which it measured potential impacts (see Chapter 4). Chapter 3 describes (1) environmental conditions that will exist at and in the region of the proposed repository site at Yucca Mountain after the conclusion of site characterization activities (Section 3.1); (2) environmental conditions along the proposed transportation corridors in Nevada that DOE could use to ship spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site (Section 3.2); and (3) environmental conditions at the 72 commercial and 5 DOE sites in the United States that manage spent nuclear fuel and high-level radioactive waste (Section 3.3).

DOE obtained baseline environmental information from many sources. These sources included reports and studies sponsored by DOE, other Federal agencies (for example, the U.S. Geological Survey), and the State of Nevada and affected units of local government. (Affected units of local government include county governments near the potential repository site and along potential transportation routes within Nevada.)

DOE received reports from the State of Nevada and affected units of local government during the EIS scoping process, informally from local government personnel, and formally during ongoing interactions between DOE and State and local governments. The subjects of these reports include socioeconomics, cultural resources, hydrology, transportation planning and emergency response, and resource supply. DOE evaluated these reports and, where appropriate, they are discussed in individual resource area sections of the EIS.

3.1 Affected Environment at the Yucca Mountain Repository Site at the Conclusion of Site Characterization Activities

To define the existing environment at and in the region of the proposed repository, DOE has compiled environmental baseline information for 13 subject areas. This environment includes the manmade structures and physical disturbances from DOE-sponsored site selection studies (1977 to 1988) and site characterization studies (1989 to 2001) to determine the suitability of the site for a repository. This chapter and supporting documents, called *environmental baseline files,* contain baseline information for:

- *Land use and ownership:* Land-use practices and land ownership information in the Yucca Mountain region (Section 3.1.1)

- *Air quality and climate:* The quality of the air in the Yucca Mountain region and the area's climatic conditions (temperature, precipitation, etc.) (Section 3.1.2)

- *Geology:* The geologic characteristics of the Yucca Mountain region both at and below the ground surface, the frequency and severity of seismic activity, volcanism, and mineral and energy resources (Section 3.1.3)

- *Hydrology:* Surface-water and groundwater features in the Yucca Mountain region and the quality of the water (Section 3.1.4)

- *Biological resources and soils:* Plants and animals that live in the Yucca Mountain region, the occurrence of special status species and wetlands, and the kinds and quality of soils in the region (Section 3.1.5)

- *Cultural resources:* Historic and archaeological resources in the Yucca Mountain region, the importance those resources hold, and for whom (Section 3.1.6)

- *Socioeconomic environment:* The labor market, population, housing, community services, and transportation services in the Yucca Mountain region (Section 3.1.7)

- *Occupational and public health and safety:* The levels of radiation that occur naturally in the Yucca Mountain air, soil, animals, and water; radiation dose estimates for Yucca Mountain workers from background radiation; radiation exposure, dispersion, and accumulation in air and water for the Nevada Test Site area from past nuclear testing and current operations; and public radiation dose estimates from background radiation (Section 3.1.8)

- *Noise:* Noise sources and levels of noise that commonly occur in the Yucca Mountain region during the day and at night, and the applicability of Nevada standards for noise in the region (Section 3.1.9)

- *Aesthetics:* The visual resources of the Yucca Mountain region in terms of land formations, vegetation, and color, and the occurrence of unique natural views in the region (Section 3.1.10)

- *Utilities, energy, and materials:* The amount of water available for the Yucca Mountain region, water-use practices, water sources, the demand for water at different times of the year, the amounts of power supplied to the region, the means by which power is supplied, and the availability of natural gas and propane (Section 3.1.11)

- *Waste and hazardous materials:* Ongoing solid and hazardous waste and wastewater management practices at Yucca Mountain, the kinds of waste generated by current activities at the site, the means by which DOE disposes of its waste, and DOE recycling practices (Section 3.1.12)

- *Environmental justice:* The locations of low-income and minority populations in the Yucca Mountain region and the income levels among low-income populations (Section 3.1.13)

DOE evaluated the existing environments in regions of influence for each of the 13 subject areas. Table 3-1 defines these regions, which are specific to the subject areas in which DOE could reasonably expect to predict potentially large impacts related to the proposed repository. Human health risks from exposure to airborne contaminant emissions were assessed for an area within approximately 80 kilometers (50 miles), and economic effects, such as job and income growth, were evaluated in a three-county socioeconomic region.

In the past, the vicinity around Yucca Mountain has been the subject of a number of studies in support of mineral and energy resource exploration, nuclear weapons testing, and other DOE activities at the Nevada Test Site. From 1977 to 1988, the Yucca Mountain Project performed studies to assist in the site selection process for a repository. These studies, which involved the development of roads, drill holes, trenches, and seismic stations, along with non-Yucca Mountain activities, disturbed about 2.5 square kilometers (620 acres) of land in the vicinity of Yucca Mountain (DOE 1998h, page 1). Yucca Mountain site characterization activities began in 1989 and will continue until 2001. These activities include surface excavations, excavations of exploration shafts, subsurface excavations and borings, and testing to evaluate the suitability of Yucca Mountain as the site for a repository. By 2001, these activities

Table 3-1. Regions of influence for the proposed Yucca Mountain Repository.

Subject area	Region of influence
Land use and ownership	Land around site of proposed repository that DOE would disturb and over which DOE would need to obtain control; analyzed land withdrawal area is 600 square kilometers[a] (Section 3.1.1).
Air and climate	An approximate 80-kilometer[b] radius around Yucca Mountain, and at boundaries of controlled lands surrounding Yucca Mountain (Section 3.1.2).
Geology	The regional geologic setting and the specific geology of Yucca Mountain (Section 3.1.3).
Hydrology	*Surface water:* construction areas that would be susceptible to erosion, areas affected by permanent changes in flow, and areas downstream of the repository that would be affected by eroded soil or potential spills of contaminants.
	Groundwater: aquifers that would underlie areas of construction and operation, aquifers that could be sources of water for construction, and aquifers downstream of the repository that repository use or long-term releases from the repository could affect (Section 3.1.4).
Biological resources and soils	Area that contains all potential surface disturbances resulting from the Proposed Action (described in Chapter 2) plus some additional area to evaluate local animal populations; roughly equivalent to the analyzed land withdrawal area of about 600 square kilometers (Section 3.1.5).
Cultural resources	Land areas that repository activities would disturb (described in Chapter 2) and areas in the analyzed land withdrawal area where impacts could occur (Section 3.1.6).
Socioeconomic environment	Three Nevada counties (Clark, Lincoln, and Nye) in which repository activities could influence local economies and populations (Section 3.1.7).
Occupational and public health and safety	An approximate 80-kilometer radius around Yucca Mountain and at the approximate boundary of analyzed land withdrawal area (Section 3.1.8).
Noise	Existing residences in the Yucca Mountain region and at the approximate edge of the analyzed land withdrawal area (Section 3.1.9).
Aesthetics	Approximate boundary of analyzed land withdrawal area (Section 3.1.10).
Utilities, energy, and materials	Public and private resources on which DOE would draw to support the Proposed Action (for example, private utilities, cement suppliers) (Section 3.1.11).
Waste and hazardous materials	On- and offsite areas, including landfills and hazardous and radioactive waste processing and disposal sites, in which DOE would dispose of site-generated repository waste (Section 3.1.12).
Environmental justice	Varies with the different subject areas. The environmental justice regions of influence will correspond to those of the specific subject areas, as defined in this table (Section 3.1.13).

a. 600 square kilometers = about 150,000 acres or 230 square miles.

b. 80 kilometers = about 50 miles.

will have disturbed about an additional 1.5 square kilometers (370 acres) in the vicinity of Yucca Mountain (TRW 1999a, Table 6-2). Reclamation activities have started and will continue to occur as sites are released from further study.

The existing environment at Yucca Mountain includes the Exploratory Studies Facility, which includes the tunnel (drift), the North and South Portal pads and supporting structures, an excavated rock storage area, a topsoil storage area, borrow pits, boreholes, trenches, roads, and supporting facilities and disturbances for site characterization activities. Table 3-2 lists existing facilities, structures, equipment, and disturbances at Yucca Mountain and at the central support site in Area 25 of the Nevada Test Site. Area 25 was used in the early 1960s by the Atomic Energy Commission (a DOE predecessor agency) and the National Aeronautics and Space Administration as part of a program to develop nuclear reactors for use in the Nation's space program. The former Nuclear Rocket Development Station administrative areas complex in Area 25 has become the Yucca Mountain Site Characterization Central Support Site.

Table 3-2. Existing facilities, structures, and disturbances at Yucca Mountain.[a]

Yucca Mountain	Area 25 Central Support Site
Exploratory Studies Facility (North Portal pad and supporting structures)	Field Operations Center
	Hydrologic research facility
Exploratory Studies Facility (South Portal pad)	Sample management facility and warehouse
Cross drift[b]	Radiological studies facility
Concrete batch plant and precast yard	Meteorology/air quality studies facility
Fill borrow pits (3) and screening plants	Project accumulation area for hazardous waste
Subdock equipment storage facility	Gas station
Equipment/supplies laydown yard	Maintenance facility
Hydrocarbon management facility	U.S. Geological Survey technical warehouse
Boxcar equipment and supplies yard	Tunnel rescue facility
Water wells J-12 and J-13	Sewage lagoon operated by the Nevada Test Site
Excavated rock storage pile	
Topsoil storage pile	
Explosives storage magazines (2)	
Water booster pump and distribution system	
Boreholes (about 300)	
Trenches and test pits (about 200)	
Busted Butte geologic test drift	
Fran Ridge heated-block test facility	
Water infiltration test sites	
Meteorological monitoring towers	
Air quality monitoring sites	
Radiological monitoring sites	
Ecological study plots	
Reclamation study plots	
Septic system	
Roads	

a. Source: Modified from DOE (1998i, all).
b. Drift is a mining term for a horizontal tunnel.

3.1.1 LAND USE AND OWNERSHIP

The region of influence for land use and ownership includes the lands that surround the site of the proposed repository over which DOE would have to obtain permanent control to operate the repository. The Department has compiled land-use and ownership information for this region. Most of the land in the region is managed by agencies of the Federal Government. Sections 3.1.1.1 and 3.1.1.2 discuss land use and ownership for the region of influence and for a larger area around Yucca Mountain. Section 3.1.1.3

describes the analyzed land withdrawal area for the repository. Section 3.1.1.4 discusses Native American views about the ownership of the land around Yucca Mountain. TRW (1999f, all) is the basis of the information in this section unless otherwise noted.

3.1.1.1 Regional Land Use and Ownership

The Federal Government manages more than 85 percent of the land in Nevada (about 240,000 square kilometers or 93,000 square miles). Most of this land is under the control of the Bureau of Land Management (which is part of the U.S. Department of the Interior), the U.S. Department of Defense, and DOE. The remainder of the Federally managed land is primarily under the jurisdiction of the Forest Service, which is part of the U.S. Department of Agriculture, with smaller areas under the control of the National Park Service and the Bureau of Reclamation, both of which are parts of the Department of the Interior. About 42,000 square kilometers (16,000 square miles) are under State, local, or private ownership, and about 5,000 square kilometers (2,000 square miles) are Native American lands. Table 3-3 summarizes Nevada land holdings and the controlling authority. Figure 3-1 shows ownership and use of lands around the site of the proposed repository.

Table 3-3. Nevada land areas and controlling authorities (square kilometers).[a,b]

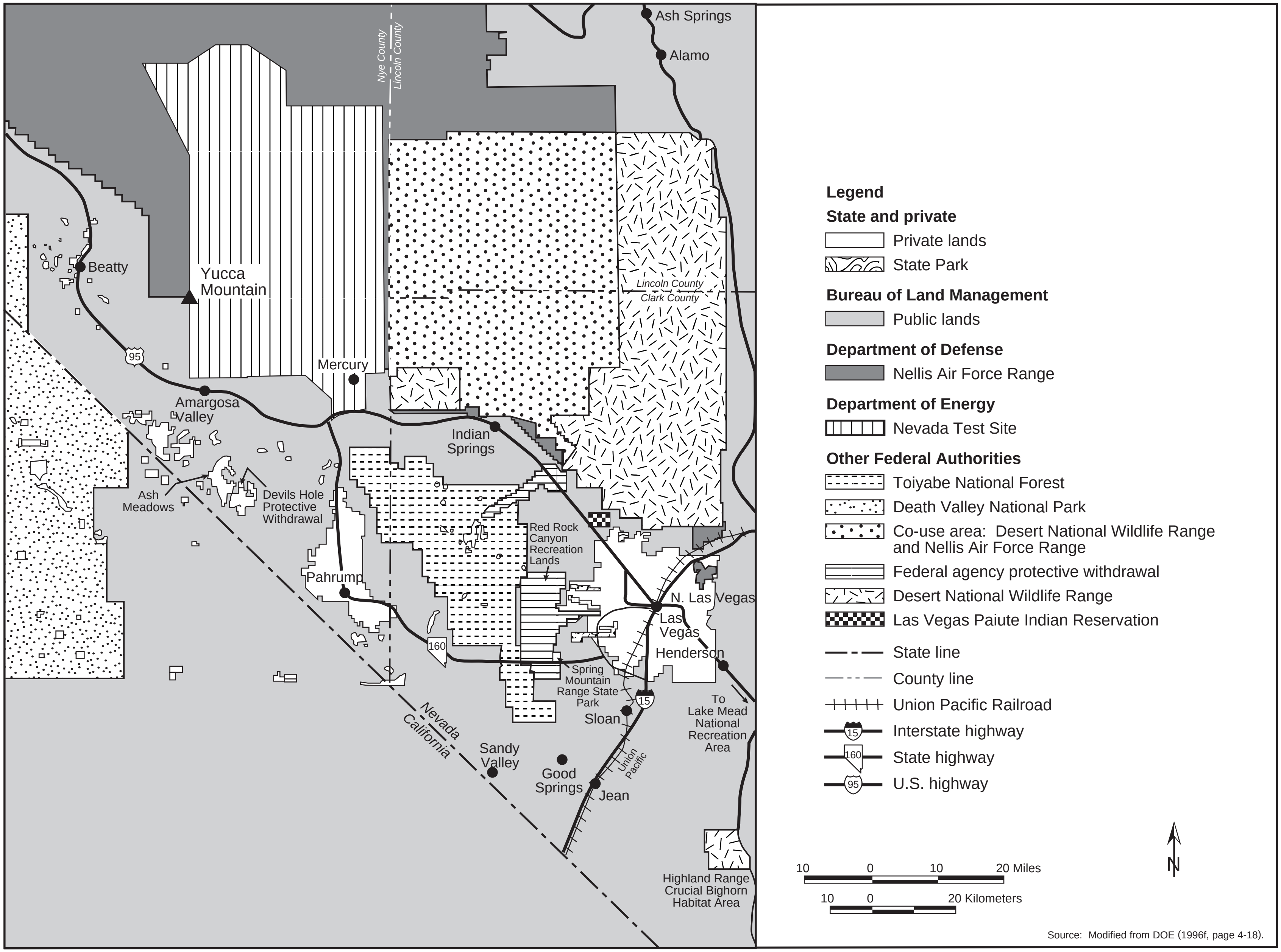
Authority	Area
State, local, county, or private	42,000
Bureau of Land Management	190,000
Department of Defense	13,000
Department of Energy	3,500
Other Federal authorities	31,000
Native American tribes	5,000

a. Source: TRW (1999f, page 1).
b. To convert square kilometers to square miles, multiply by 0.3861.

The Nevada Test Site, which is a DOE facility, covers about 3,500 square kilometers (1,400 square miles). The Atomic Energy Commission, a DOE predecessor agency, established the Nevada Test Site in the 1950s to test nuclear devices. More information on current and future uses of the Nevada Test Site is available in the *Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada* (DOE 1996f, all). The U.S. Air Force operates the Nellis Air Force Range, which covers about 13,000 square kilometers (5,000 square miles) and is one of the largest and most active military training ranges in the United States. More information on current and future uses of the Nellis Air Force Range is available in the *Renewal of the Nellis Air Force Range Land Withdrawal Legislative Environmental Impact Statement* (USAF 1999, all).

The region has special-use areas, which generally are excluded from development that would require terrain alterations unless such alterations would benefit wildlife or public recreation. The Fish and Wildlife Service of the U.S. Department of the Interior manages the Desert National Wildlife Refuge and the Ash Meadows National Wildlife Range, which are about 50 kilometers (30 miles) east and 39 kilometers (24 miles) south of Yucca Mountain, respectively (Figure 3-1). These areas provide habitat for a number of resident and migratory animal species in relatively undisturbed natural ecosystems. The National Park Service manages Death Valley National Park, which is in California approximately 35 kilometers (22 miles) southwest of Yucca Mountain. The small enclave of Devils Hole Protective Withdrawal in Nevada south of Ash Meadows is also administered by the National Park Service (Figure 3-1).

There is virtually no State-owned land immediately adjacent to the repository site. There are scattered tracts of private land in and near the Towns of Beatty, Amargosa Valley, and Indian Springs in Nevada. There are also larger private tracts in the agricultural areas of the Las Vegas Valley, near Pahrump, and in the Amargosa Desert south of the Town of Amargosa Valley. The closest year-round housing is at Lathrop Wells in the Amargosa Valley, about 22 kilometers (14 miles) south of the site. There is



Source: Modified from DOE (1996f, page 4-18).

Figure 3-1. Land use and ownership in the Yucca Mountain region.

farming—primarily grasses and legumes—for hay and dairy operations about 30 kilometers (19 miles) south of the proposed repository in the Town of Amargosa Valley (Figure 3-1).

3.1.1.2 Current Land Use and Ownership at Yucca Mountain

DOE has established land-use agreements to support its site characterization activities at Yucca Mountain. The Yucca Mountain Site Characterization Zone (Figure 3-2) includes DOE, Bureau of Land Management, and Air Force lands.

The Bureau of Land Management granted DOE a right-of-way reservation (N-47748) for Yucca Mountain site characterization activities (BLM 1988, all). This reservation comprises 210 square kilometers (81 square miles). The land in this reservation is open to public use, with the exception of about 20 square kilometers (8 square miles) near the site of the proposed repository that were withdrawn in 1990 from the mining and mineral leasing laws to protect the physical integrity of the repository rock (P.L. Order 6802, "Withdrawal of Public Land to Maintain the Physical Integrity of the Repository Rock"). The lands in this reservation not withdrawn from the mining and mineral leasing laws contain a number of unpatented mining claims (lode and placer). In addition, there is one patented mining claim in the reservation. Patented Mining Claim No. 27-83-0002 covers 0.8 square kilometer (0.3 square mile) to mine volcanic cinders used as a raw material in the manufacture of cinderblocks.

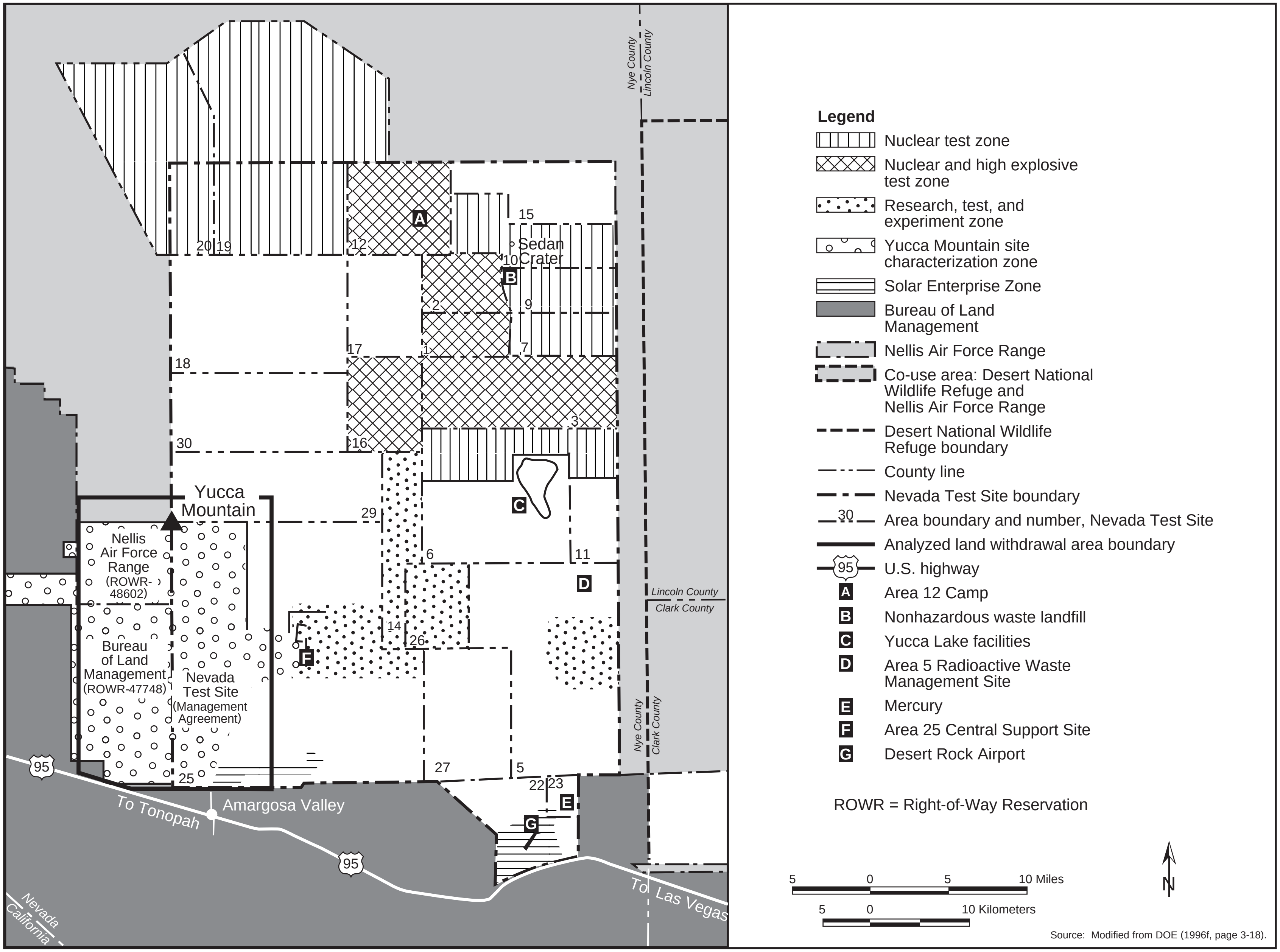
The Bureau of Land Management manages surface resources on the Nellis Air Force Range. In 1994, the Bureau granted DOE a right-of-way reservation (N-48602) to use about 75 square kilometers (29 square miles) of Nellis land for Yucca Mountain site characterization activities (BLM 1994a, all). This land, which is closed to public access and use, has been studied extensively. Many of the exploratory facilities are on Nellis land.

The Yucca Mountain Site Characterization Office and the DOE Nevada Operations Office have a management agreement that allows the use of about 230 square kilometers (90 square miles) of Nevada Test Site land for site characterization activities.

3.1.1.3 Potential Repository Land Withdrawal

Nuclear Regulatory Commission licensing conditions for a monitored geologic repository (10 CFR Part 60) include a requirement that DOE have either ownership or permanent control of the lands for which it is seeking a repository license. As noted, portions of the lands being used for site characterization that would be required for the repository are controlled by the Bureau of Land Management, the Air Force, and the DOE Nevada Operations Office. Because all of these lands are not under permanent DOE control, a land withdrawal would be required.

The procedure for land withdrawal is the method by which the Federal Government places exclusive control over land it owns with a particular agency for a particular purpose. Only Congress has the power to withdraw Federal lands permanently for the exclusive purposes of specific agencies. Congress can authorize and direct a permanent withdrawal of lands such as those required for the proposed repository at Yucca Mountain. The extent and conditions of the withdrawal would be determined by Congress. The extent of a land withdrawal area is important to the analysis and understanding of the impacts of the Proposed Action. For example, the magnitude of impacts to a member of the public from an accident at an operating repository would be determined in part by the proximity of the land withdrawal boundary to the repository operations areas. As a consequence, DOE used a land withdrawal area as the basis for analysis in this EIS.



Source: Modified from DOE (1996f, page 3-18).

Figure 3-2. Land use and ownership in the analyzed land withdrawal area and vicinity.

Figure 3-2 shows the land withdrawal area analyzed in this EIS that encompasses the current right-of-way reservations for site characterization. This area includes about 600 square kilometers (150,000 acres) of land. The land in this area is currently under the control of the Air Force, DOE, and the Bureau of Land Management (Table 3-4).

Table 3-4. Current land ownership and public accessibility to the analyzed land withdrawal area.[a,b]

Agency	Area (square kilometers)[c]	Current accessibility
DOE (Nevada Test Site)	300	No public access
U.S. Air Force (Nellis Air Force Range)	97	No public access
Bureau of Land Management (public land)	200	Public access
Private land (one patented mining claim)	1	No public access

a. Source: DOE (1998j, all).

b. A description of the area by township, range, and section is available from DOE, Las Vegas, Nevada.

c. To convert square kilometers to square miles, multiply by 0.3861.

Most of the land controlled by the Bureau of Land Management in the analyzed land withdrawal area is associated with the current right-of-way reservation (N-47748) for Yucca Mountain site characterization activities. This land is open to public use, with the exception of about 20 square kilometers (8 square miles) near the site of the proposed repository that are withdrawn from the mining and mineral leasing laws except for an existing patented mining claim. That claim (No. 27-83-0002) covers 0.8 square kilometer (0.3 square mile) to mine volcanic cinders (a raw material used in the manufacture of cinderblocks). The lands open to public use also contain a number of unpatented mining claims (lode and placer). Off-road vehicle use is permitted in these lands. There is a designated utility corridor in the southern portion of these lands.

More detailed descriptions of the land under the control of the Bureau of Land Management in the region of Yucca Mountain are available in the *Proposed Las Vegas Resource Management Plan and Final Environmental Impact Statement* (BLM 1998, all).

3.1.1.4 Native American Treaty Issue

One Native American ethnic group with cultural and historic ties to the Yucca Mountain region is the Western Shoshone. A special concern of the Western Shoshone people is the Ruby Valley Treaty of 1863. The Western Shoshone people maintain that the treaty gives them rights to 97,000 square kilometers (24 million acres) in Nevada, including the Yucca Mountain region (Western Shoshone v. United States 1997, all). The legal battle over the land began in 1946 when the Indian Claims Commission Act gave tribes the right to sue the Federal Government for unkept treaty promises. If a tribe were to win a claim against the Government, the Act specifies that the tribe could receive only a monetary award and not land or other remunerations.

The Western Shoshone people filed a claim in the early 1950s alleging that the Government had taken their land. The Indian Claims Commission found that Western Shoshone title to the Nevada lands had gradually extinguished and set a monetary award as payment for the land. In 1977, the Commission granted a final award to the Western Shoshone people, who dispute the Commission findings and have not accepted the monetary award for the lands in question. They maintain that no payment has been made (the U.S. Treasury is holding these monies in an interest-bearing account) and that Yucca Mountain is on Western Shoshone land. A 1985 U.S. Supreme Court decision (United States v. Dann 1985, all) ruled that even though the money has not been distributed, the United States has met its obligations with the Commission’s final award and, as a consequence, the aboriginal title of the land had been extinguished.

3.1.2 AIR QUALITY AND CLIMATE

The region of influence for air quality is an area within a radius of about 80 kilometers (50 miles) around the site of the proposed repository and at the boundaries of controlled lands around Yucca Mountain. This region encompasses portions of Clark and Nye Counties in Nevada and a portion of Inyo County, California. To determine the air quality and climate for the Yucca Mountain region, DOE site characterization activities have included the monitoring of air quality and meteorological conditions. The Department has monitored the air for gaseous criteria pollutants (carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide) and for particulate matter. This section describes the existing air quality and climate at the proposed repository site and in the surrounding region. Sections 3.1.2.1 and 3.1.2.2 describe the air quality and climate, respectively. Unless otherwise noted, the *Environmental Baseline File for Meteorology and Air Quality* (TRW 1999g, all) is the basis for the information provided in this section.

3.1.2.1 Air Quality

Air quality is determined by measuring concentrations of certain pollutants in the atmosphere. The U.S. Environmental Protection Agency designates an area as being *in attainment* for a particular pollutant if ambient concentrations of that pollutant are below National Ambient Air Quality Standards (Table 3-5).

Table 3-5. National and Nevada ambient air quality standards.[a]

	Primary and Secondary NAAQS,[b] except as noted			
Pollutant	Period	Concentration	Highest measured Yucca Mountain concentration[c]	Nevada standards[d]
Sulfur dioxide	Annual[e]	0.03 part per million	0.002	Same
	24-hour[f]	0.14 part per million	0.002	
Sulfur dioxide (secondary)	3-hour[f]	0.5 part per million	0.002	
PM_{10}[g]	Annual[h]	50 micrograms per cubic meter	12	Same
	24-hour[i]	150 micrograms per cubic meter	67	
$PM_{2.5}$[j]	Annual[h]	15 micrograms per cubic meter	N/A[k]	None
	24-hour[l]	65 micrograms per cubic meter	N/A	
Carbon monoxide	8-hour[f]	9 parts per million	0.2	Same[m]
	1-hour[f]	35 parts per million	0.2	Same
Nitrogen dioxide	Annual[e]	0.053 part per million	0.002	Same
Ozone	1-hour[n]	0.12 part per million	0.1	Same
	8-hour[o]	0.08 part per million	N/A	None

a. Sources: 40 CFR 50.4 through 50.11; Nevada Administrative Code 445B.391.
b. NAAQS = National Ambient Air Quality Standard.
c. Units correspond to the units listed in the concentration column.
d. Nevada Administrative Code 445B.391.
e. Average not to be exceeded in the period shown.
f. Average not to be exceeded more than once in a calendar year.
g. PM_{10} = particulate matter with a diameter less than 10 micrometers (0.0004 inch). If and until the revised State Implementation Plan is approved 40 CFR 50.6 applies; then 40 CFR 50.7 would apply.
h. Expected annual arithmetic mean should be less than value shown.
i. Number of days per calendar year exceeding this value should be less than 1. Under 40 CFR 50.7, 99th-percentile value should be less than value shown.
j. $PM_{2.5}$ = particulate matter with a diameter less than 2.5 micrometers (0.0001 inch). Standard has not been implemented.
k. N/A = not available; no monitoring data has been collected since the new standard was implemented.
l. 98th-percentile value should be less than value shown.
m. The Nevada ambient air quality standard for carbon monoxide is 9 parts per million at less than 1,500 meters (4,900 feet) above mean sea level and 6 parts per million at or above 1,500 meters; Nevada Administrative Code 445B.31.
n. This standard was replaced in 1998 by 40 CFR 50.10 for all air quality regions of interest.
o. Standard implemented in 1998. Three-year average of the fourth-highest monitored daily maximum 8-hour average concentration.

(Ambient air is that part of the atmosphere outside buildings to which the general public has access.) The Environmental Protection Agency established the national standards, as directed by the Clean Air Act, to define levels of air quality that are necessary, with an adequate margin of safety, to protect the public health (primary standards) and the public welfare (secondary standards). The standards specify the maximum pollutant concentrations and frequencies of occurrence for specific averaging periods.

Areas in violation of one or more of these standards are called *nonattainment areas*. If there are not enough air quality data to determine the status of attainment of a remote or sparsely populated area, the area is listed as *unclassified*. For regulatory purposes, unclassified areas are considered to be in attainment.

The quality of the air at the site of the proposed repository and the surrounding parts of the Nevada Test Site, Nellis Air Force Range, and southern Nye County is unclassified because there are limited air quality data (40 CFR 81.329). Data collected at the site indicate the air quality is within applicable standards. Portions of Clark County in the air quality region of influence are in attainment with the National Ambient Air Quality Standards. Inyo County, California, is in attainment with national and California ambient air quality standards for carbon monoxide, nitrogen dioxide, and sulfur dioxide. It is in attainment with the national PM_{10} standard, but in nonattainment with the more restrictive California standard (CEPA 1998, pages H6 to H35).

Air quality in attainment areas is controlled under the Prevention of Significant Deterioration program of the Clean Air Act, with the goal of preventing significant deterioration of existing air quality. Under the Prevention of Significant Deterioration provisions, Congress established a land classification scheme for areas of the country with air quality better than the National Ambient Air Quality Standards. Class I allows very little deterioration of air quality; Class II allows moderate deterioration; and Class III allows more deterioration; but in all cases the pollution concentrations shall not violate any of the National Ambient Air Quality Standards. Congress designated certain areas as mandatory Class I, which precludes redesignation to a less restrictive class, to acknowledge the value of maintaining these areas in relatively pristine condition. Congress also protected other nationally important lands by originally designating them as Class II and restricting redesignation to Class I only.

All other areas were initially classified as Class II, and can be redesignated as either Class I or Class III. In the region of influence, all areas are designated as Class II. There are no Class I areas, although one area, the Death Valley National Park, is a national monument and a protected Class II area that could be redesignated as Class I (EPA 1999a, all; EPA 1999b, all). It is about 35 kilometers (22 miles) southwest of Yucca Mountain.

The construction and operation of a facility in an attainment area could be subject to the requirements of the Prevention of Significant Deterioration program if the facility received a classification as a major source of air pollutants. At present, the proposed repository site and the Nevada Test Site have no sources subject to those requirements (DOE 1996f, page 4-146).

As part of Yucca Mountain site characterization, DOE obtained an air quality operating permit from the State of Nevada (NDCNR 1996, all). The permit places specific operating conditions on various systems that DOE uses during site characterization activities. These conditions include limiting the emission of criteria pollutants, defining the number of hours a day and a year a system is allowed to operate, and determining the testing, monitoring, and recordkeeping required for the system.

In 1989, DOE began monitoring particulate matter at the site of the proposed repository as part of site characterization activities and later as part of the Nevada Air Quality operating permit requirements. Concentration levels of inhalable particles smaller than 10 micrometers in diameter have been well below applicable National Ambient Air Quality Standards, with annual average concentrations 20 to 25 percent of the standard (see Table 3-5).

In 1997, the Environmental Protection Agency issued National Ambient Air Quality Standards for ozone and particulate matter. The new standard for particulate matter (40 CFR 50.7) includes fine particles in the respirable range with diameters smaller than 2.5 micrometers (see Table 3-5). The implementation of this new standard applies to all areas, but initial monitoring will focus on urban areas because (1) this pollutant comes primarily from combustion (auto exhaust, etc.) rather than fugitive dust sources (windblown dust, etc.) and (2) the first priority for monitoring programs is the assessment of densely populated areas.

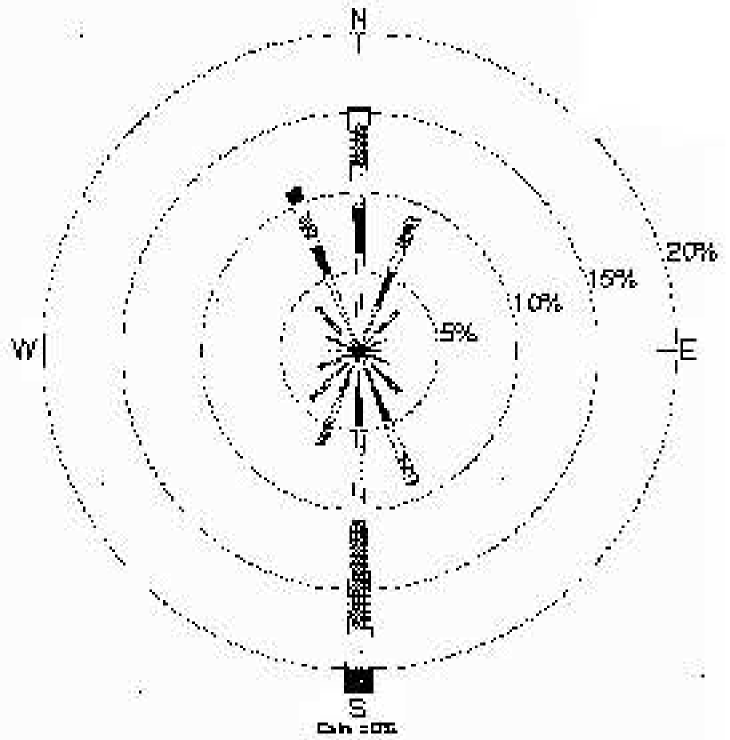
From October 1991 through September 1995, DOE monitored the site of the proposed repository for gaseous criteria pollutants (carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide) as part of site characterization. The concentration levels of each pollutant were well below the applicable National Ambient Air Quality Standards (see Table 3-5). In fact, concentrations of carbon monoxide and sulfur dioxide were not detectable during the entire monitoring period. Nitrogen dioxide was detected occasionally at concentrations of a few parts per billion (around 0.002 part per million) by volume, probably from nearby vehicle exhausts, about 4 percent of the applicable annual average standard (see Table 3-5). Ozone was the only criteria pollutant routinely detected, although these concentrations were barely detectable (0.081 to 0.096 part per million) and ranged from 67 to 80 percent of the 1-hour regulatory standard. The source of the ozone has not been determined, but could be urban areas in southern California. In 1998, the Environmental Protection Agency revoked the 1-hour ozone standard for all counties in the United States with no current measured violations, including all of Nevada and the region around Yucca Mountain, and replaced it with a new 8-hour ozone standard. Nonattainment areas for the new ozone standard will be designated in 2000.

3.1.2.2 Climate

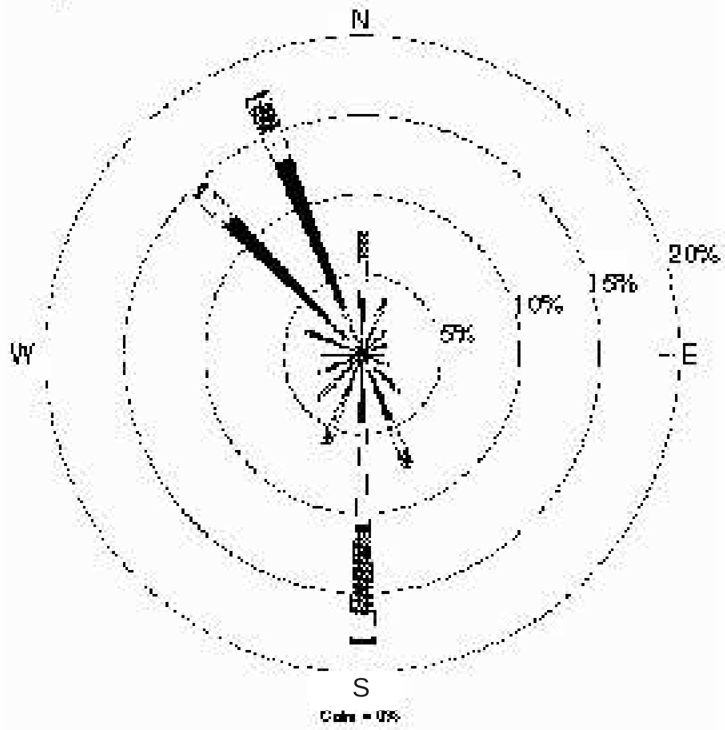
The Yucca Mountain region has a relatively arid climate, with annual precipitation totals ranging between approximately 10 and 25 centimeters (4 and 10 inches) per year (DOE 1998a, Volume 1, page 2-29). Precipitation at a given location depends on nearby topographic features. The winter season is mild, with some periods of below freezing temperatures. Occasional periods of persistent rain have produced more than 5 centimeters (2 inches) of rainfall in daily periods. The summer season is typically hot and dry, with occasional periods of monsoon thunderstorms producing locally large amounts of rain. Storms can produce more than 2.5 centimeters (1 inch) of rain in a matter of hours.

Mean nighttime and daytime air temperatures typically range from 22°C to 34°C (72°F to 93°F) in the summer and from 2°C to 10.5°C (34°F to 51°F) in the winter (TRW 1997a, pages A-1 to A-16). Temperature extremes range from -15°C to 45°C (5°F to 113°F). On average, the daily range in temperature change is about 10°C (18°F). Higher elevations are cooler, though the coldest areas can be in canyons and washes to which heavy cold air flows at night. Relative humidity levels range from about 10 percent on summer afternoons to about 50 percent on winter mornings and to near 100 percent during precipitation events.

In the valleys, airflow is channeled by local topography, particularly at night during stable conditions (TRW 1997a, pages 4-13 to 4-16). With the exception of the nearby confining terrain, which includes washes and small canyons on the east side of Yucca Mountain, local wind patterns have a strong daily cycle of daytime winds from the south and nighttime winds from the north. Confined areas also have daily cycles, but the wind directions are along terrain axes, typically upslope in the daytime and downslope at night. Wind direction can also vary with height. As shown in Figure 3-3, the winds at a height of 60 meters (200 feet) show a strong north-south flow up and down the valley. The winds at



Wind data from 60 meters above ground.



Wind data from 10 meters above ground.

Figure 3-3. Wind rose plots for 10 and 60 meters (33 and 200 feet) above ground in the proposed repository facilities vicinity.

10 meters (33 feet) show a strong southerly flow, but at night the wind pattern reflects more of the drainage flow downslope from Yucca Mountain. Hourly average wind speeds are usually greater than 1.8 meters a second (4 miles an hour), indicating few calm periods. Over the entire monitoring network, the average wind speed ranges from 2.5 to 4.4 meters a second (5.6 to 9.8 miles an hour); the fastest 1-minute wind speeds range from 19 to 33 meters a second (42 to 74 miles an hour); and the peak gusts range from 26 to 38 meters a second (59 to 86 miles an hour). The highest wind speeds typically occur on exposed ridges.

Severe weather can occur in the region, usually in the form of summer thunderstorms. These storms can generate an abundant amount of lightning, strong winds, and heavy and rapid precipitation. Tornadoes can occur, though they are not a substantial threat in the region; four have been recorded within 240 kilometers (150 miles) of the site of the proposed repository during the past 53 years, and one occurred in 1987 in Amargosa Valley about 50 kilometers (30 miles) south of the site (TRW 1997a, page 4-26).

3.1.3 GEOLOGY

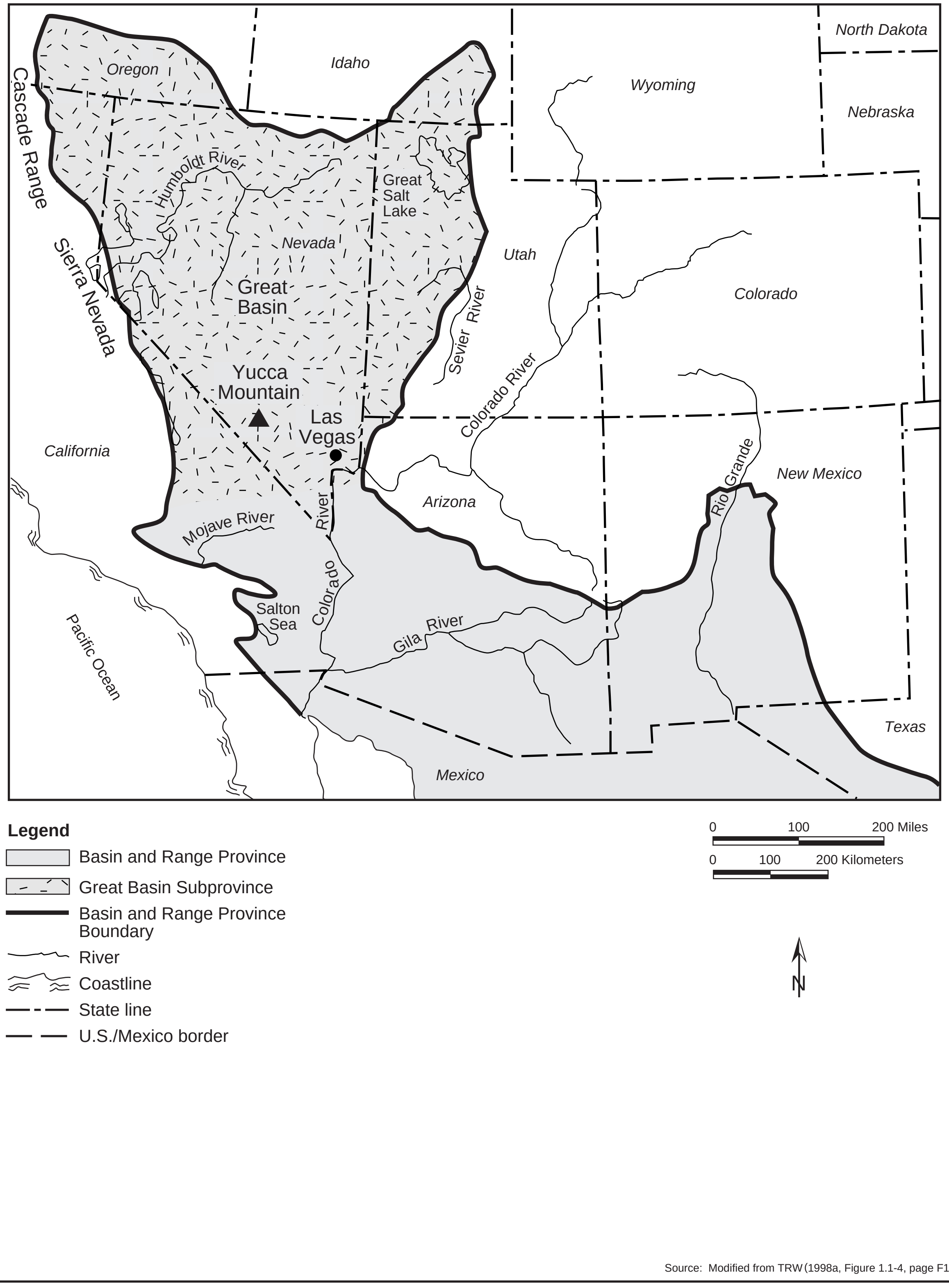
DOE has studied the existing physiographic setting (characteristic landforms), stratigraphy (rock strata), and geologic structure (structural features resulting from rock deformations) at Yucca Mountain and in the surrounding region. These studies have yielded detailed information about the surface and subsurface features in the region. This section describes the baseline conditions of the region's geology. DOE investigated seismicity (earthquake activity) in the Yucca Mountain region; the investigations focused on understanding the Quaternary history of movement on faults in the region and the historic record of earthquake activity. The Department also investigated volcanoes in the Yucca Mountain region to assess the potential for volcanism to result in adverse effects to a repository. In addition, DOE considered the possibility that there might be minerals and energy resources at or near the site of the proposed repository. Unless otherwise referenced, the information in this section is from the *Geology/Hydrology Environmental Baseline File* (TRW 1999h, all), the *Yucca Mountain Site Description* (TRW 1998a, all), or the *Viability Assessment of a Repository at Yucca Mountain* (DOE 1998a, all).

3.1.3.1 Physiography (Characteristic Landforms)

Yucca Mountain is in the southern part of the Great Basin subprovince of the Basin and Range Physiographic Province (Figure 3-4), a region characterized by generally north-trending, linear mountain ranges separated by intervening valleys (basins). The Great Basin encompasses nearly all of Nevada plus parts of Utah, Idaho, Oregon, and California. Mountain ranges of the Great Basin, including Yucca Mountain, are mostly tilted, fault-bounded crustal blocks that are as much as 80 kilometers (50 miles) long and 8 to 24 kilometers (5 to 15 miles) wide. Ranges typically rise from 300 to 1,500 meters (1,000 to 4,900 feet) above the adjacent valley floors and occupy 40 to 50 percent of the total land area.

Valleys between the mountain ranges are filled with alluvial sediments (deposits of sand, mud, and other such materials formed by flowing water) from the adjacent ranges. Most valleys are called *closed basins* because they lack a drainage outlet. Water and sediment from adjacent ranges become trapped and move to the lowest part of such valleys to form a *playa*, a flat area that is largely vegetation-free owing to high salinity, which results from evaporation of the water. Valleys with drainage outlets have intermittent stream channels that carry eroded sediment to lower drainage areas.

The present landscape, distinguished by the broad series of elongated mountain ranges alternating with parallel valleys, is the result of past episodes of faulting that elevated the ranges above the adjacent valleys. Section 3.1.3.2 addresses such faulting. Yucca Mountain is an irregularly shaped volcanic upland, 6 to 10 kilometers (4 to 6 miles) wide and 40 kilometers (25 miles) long. This mountain is part of



Source: Modified from TRW (1998a, Figure 1.1-4, page F1.1-4).

Figure 3-4. Basin and Range Physiographic Province and Great Basin Subprovince.

a volcanic plateau formed between about 14 million and 11.5 million years ago (Sawyer et al. 1994, page 1304) known as the Southwestern Nevada volcanic field. Although Yucca Mountain is a product of both volcanic activity and faulting, the region exhibits evidence of a complex history of deformation associated with past interactions of crustal segments (plates) (TRW 1998a, page 3.2-1). Geologic relations indicate that many of the current features and the landscape in the Yucca Mountain region formed between 12.7 million and 11.7 million years ago (TRW 1998a, page 3.4-2). Remnants of the Timber Mountain caldera (one of the centers of the southwestern Nevada volcanic field from which most of the volcanic rocks on the surface of Yucca Mountain were erupted) and other calderas are north of Yucca Mountain (see Figure 3-5).

CALDERA

A volcanic crater that has a diameter many times that of the vent. It is formed by collapse of the central part of a volcano or by explosions of extraordinary violence. The erupted materials are commonly spread over great distances beyond the caldera. Volcanic debris that erupted from the Timber Mountain and other calderas north of Yucca Mountain formed the southwestern Nevada volcanic field of which the volcanic rocks at Yucca Mountain are a part.

Almost without exception, west-facing slopes at Yucca Mountain are steep and east-facing slopes are gentle, which expresses the underlying geologic structure (see Section 3.1.3.2). Small valleys eroded in the mountain are narrow, V-shaped drainages that flatten and broaden near the mountain base. The crest of Yucca Mountain is between 1,400 meters (4,600 feet) and 1,500 meters (4,900 feet) above sea level. The bottoms of the adjacent valleys are approximately 600 meters (2,000 feet) lower.

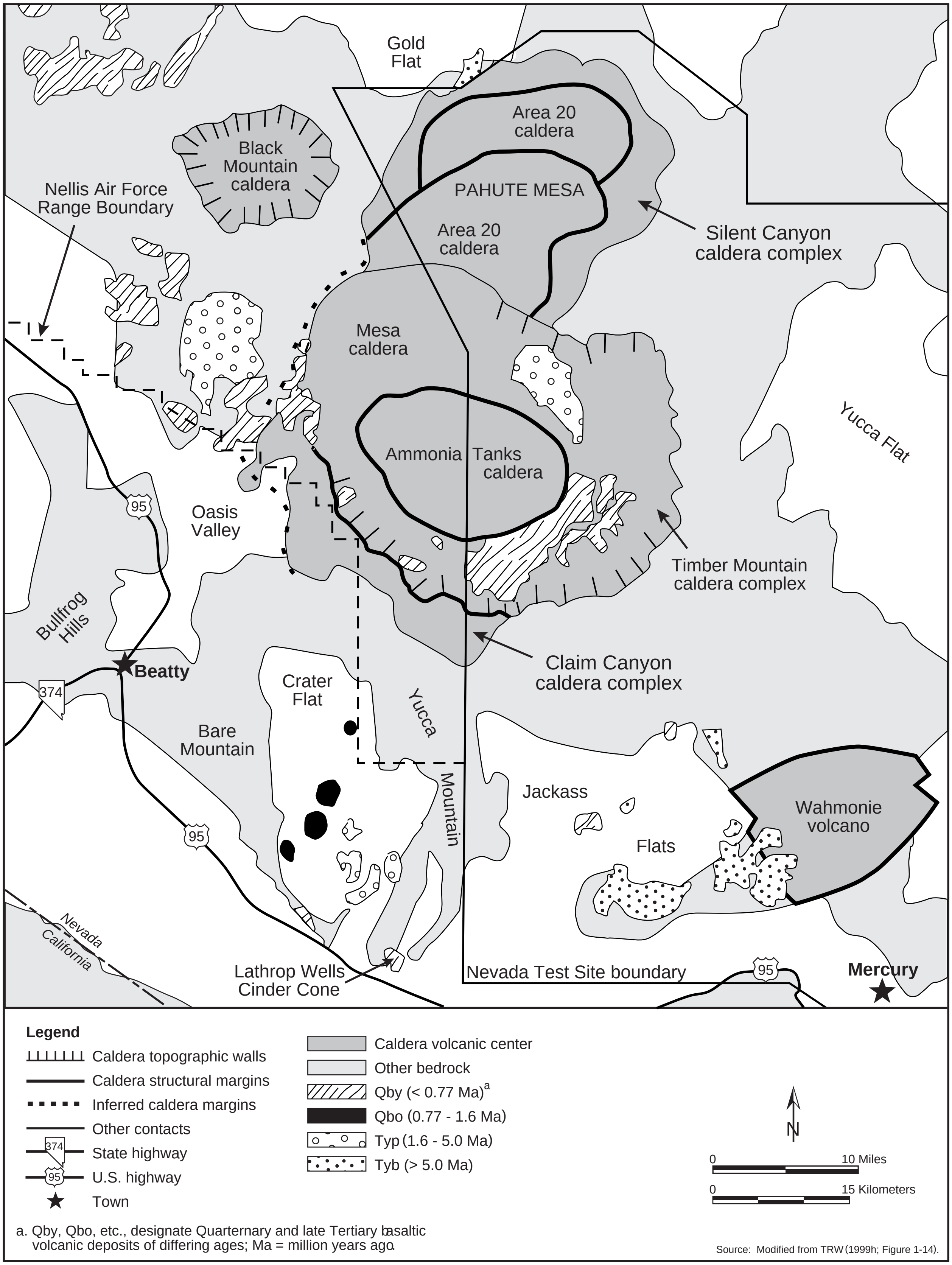
Yucca Mountain is bordered on the north by Pinnacles Ridge and Beatty Wash, on the west by Crater Flat, on the south by the Amargosa Valley, and on the east by the Calico Hills and by Jackass Flats, which contains Fortymile Wash (Figure 3-6). Beatty Wash is one of the largest tributaries of the Amargosa River (see Section 3.1.4.1) and drains the region north and west of Pinnacles Ridge, including the northern end of Yucca Mountain.

Crater Flat (Figure 3-6) is an oval-shaped valley between Yucca Mountain and Bare Mountain. It contains four prominent volcanic cinder cones and related lava flows that rise above the valley floor. Crater Flat drains to the Amargosa River through a gap in the southern end of the basin.

Jackass Flats is an oval-shaped valley east of Yucca Mountain bordered by Yucca, Shoshone, Skull, and Little Skull Mountains (Figure 3-6). It drains southward to the Amargosa River. Fortymile Wash is the most prominent drainage through Jackass Flats to the Amargosa River.

Site Stratigraphy and Lithology

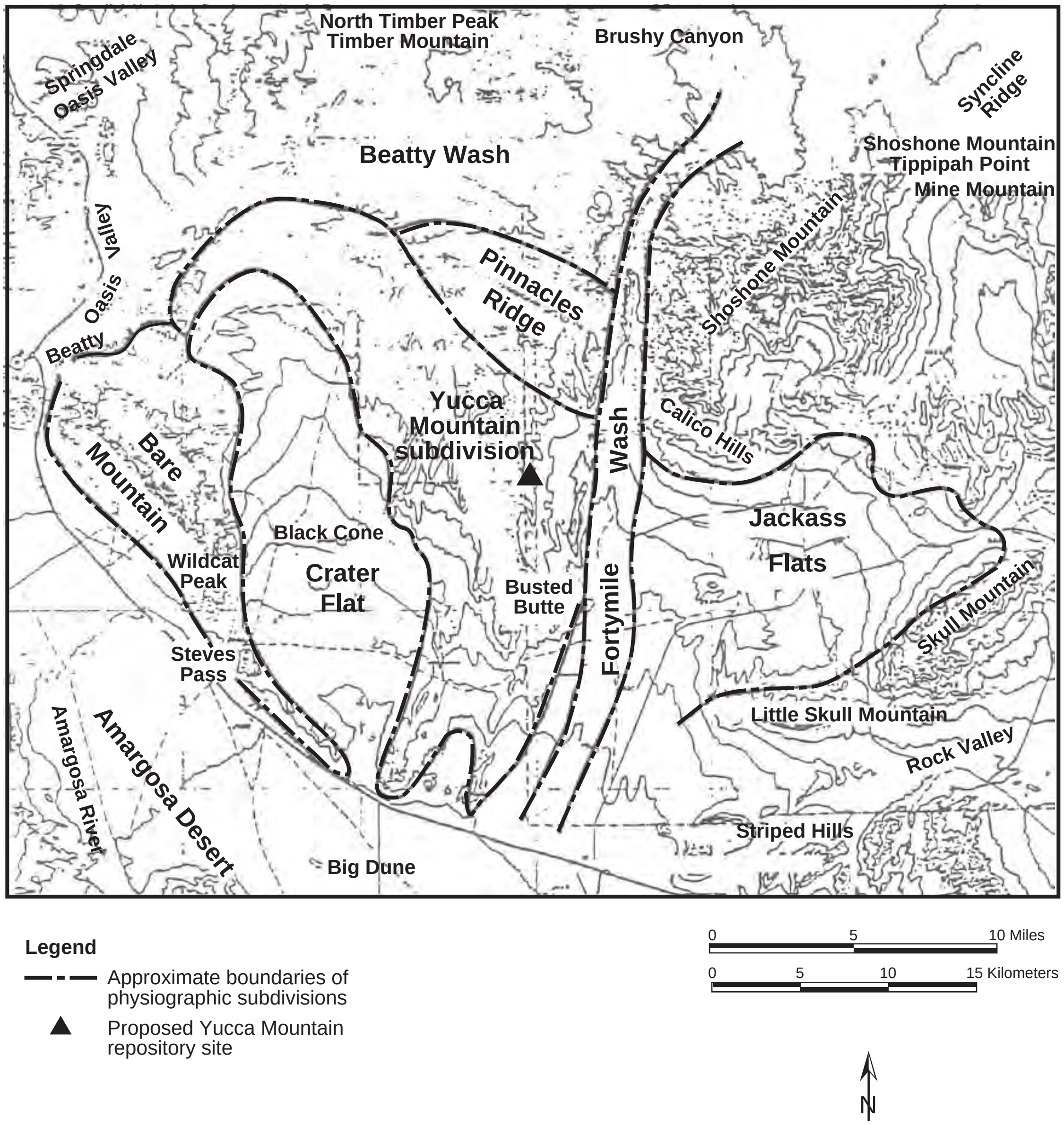
The exposed stratigraphic section at Yucca Mountain is dominated by mid-Tertiary volcanic ash-flow and ash-fall deposits with minor lava flows and reworked materials. These deposits originated in the calderas shown in Figure 3-5. Regionally, the thick series of volcanic rocks that form Yucca Mountain overlies Paleozoic sedimentary rocks that are largely of marine origin. The volcanic rocks, in turn, are covered in many areas by a variety of late Tertiary and Quaternary surficial deposits. The stratigraphic section is summarized in Table 3-6, which depicts rock assemblages according to the geologic age during which they were deposited. The stratigraphic sequence of the Yucca Mountain area consists, from oldest to youngest, of Pre-Cenozoic sedimentary and metasedimentary (sedimentary rocks that have been altered by metamorphism), mid-Tertiary siliceous (rich in silica) volcanic rocks, Tertiary to Quaternary basalts, and late Tertiary to late Quaternary surficial deposits.



a. Qby, Qbo, etc., designate Quarternary and late Tertiary basaltic volcanic deposits of differing ages; Ma = million years ago.

Source: Modified from TRW (1999h; Figure 1-14).

Figure 3-5. Calderas of the southwest Nevada volcanic field in the Yucca Mountain vicinity.



Source: Modified from DOE (1988a, Volume 1, Part A, Figure 1-6, page 1-20).

Figure 3-6. Physiographic subdivisions in the Yucca Mountain vicinity.

Table 3-6. Highly generalized stratigraphy summary for the Yucca Mountain region.[a]

Geologic age designation	Major rock types (lithologies)
Cenozoic Era	
Quaternary Period (< 1.6 Ma)[b]	Alluvium; basalt
Tertiary Period (< 65 - 1.6 Ma)	Silicic ash-flow tuffs; minor basalts. Predominantly volcanic rocks of the southwestern Nevada volcanic field (includes Topopah Spring Tuff, host rock for the potential repository). Table 3-7 lists major volcanic formations at Yucca Mountain.
Mesozoic Era (240 - 65 Ma)	No rocks of this age found in Yucca Mountain region.
Paleozoic Era (570 - 240 Ma)	Three major lithologic groups (lithosomes) predominate: a lower (older) carbonate (limestone, dolomite) lithosome deposited during the Cambrian through Devonian Periods (see Figure 3-15), a middle fine-grained clastic lithosome (shale, sandstone) formed during the Mississippian Period, and an upper (younger) carbonate lithosome formed during the Pennsylvanian and Permian Periods.
Precambrian Era (> 570 Ma)	Quartzite, conglomerates, shale, limestone, and dolomite that overlie older igneous and metamorphic rocks that form the crystalline "basement."

a. Source: Adapted from TRW (1999h, Section 1.2, pages 1-8 to 1-15).
b. Ma = approximate years ago in millions.

Only Tertiary and younger rocks are exposed at Yucca Mountain. Parts of the older (Pre-Cenozoic) rock assemblages described in Table 3-6 are exposed at Bare Mountain (Figure 3-6) about 15 kilometers (9 miles) west of Yucca Mountain and at other localities scattered around the region. Many of these older rocks are widespread in the Great Basin where their cumulative thickness is thousands of feet. Detailed information about their characteristics is lacking at Yucca Mountain because only one borehole, about 2 kilometers (1.2 miles) east of Yucca Mountain, has penetrated these rocks. Paleozoic carbonate rocks were penetrated in this borehole at a depth of about 1,250 meters (4,100 feet) (Carr et al. 1986, page 5-5). Paleozoic carbonate rocks form important aquifers in southern Nevada (Winograd and Thordarson 1975, all).

Table 3-7 lists the principal mid-Tertiary volcanic stratigraphic units mapped at the surface, encountered in boreholes, and examined in the Exploratory Studies Facility that have been a major focus of site characterization investigations. The proposed repository and access to it would be entirely in the Paintbrush Group, so investigations have focused particularly on the formations in that stratigraphic unit. Detailed descriptions of the volcanic stratigraphic units are in the Yucca Mountain Project Stratigraphic Compendium (DOE 1996g, all). The following paragraphs provide a general summary based on the *Yucca Mountain Site Description* (TRW 1998a, pages 3.5-1 to 3.5-28).

The bulk of the volcanic sequence consists of tuffs. Volcanic rocks known as ash-flow tuff (or pyroclastic flow deposits) form when a hot mixture of volcanic gas and ash violently erupts and flows. As the ash settles, it is subjected to various degrees of compaction and fusion depending on temperature and pressure conditions. If the temperature is high enough, glass and pumice fragments are compressed and fused to produce welded tuff (a hard, brick-like rock with very little open pore space in the rock matrix). Nonwelded tuffs, compacted and consolidated at lower temperatures, are less dense and brittle and generally have greater porosity. Ash-fall tuffs are formed from ash that cooled before settling on the ground surface, and bedded tuffs are composed of ash that has been reworked by stream action. All of these are found in the volcanic assemblage at Yucca Mountain.

In general, characterization of the various volcanic units is based on changes in depositional features, the development of zones of welding and devitrification (crystallization of glassy material), and the

Table 3-7. Tertiary volcanic rock sequence at Yucca Mountain.[a]

Name	Age millions of years)	Thickness (meters)[b]	Characteristics
Timber Mountain Group			
• Ammonia Tanks Tuff	11.5	215	Welded to nonweld rhyolite tuff; exposed in southern Crater Flat.
• Rainier Mesa Tuff	11.6	< 30 - 40	Nonwelded to moderately welded vitric to devitrified tuff exposed locally along downthrown sides of large normal faults.
Post-Tiva Canyon, pre-Rainier Mesa Tuffs	12.5	0 - 61	Pyroclastic flows and fallout tephra deposits in subsurface along east flank of Yucca Mountain.
Paintbrush Group			Four formations (below) interlayered locally with lava flows and reworked volcanic deposits.
• Tiva Canyon Tuff	12.7	< 50 - 175	Crystal-rich to crystal-poor densely welded rhyolite tuff that forms most rock at surface of Yucca Mountain.
• Yucca Mountain Tuff	--[c]	0 - 45	Mostly nonwelded tuff but is partially to densely welded where it thickens to north and west.
• Pah Canyon Tuff	--	0 - 70	Northward-thickening nonwelded to moderately welded tuff with pumice fragments.
• Topopah Spring Tuff	12.8	Maximum: 380	Rhyolite tuff divided into upper crystal-rich member and lower crystal-poor member. Each member contains variations in lithophysal content, zones of crystallization, and fracture density. Glassy unit (vitrophyre) present at the base. Proposed host for repository.
Calico Hills Formation	12.9	15 - 460	Northward-thickening series of pyroclastic flows, fallout deposits, lavas, and basal sandstone; abundant zeolites except where entire formation is vitric in southwest part of central block of Yucca Mountain.
Crater Flat Group			Pyroclastic flows and interbedded tuffs of rhyolitic composition distinguished by abundance of quartz and biotite.
• Prow Pass Tuff	13.1	60 - 228	Sequence of variably welded pyroclastic deposits.
• Bullfrog Tuff	13.3	76 - 275	Partially welded, zeolytic upper and lower parts separated by a central densely welded tuff.
• Tram Tuff	13.5	60 - 396	Lower lithic-rich unit overlain by upper lithic-poor unit.
• Lithic Ridge Tuff	14.0	185 - 304	Southward thickening wedge of welded and nonwelded pyroclastic flows and interbedded tuff extensively altered to clays and zeolites.
Pre-Lithic Ridge	+14.0	180 - 345+	Mostly altered pyroclastic flows, lavas, and bedded tuff of rhyolitic composition.

a. Modified from TRW (1999h, pages 1-16 to 1-28).
b. To convert meters to feet, multiply by 3.208.
c. -- = no absolute dates.

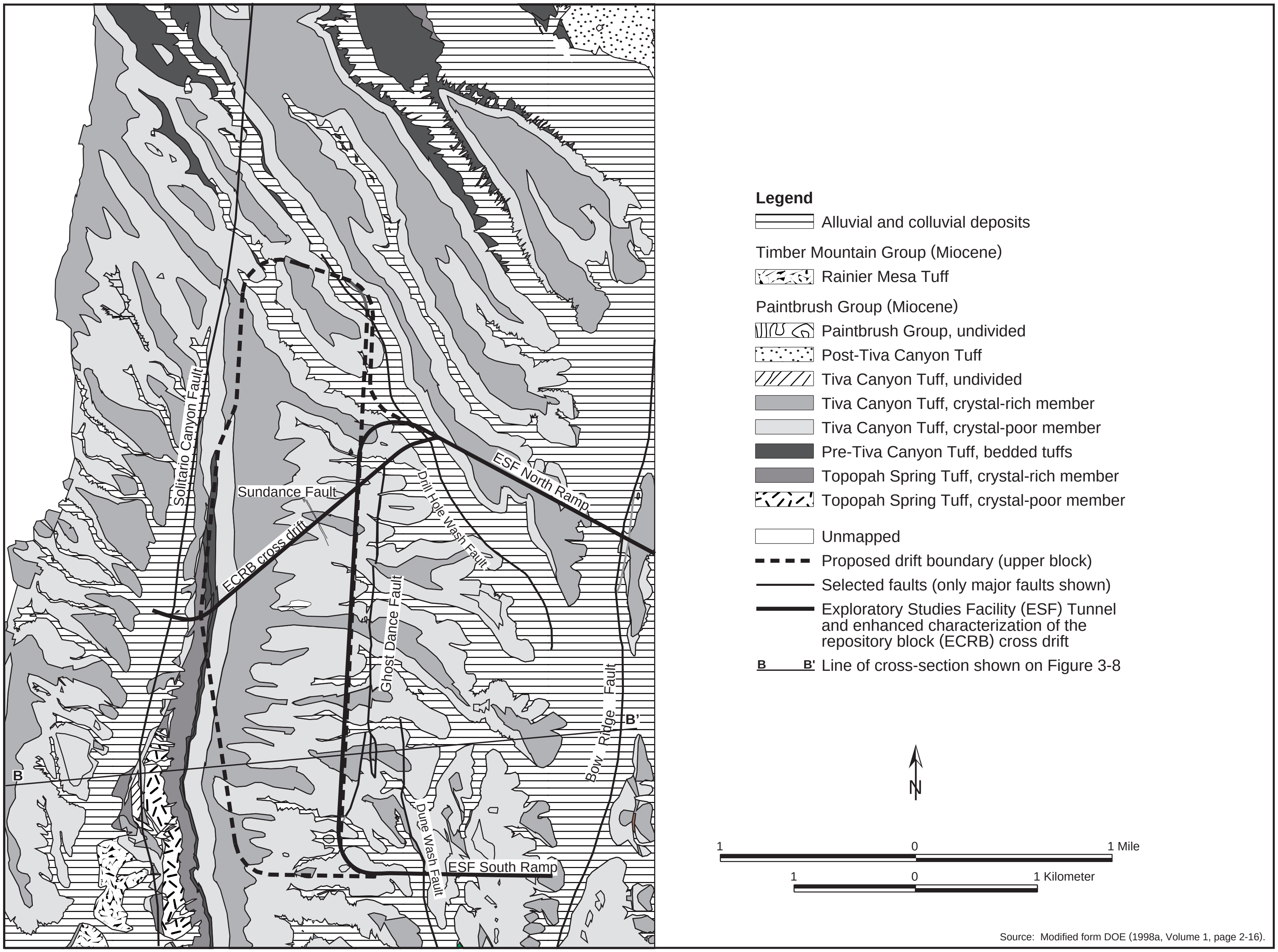
development of alteration products in some rocks. Mineral and chemical composition and properties such as density and porosity also have been used in distinguishing some units. Most of the formations listed in Table 3-7 contain phenocrysts (mineral grains distinctly larger than the surrounding rock matrix) and lithic clasts (rock fragments), have some part that is at least partially welded, and typically have some part that has devitrified during cooling of the deposit. In addition, the vitric (glassy) parts of many formations have been partly altered to clay and zeolite minerals, and all the rocks have developed various amounts of fractures, some of which contain secondary mineral fillings.

Lithophysal cavities are prominent features in some units, notably in the Tiva Canyon and Topopah Spring Tuffs, where they range from 1 to 50 centimeters (0.4 to 20 inches) in diameter and are a basis for the further subdivision of these formations. Lithophysal cavities are voids resulting from vapors trapped in densely welded parts of the formations. Lithophysal zones contain fewer fractures compared to nonlithophysal zones.

Although welded tuffs dominate the volcanic sequence, bedded tuffs are present in the Paintbrush Group and in some older parts of the sequence. Joints and fractures are common in the welded tuffs, producing much greater bulk permeabilities than those of the nonwelded and bedded tuffs. This is an important distinction with regard to investigation of hydrologic conditions.

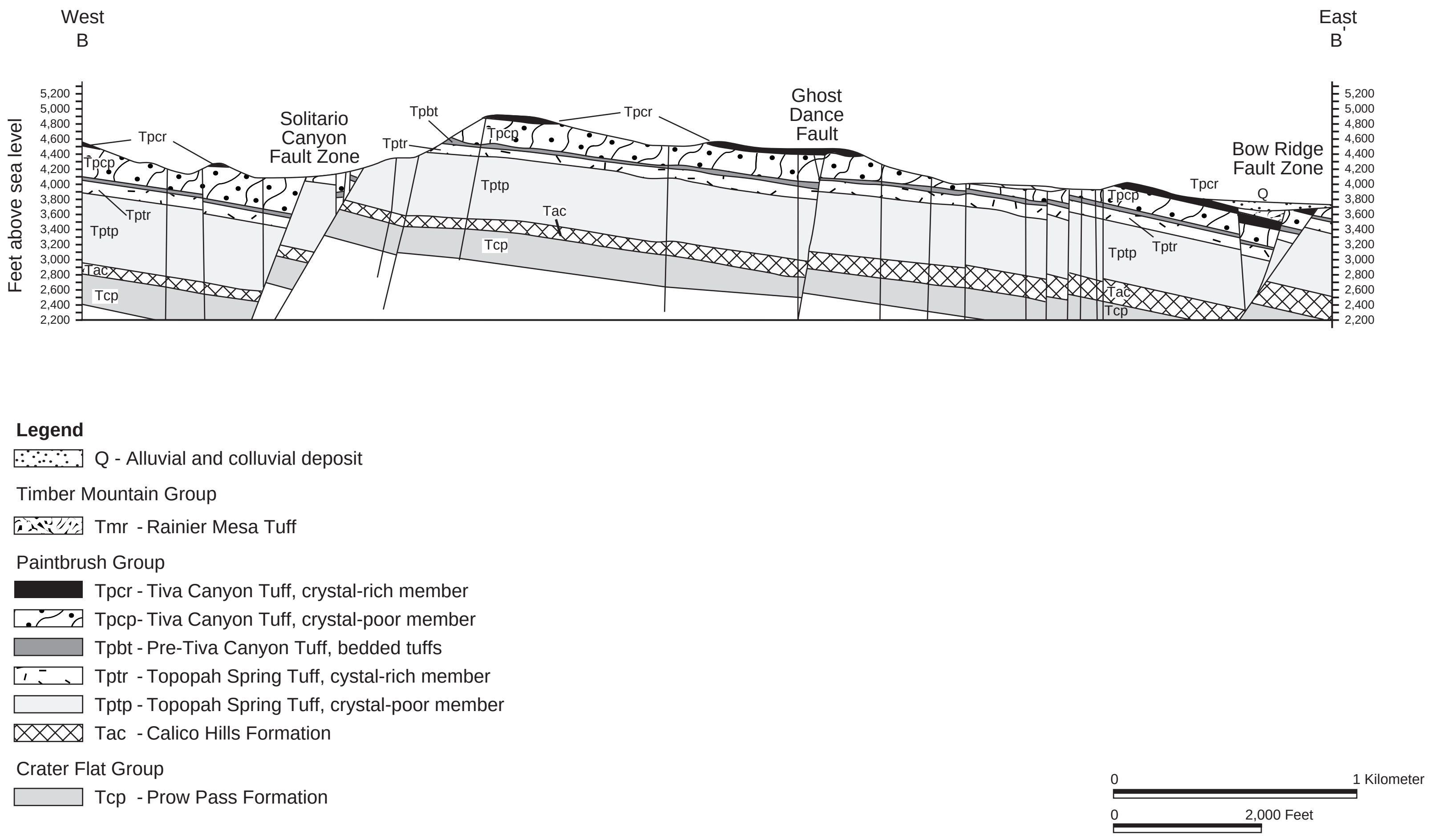
Some parts of the volcanic formations contain secondary mineral products created by alteration of the original materials after their original deposition and consolidation. Some alteration has resulted from reactions with groundwater, and the types of new mineral substances found can differ based on occurrence below or above the water table. Alteration products such as clay minerals and zeolites occur in several parts of the volcanic sequence; in some places, in-filling with zeolites has reduced the porosity and thus affected hydrologic properties. In most of the formations, contacts between vitric and devitrified layers are commonly marked by an interval containing clay or zeolite alteration minerals. A notable example is the interval, as much as several meters thick, where glassy rock at the base of the Topopah Spring Tuff (the basal vitrophyre) is in contact with the overlying nonlithophysal zone; this interval of alteration occurs in most boreholes in the vicinity of the proposed site. Subtle differences in geochemical conditions are believed to have given rise locally over short distances to some unusual zeolites. One in particular is the fibrous zeolite erionite, which is a potential human health hazard (see Section 3.1.8). Data from rock samples show that in the potential repository horizon erionite, if it occurs, is either in the altered zone immediately above the Topopah Spring lower vitrophyre or in the moderately welded zone underlying this vitrophyre. It has also been identified in the lower Tiva Canyon Tuff (DOE 1998a, Volume 1, page 2-25).

Figure 3-7 is a geologic map that shows the surficial distribution of Tertiary volcanic units and younger surficial deposits in the vicinity of the proposed site. Figure 3-8 is a vertical cross-section through the southern part of this area that shows the subsurface expression of the mapped units, including structural aspects (east-dipping rock units and predominantly west-dipping normal faults). Volcanic rocks younger than the Tertiary units occur locally at and in the Yucca Mountain vicinity but are of limited extent (Figure 3-5). They represent such relatively quiet, nonexplosive eruptions of basaltic materials as lava flows and cinder cones. Examples include the lava flows that cap Skull and Little Skull Mountains at the south and southeast margins of Jackass Flats, a basalt ridge that forms the southern boundary of Crater Flat, and a basaltic dike dated at 10 million years that intrudes in the northern part of the Solitario Canyon fault, which bounds the west flank of Yucca Mountain. A north-trending series of cinder cones and lava flows on the southeast side of Crater Flat has been dated at 3.7 million years, and in the center of Crater Flat a series of four northeast-trending cinder cones (Qbo in Figure 3-5) has been dated at about 1 million years. The youngest basaltic center is the Lathrop Wells center, which is a single cone estimated to be 75,000 years old.



Source: Modified form DOE (1998a, Volume 1, page 2-16).

Figure 3-7. General bedrock geology of the proposed repository Central Block Area.



Note: Line of cross-section indicated on Figure 3-7. Faults consistent with Figure 3-10.

Source: Modified from DOE (1998a, Volume 1, page 2-17).

Figure 3-8. Simplified geologic cross-section of Yucca Mountain, west to east.

The youngest stratigraphic units at Yucca Mountain are the predominantly unconsolidated surficial deposits of late Tertiary and Quaternary age. They are shown in Figure 3-7 as alluvium (material such as sand, silt, or clay deposited on land by water) and colluvium (loose earth material that has accumulated at the base of a hill through the action of gravity) but have been classified in more detail as stream (alluvial) deposits, hillslope (colluvial) deposits, spring deposits, and windblown (eolian) deposits (TRW 1998a, pages 3.4-1 to 3.4-33). Most Quaternary units exposed at the surface were deposited during the last 100,000 years (DOE 1998a, Volume 1, page 2-26). The bulk of these consist of alluvium deposited by intermittent streams that transported rock debris from hillslopes to adjacent washes and valleys.

Selection of Repository Host Rock

Selection of the Topopah Spring tuff as the repository host rock was based on several considerations, which include (1) depth below the ground surface sufficient to protect nuclear waste from exposure to the environment, (2) extent and characteristics of the host rock, (3) location of faults that could adversely affect the stability of underground openings or act as pathways for water flow that could eventually lead to radionuclide release, and (4) location of groundwater in relation to the proposed repository (TRW 1993, pages 5-99 to 5-101).

DOE selected the middle to lower portion of the Topopah Spring tuff as the potential repository horizon. The rock is strongly welded with variable fracture density and void space; experience gained from the excavation of the Exploratory Studies Facility shows the capability to construct stable openings in this rock. Thermal and mechanical properties of this section of rock should enable it to accommodate the range of temperatures anticipated (thermal properties will not be affected greatly by construction and operation, as compared to postemplacement), and the identified repository volume is between major faults. Finally, the selected repository horizon is well above the present groundwater table. Based on geologic evidence the water table under Yucca Mountain has not been more than about 100 meters (330 feet) higher than its present level in the past several hundred thousand years; at such levels the water table would still be about 100 to 200 meters (330 to 660 feet) below the selected repository horizon (DOE 1998a, Volume 1, page 2-24). Section 3.1.4 discusses the water table level further.

Potential for Volcanism at the Yucca Mountain Site

DOE has performed extensive investigations to determine the ages and nature of the volcanic episodes that produced the rocks described above (see Chapter 5). The rocks that form the southwestern Nevada volcanic field, characterized by large-volume silicic ash flows (including the host rock for the proposed repository), were erupted during a period of intense tectonic activity associated with active geologic faulting (Sawyer et al. 1994, all). The volcanism that produced these ash flows is complete and, based on the geology of similar volcanic systems in the Great Basin, no additional large-volume silicic activity is likely.

Basaltic volcanism in the Yucca Mountain region began about 11 million years ago as silicic eruptions waned and continued as recently as about 75,000 years ago (TRW 1998a, pages 3.2-18 and 3.2-19). Basaltic volcanic events were much smaller in magnitude and less explosive than the events that produced the ash flows mentioned above. Typical products are the small volcanoes or cinder cones and associated lava flows in Crater Flat (about 1 million years old) and the Lathrop Wells volcano (possibly as young as 75,000 years).

Differing views on the likelihood of volcanism near Yucca Mountain result from uncertainties in the hazard assessment. To address these uncertainties, DOE has performed analyses, conducted extensive volcanic hazard assessments, considered alternative interpretations of the geologic data, and consulted with recognized experts, representing other Federal agencies (for example, the U.S. Geological Survey), national laboratories, and universities (for example, the University of Nevada and Stanford University). A panel of 10 scientists with expertise in volcanism reviewed the extensive information on volcanic activity in the Yucca Mountain vicinity and assessed the likelihood that future volcanic activity could occur at or in the vicinity of the repository.

The probability of basaltic lava intruding into the repository is expressed as the annual probability that a volcanic event would disrupt (intersect) a repository, given that a volcanic event would occur during the period of concern. In 1995 and 1996, DOE convened the panel of recognized experts representing other Federal agencies (for example, the U.S. Geological Survey, national laboratories) and universities (for example, the University of Nevada and Stanford University) to assess uncertainties associated with the data and models used to evaluate the potential for disruption of the potential Yucca Mountain Repository by a volcanic intrusion (dike) (Geomatrix and TRW 1996, all). The panel estimated the probability of a dike disrupting the repository during the first 10,000 years after closure to be 1 chance in 7,000.

3.1.3.2 Geologic Structure

Geologic structures (folds, faults, etc.) are features that result from deformation to rocks after their original formation. The present-day geologic structure of the Great Basin, including the Yucca Mountain region, is the cumulative product of multiple episodes of deformation caused by both compression and extension (stretching) of the Earth’s crust.

Major crustal compression occurred in the Great Basin between about 350 million and 50 million years ago, which resulted in older rocks being thrust over younger rocks for great distances (for example, thrust faults) to produce mountains. During the last 15 million years, crustal extension has resulted in the pattern of elongated mountain ranges and intervening basins. Crustal extension has resulted in vertical, lateral, and oblique movements (Figure 3-9). By about 11.5 million years ago the present mountains and valleys were well developed (Scott and Bonk 1984, all; Day et al. 1996, all).

Figure 3-7 shows the bedrock geology at the Yucca Mountain site and Figure 3-8 shows geologic structure. Figure 3-10 shows the surface traces of faults and their characteristic northerly alignment.

The crustal extension during the last 15 million years fractured the crust along the generally north-trending normal faults. Some of the crustal blocks were downdropped and tilted by movement along their bounding faults (called block-bounding faults). The estimated total displacement along the major north-trending block-bounding faults during the last 12 million years ranges from less than 100 meters (330 feet) to as much as 600 meters (2,000 feet).

The total estimated displacement along the most active north-trending block-bounding faults in the Yucca Mountain region during the past 1.6 million years is less than 50 meters (165 feet) (Simonds et al. 1995, all). During the last 730,000 years the total displacement of north-trending block bounding faults has been as much as 6 meters (20 feet). However, during the past 128,000 years the typical total displacement has been about 1 to 2.5 meters (about 3.3 to 8 feet).

Table 3-8 lists the characteristics of the faults that are important to an understanding of seismic hazards to the potential repository. The Solitario Canyon fault along the west side of Yucca Mountain is the major block-bounding fault. The proposed repository has been configured so that there would be no block-bounding faults in the emplacement zone.

Between the major north-trending, block-bounding faults are many subsidiary northwest-trending faults with smaller displacements (Scott and Bonk 1984, all). There is no clear evidence that displacements have occurred along these subsidiary faults during the last 1.6 million years (Simonds et al. 1995, all). One short northwest-trending subsidiary fault, called the Sundance fault, transects the potential repository area (Figure 3-10). In addition, there is one intrablock fault, called the Ghost Dance fault, in the area of

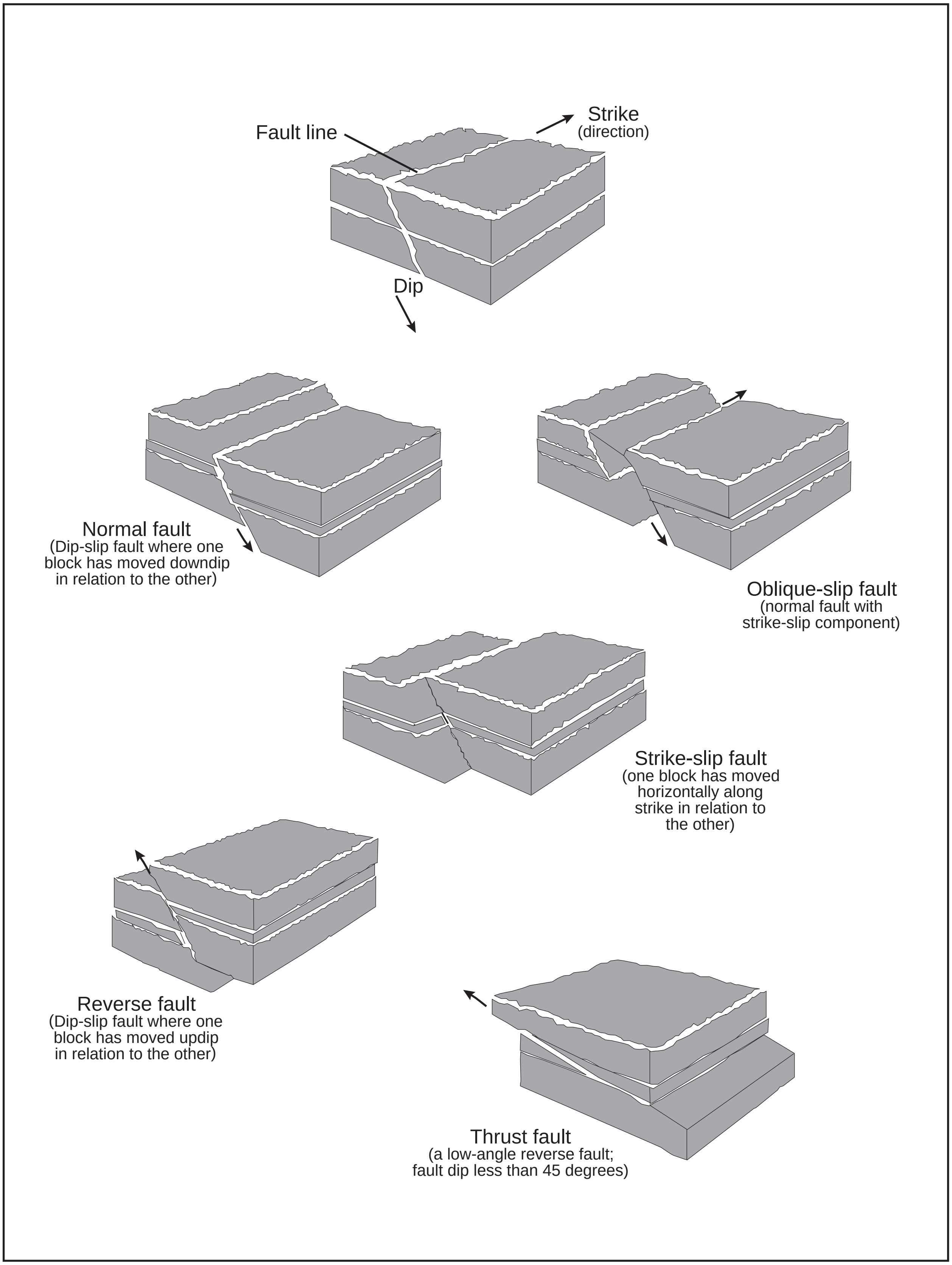
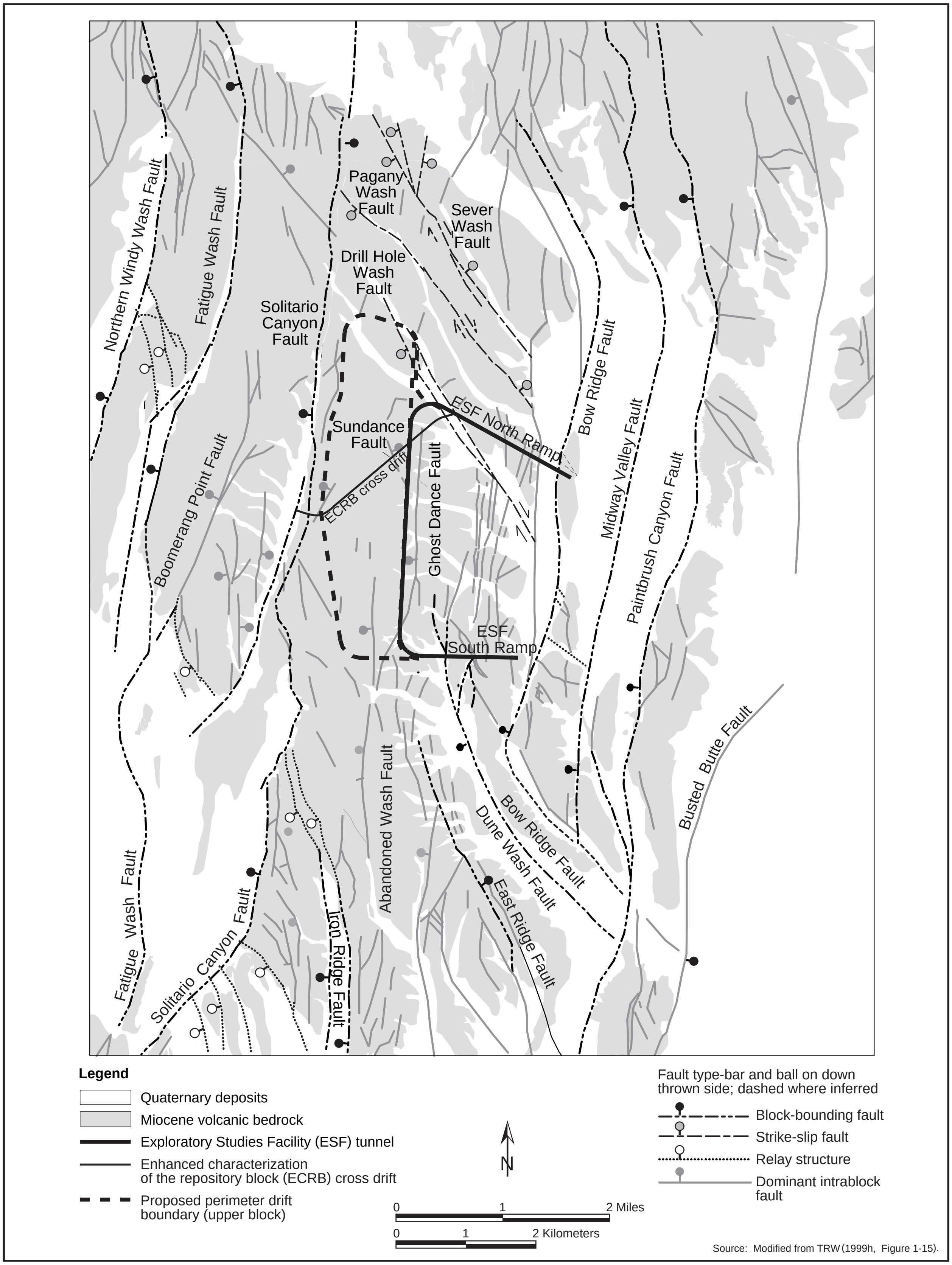


Figure 3-9. Types of geologic faults.



Source: Modified from TRW (1999h, Figure 1-15).

Figure 3-10. Mapped faults at Yucca Mountain and in the Yucca Mountain vicinity.

Table 3-8. Characteristics of major faults at Yucca Mountain.[a]

Fault	Surface features	Evidence of late Quaternary displacement	Quaternary displacement (past 1.6 million years)	Total displacement; type of movement	Fault length (kilometers)[b] and dip
Windy Wash fault[c]	East-facing fault-line scarps in alluvium; bedrock-alluvium fault contacts; merges with Fatigue Wash fault.	Two trenches show multiple ruptures; basalt ash in fault plane; fractures and scarps in alluvium.	1 meter[d] in late Quaternary; < 0.1 meter during past 10,000 years.	Increases southward to 500 meters; dip-slip, west side down.	3 - 25; 61° west.
Fatigue Wash fault[c]	Bedrock and alluvial scarps; fault-line scarps, lineaments in alluvium; merges with Fatigue Wash fault.	One trench shows multiple ruptures; basalt ash in fault plane; fractures and scarps in alluvium.	2.2 meters in late Quaternary.	72 meters; oblique left-lateral, west side down.	9.5 - 17; 71° west.
Solitario Canyon fault[c]	Prominent fault-line scarp; discontinuous fault traces; subtle scarps in alluvium; merges with Stagecoach Road fault.	Nine trenches show multiple ruptures; basalt ash in fault plane; fractures and scarps in alluvium.	1.7 - 2.5 meters in late Quaternary.	Increases southward from 61 meters to > 500 meters; oblique left-lateral, down on east at north end, down on west at south end.	12.5 - > 21; 68° to 71° west.
Ghost Dance fault zone[e]	Bedrock fault in zone of subparallel minor faults and breccia zones.	None	None	Increases southward from 0 - 30 meters; dip-slip, west side down.	3 - 9; ~vertical.
Bow Ridge fault[c]	Fault-line scarp along bedrock/alluvium contact; subtle lineaments; may merge with Paintbrush Canyon fault.	Five trenches show multiple ruptures; basalt ash in fault plane; fractures and scarps in alluvium.	0.5 - 1.3 meters in late Quaternary.	125 meters; oblique left-lateral, west side down.	0.8 - 107; 75° west.
Midway Valley fault[c]	None, fault located on basis of geophysical evidence.	None	None	40 - 60 meters; dip-slip, west side down.	1 - 8 ; west[f]
Paintbrush Canyon fault[c]	Bedrock and alluvial faults, scarps, and lineaments; possibly merges with Stagecoach Road fault.	Four trenches and exposures at Busted Butte show multiple ruptures; basalt ash in fault plane; fractures in alluvium.	1.7 - 2.7 meters (4.6 - 6.3 meters at Busted Butte in last 730,000 years).	250 - 300 meters; dip-slip and oblique left-lateral, west side down.	10 - > 26; 75° west.
Northwest-trending faults[g]	Bedrock faults with local scarps; most located by drilling and geophysical surveys.	None, with the exception of one trench across Pagany Wash fault showing possible Quaternary displacement.	None (see column to left).	40 meters right-lateral, 5 - 10 meters vertical.	2 - 8 per fault; > 70° south.

a. Source: Modified from TRW (1999h, Table 1-2, pages 1-40 and 1-41).
b. To convert kilometers to miles, multiply by 0.62137.
c. Block-bounding fault.
d. To convert meters to feet, multiply by 3.2808.
e. Intrablock fault.
f. The dip and direction of this fault are uncertain.
g. Subsidiary faults (to be verified).

the proposed repository. The Ghost Dance fault has a near-vertical dip from the surface to the depth of the repository (TRW 1998a, page 3.6-24). This fault crosses the Exploratory Studies Facility tunnel. There is no evidence of Quaternary movement along the Ghost Dance fault (Table 3-8).

DOE identified and described alternative tectonic models to explain the current geologic structure resulting from past tectonic processes and deformation events that have affected the Yucca Mountain site. These models are described in the *Yucca Mountain Site Description* (TRW 1998a, Section 3.3), and were considered by the experts in the Probabilistic Seismic Hazard Analysis (USGS 1998, all) discussed below. Computer models provide a means of integrating data on volcanism, deposition, and fault movement, and include a representation of the existing geologic structures and the processes that operate at depth. Tectonic models provide a basis for evaluating the processes and events that could occur in the future and potentially affect the performance of a repository. The DOE hazard assessments used models that are supported by data.

3.1.3.3 Modern Seismic Activity

DOE has monitored seismic activity at the Nevada Test Site since 1978. The epicenters of many earthquakes that the Southern Great Basin Seismic Network has located within 20 kilometers (12 miles) of Yucca Mountain do not correlate with mapped surface traces of Quaternary faults. This lack of correlation is a common feature of earthquakes, particularly those of smaller magnitude, in the Great Basin and elsewhere. Earthquakes in the Yucca Mountain region have focal depths (the point of origin of an earthquake below the ground surface) ranging from near-surface to about 15 kilometers (9 miles). The earthquake focal mechanisms are strike-slip to normal oblique-slip along moderately to steeply dipping fault surfaces. These focal mechanisms indicate the nature of the fault planes on which the earthquakes occur, as shown in Figure 3-9.

The largest recorded historic earthquake within 50 kilometers (30 miles) of Yucca Mountain was the Little Skull Mountain earthquake in 1992, which had a Richter magnitude of 5.6. This seismic event occurred about 20 kilometers (12 miles) southeast of Yucca Mountain, about a day after the magnitude 7.3 earthquake at Landers, California, 300 kilometers (190 miles) south-southeast of Yucca Mountain. The Little Skull Mountain event caused no damage at Yucca Mountain, although some damage occurred at the Field Office Center in Jackass Flats about 5 kilometers (3 miles) north of the epicenter.

Seismic Hazard

DOE based the design ground motion and fault displacement that could be associated with future earthquakes at Yucca Mountain on the record of historic earthquakes in the Great Basin, evaluation of prehistoric earthquakes based on investigations (trenching and detailed mapping) of the faults at Yucca Mountain, and observation of ground motions associated with modern earthquakes using the Southern Great Basin Seismic Network.

Experts have evaluated site data and other relevant information (including differing models) to assess where and how often future earthquakes will occur, how large they will be, how much offset will occur at the Earth’s surface, and how ground motion will diminish as a function of distance. Two panels of scientific experts conducted the Probabilistic Seismic Hazard Analysis (USGS 1998, all); one panel characterized sources of future earthquakes and their potential for surface fault displacement and the second addressed ground motion for the Yucca Mountain region. The results of this analysis are hazard curves that show the ground motions and potential fault displacements plotted with annual frequency of being exceeded. These are used to determine the design-basis ground motions and to assess the postclosure performance of the site.

The expert assessments indicate that geologic fault displacement hazard is generally low. For locations not on a major block-bounding fault, displacements greater than 0.1 centimeter (0.04 inch) will be exceeded an average of less than once in 100,000 years, whereas the mean displacements that are likely to be exceeded on the block-bounding Bow Ridge and Solitario Canyon faults are 7.8 and 32 centimeters (3.1 and 13 inches), respectively. Mitigating potential fault displacement effects would involve avoiding faults in laying out repository facilities.

Ground motion studies have investigated the level of shaking produced at Yucca Mountain by both local and regional earthquakes, and have estimated expected ground motion from hypothetical earthquakes. These predictions of probable ground motion amplitudes and frequencies support preliminary design requirements (the Exploratory Studies Facility), and future studies will provide additional site-specific information on soil and rock properties that will enable refinement of preliminary results and facilitate design analyses to mitigate seismic risk to a potential repository (DOE 1998a, Volume 1, pages 2-86 and 2-87).

The seismic design basis for the repository specifies that structures, systems, and components important to safety should be able to withstand the horizontal motion from an earthquake with a return frequency of once in 10,000 years (annual probability of occurrence of 0.0001) (Kappes 1998, page VII-3). A recent comprehensive evaluation of the seismic hazards associated with the site of the proposed repository (USGS 1998, Figure 7-4) concluded that a 0.0001-per-year earthquake would produce peak horizontal accelerations at a reference rock site at Yucca Mountain of about 0.53*g* (mean value). DOE needs to complete additional investigations of ground motion site effects before it can produce the final seismic design basis for the surface facilities.

A recent study published in *Science* magazine (Wernicke et al. 1998, all) claims that the crustal strain rates in the Yucca Mountain area are at least an order of magnitude higher than would be predicted from the Quaternary volcanic and tectonic history of the area. If higher strain rates are present, the potential volcanic and seismic hazards would be underestimated on the basis of the long-term geologic record.

As part of the Yucca Mountain site characterization activities, DOE established a 13-station, 50-kilometer (30-mile), geodetic array, centered on Yucca Mountain, and conducted surveys in 1983, 1984, and 1993. As interpreted by Savage et al. (1994, all), the surveys indicated no large strain accumulation and thus do not support the claims in Wernicke et al. (1998, all). The Yucca Mountain array was resurveyed in 1998 (Savage, Svarc, and Prescott 1998, all). After correction for deformation associated with the Little Skull Mountain earthquake, the data continue to indicate a strain rate about an order of magnitude lower than that reported by Wernicke et al. (1998, all).

DOE is continuing to monitor crustal strain in the Yucca Mountain region to determine if it can confirm the results of Wernicke et al. (1998, all). Through the University of Nevada, DOE is supporting continued monitoring by Dr. Wernicke. If the higher crustal strain rates are confirmed, DOE will reassess the volcanic and seismic hazard at Yucca Mountain.

3.1.3.4 Mineral and Energy Resources

The southern Great Basin contains valuable or potentially valuable mineral and energy resources, including deposits with past or current production of gold, silver, mercury, base metals, and uranium. The proximity of known deposits and the identification of similar geologic features at Yucca Mountain have led some investigators to propose that the analyzed Yucca Mountain land withdrawal area (see Figure 3-2) could have the potential for mineral resources (Weiss, Noble, and Larson 1996, page 5-26).

DOE site investigations included evaluation of the potential for mineral and energy resources in the analyzed withdrawal area because the presence of such resources could lead to exploration and inadvertent human intrusion (see Chapter 5). The *Yucca Mountain Site Description* (TRW 1998a, Section 3.11) describes results of investigations that address relevant natural resources. Site characterization investigators identified no economic deposits of base or precious metals, industrial rocks or minerals, and energy resources, based on present use, extraction technology, and economic value of the resources. DOE believes the potential for economically useful mineral or energy resources in the analyzed Yucca Mountain withdrawal area is low.

3.1.4 HYDROLOGY

This section describes the current hydrologic conditions in the Yucca Mountain region in terms of surface-water and groundwater system characteristics. Unless otherwise specified, the primary references for this section are the *Environmental Baseline File for Water Resources* (TRW 1999i, all) and the *Geology/Hydrology Environmental Baseline File* (TRW 1999h, all). Section 3.1.4.1 describes surface-water conditions, and Section 3.1.4.2 describes groundwater conditions.

The hydrologic system in the Yucca Mountain region is characterized and influenced by a very dry climate, limited surface water [annual average precipitation of about 10 to 25 centimeters (4 to 10 inches) (Section 3.1.2.2), potential evaporation of almost 170 centimeters (66 inches) per year (DOE 1998a, Volume 1, page 2-29)], and deep aquifers. Important characteristics of the hydrologic system include drainages and streambeds, streams, springs, and playa lakes. In addition, water quantity and quality are important characteristics. Yucca Mountain is in the Alkali Flat-Furnace Creek Ranch sub-basin of the larger Death Valley Regional Groundwater Flow System. Death Valley is a terminal hydrologic basin; surface water and groundwater cannot leave except by evapotranspiration (Luckey et al. 1996, page 30). Important characteristics of the groundwater system include recharge zones (areas where water infiltrates from the surface and reaches the saturated zone), discharge points (locations where groundwater reaches the surface), unsaturated zones (the portion of the groundwater system above the water table), saturated zones (the portion of the groundwater system below the water table), and aquifers (water-bearing layers of rock that provide water in usable quantities). In combination, these characteristics define the quantity and quality of the available groundwater. This section also describes groundwater use as part of the system.

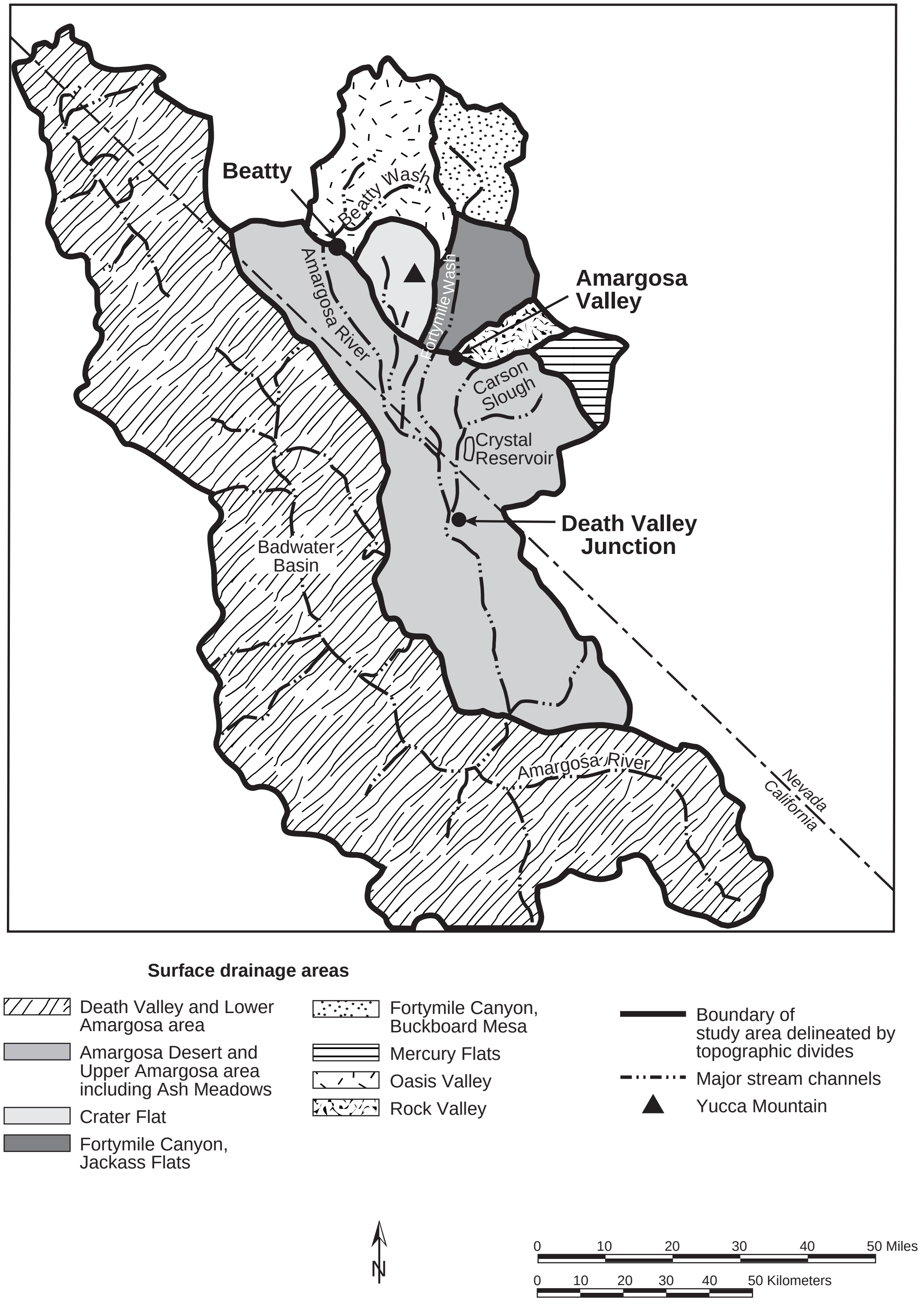
EVAPOTRANSPIRATION

Evapotranspiration is the loss of water by evaporation from the soil and other surfaces, including evaporation of moisture emitted or transpired from plants.

3.1.4.1 Surface Water

3.1.4.1.1 *Regional Surface Drainage*

Yucca Mountain is in the southern Great Basin, which generally lacks permanent streams and other surface-water bodies. The Amargosa River system drains Yucca Mountain and the surrounding areas (Figure 3-11). Although referred to as a river, the Amargosa and its tributaries (the washes that drain to it) are dry along most of their lengths most of the time. Exceptions include short stretches where groundwater discharges to the channel near Beatty, Nevada, south of Tecopa, California, and in southern Death Valley, California (TRW 1998a, page 5.1-4). The river drains an area of about 8,000 square kilometers (3,100 square miles) by the time it reaches Tecopa (Bostic et al. 1997, pages 103 and 112), and its course extends roughly 90 kilometers (56 miles) farther before it ends in the Badwater Basin in Death Valley, which is more than 80 meters (260 feet) below sea level. The nearest surface-water impoundments are Peterson Reservoir, Crystal Reservoir, Lower Crystal Marsh, and Horseshoe



Source: Modified from Waddell (1982, all).

Figure 3-11. Surface areas drained by the Amargosa River and its tributaries.

Reservoir. The largest of these is Crystal Reservoir, a manmade impoundment at Ash Meadows, which captures the discharge from several springs in the area and has a capacity of 1.8 million cubic meters (1,500 acre-feet). Crystal Reservoir and other smaller pools in Ash Meadows drain to the Amargosa River through Carson Slough (TRW 1998a, page 5.1-4).

3.1.4.1.2 *Yucca Mountain Surface Drainage*

Occurrence. No perennial streams, natural bodies of water, or naturally occurring wetlands occur at Yucca Mountain or in the analyzed land withdrawal area. Fortymile Wash, a major wash that flows to the Amargosa River, drains the eastern side of Yucca Mountain (Figure 3-12). The primary washes draining to Fortymile Wash at Yucca Mountain include Yucca Wash to the north; Drill Hole Wash, which, together with its tributary, Midway Valley Wash, drains most of the repository site; and Busted Butte (Dune) Wash to the south. The western side of Yucca Mountain is drained through Solitario Canyon Wash and Crater Flat, both of which eventually drain to the Amargosa River. In this area, most of the water from summer storms is lost relatively quickly to evapotranspiration unless a storm is intense enough to produce runoff or subsequent storms occur before the water is lost. Thunderstorms in the area can be local and intense, creating runoff in one wash while an adjacent wash receives little or no rain. Evapotranspiration is lower during the winter, when water from precipitation or melting snow has a better chance to result in stream flow.

Flood Potential. Although flow in most washes is rare, the area is subject to flash flooding from intense summer thunderstorms or sustained winter precipitation. When it occurs, intense flooding can include mud and debris flows in addition to water runoff (Blanton 1992, page 2). Table 3-9 lists peak discharges for estimated floods along the main washes at Yucca Mountain, including an estimate for a regional maximum flood. In addition to the flood estimates listed in the table, DOE used another estimating method, the *probable maximum flood* methodology [based on American National Standards Institute and American Nuclear Society Standards for Nuclear Facilities (ANS 1992, all)] to generate another maximum flood value for washes adjacent to the existing facilities and operations at the North and South Portals (Blanton 1992, all; Bullard 1992, all). The flood value this method generates, which includes a bulking factor to account for mud and debris, is the most severe reasonably possible for the location under evaluation and is larger than the regional maximum flood listed in Table 3-9. DOE used the probable maximum flood values to predict the areal extent of flooding and to determine if facilities and operations are at risk of flood damage.

PREDICTED FLOODS

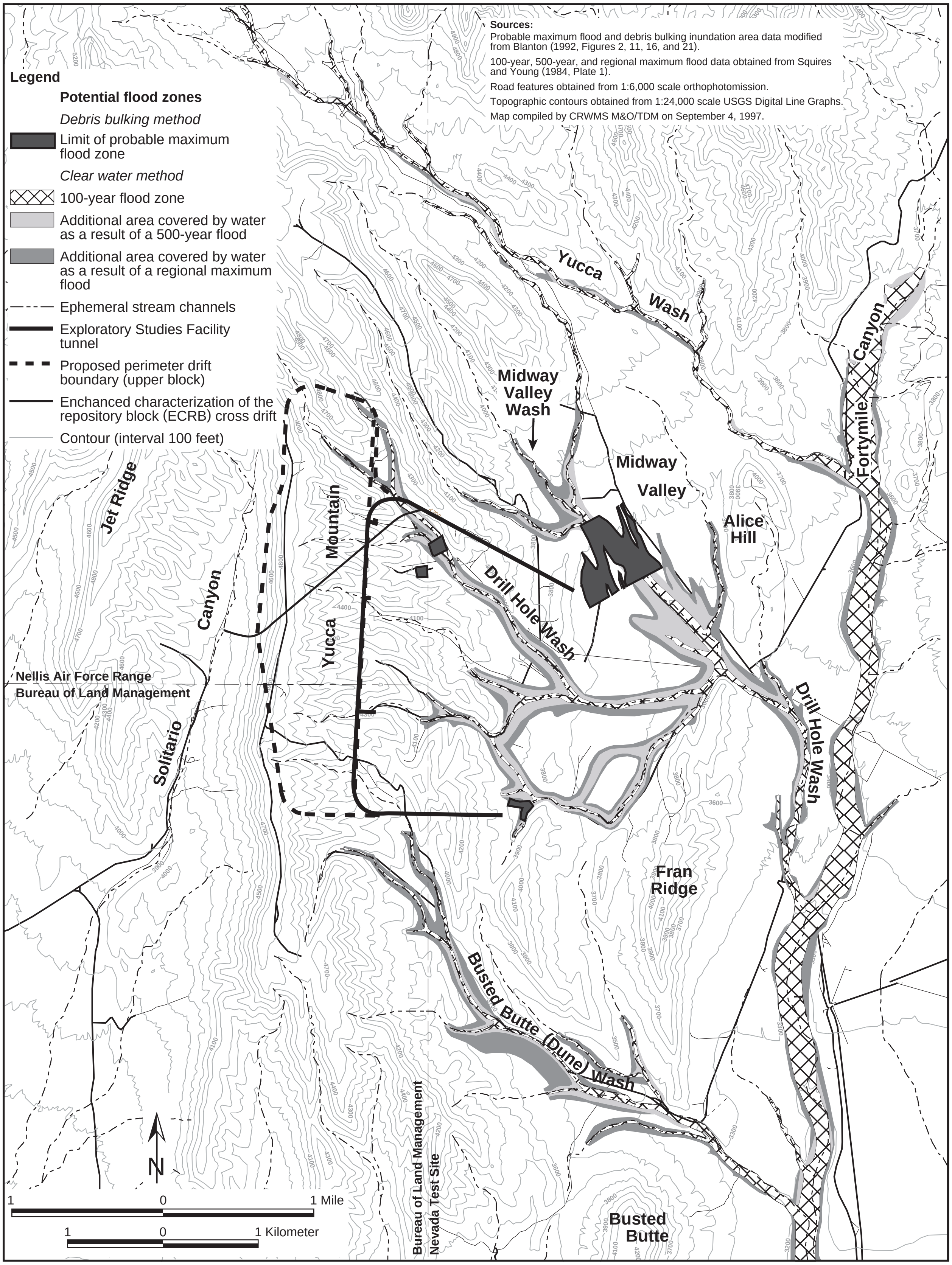
100-year flood: The magnitude of peak discharge at any point on a river or drainage channel that can be expected to occur or be exceeded, on average, once in 100 years.

500-year flood: The magnitude of peak discharge at any point on a river or drainage channel that can be expected to occur or be exceeded, on average, once in 500 years.

Regional maximum flood: The magnitude of a peak discharge based on data from extreme floods, in this case, occurring elsewhere in Nevada and in nearby states.

Probable maximum flood: The hypothetical peak discharge considered to be the most severe reasonably possible based on a probable maximum precipitation and other factors favorable for runoff.

Figure 3-12 shows the extent of estimated floods calculated for the proposed repository before the construction of the Exploratory Studies Facility. It shows the area that the estimated 100- and 500-year floods would inundate as well as the inundation area for the most conservative (highest) of the estimated maximum floods. As indicated on the figure, the partial or discontinuous inundation areas in Midway



Sources:
Probable maximum flood and debris bulking inundation area data modified from Blanton (1992, Figures 2, 11, 16, and 21).
100-year, 500-year, and regional maximum flood data obtained from Squires and Young (1984, Plate 1).
Road features obtained from 1:6,000 scale orthophotomission.
Topographic contours obtained from 1:24,000 scale USGS Digital Line Graphs.
Map compiled by CRWMS M&O/TDM on September 4, 1997.

Figure 3-12. Site topography and potential flood areas.

Table 3-9. Estimated peak discharges along washes at Yucca Mountain.[a]

Name	Drainage area (square kilometers)[b]	Peak discharge 100-year flood (cubic meters per second)[c]	Peak discharge 500-year flood (cubic meters per second)	Regional maximum flood (cubic meters per second)
Fortymile Wash	810	340	1,600	15,000
Busted Butte (Dune) Wash	17	40	180	1,200
Drill Hole Wash[d]	40	65	280	2,400
Yucca Wash	43	68	310	2,600

a. Source: TRW (1999h, page 2-4).
b. To convert square kilometers to square miles, multiply by 0.3861.
c. To convert cubic meters to cubic feet, multiply by 35.314.
d. Includes Midway Valley and Coyote Washes as tributaries—North and South Portal Areas.

Valley Wash and the upper reaches of Drill Hole Wash are based on the probable maximum flood values derived in accordance with guidelines of the American National Standards Institute and American Nuclear Society; for other areas, the most extensive flood zones are based on the regional maximum flood levels listed in Table 3-9. The figure also shows that all floods along Fortymile Wash and Yucca Wash would remain within existing stream channels.

Along Busted Butte (Dune) and Drill Hole Washes, the 500-year flood would exceed stream channels at several places, and the probable maximum flood would inundate broad areas in Midway Valley Wash near the North Portal. In no case, however, would flood levels reach either the North or South Portal opening to the subsurface facilities, which would be at either end of the Exploratory Studies Facility tunnel shown in the figure.

The U.S. Geological Survey (Thomas, Hjalmarson, and Waltemeyer 1997, all) recently published a revised methodology for calculating peak flood discharges in the southwestern United States. A preliminary evaluation indicates that the methodology, if appropriate for use, could result in estimates for 100-year floods that are larger than those listed in Table 3-8 and shown in Figure 3-12. However, the new methodology affects only the 100-year flood estimate, so discharge numbers and expanded inundation lines resulting from its use would be within the bounds set by the 500-year flood.

DOE has prepared a floodplain assessment for the Proposed Action in accordance with the requirements of 10 CFR Part 1022. Appendix L contains the floodplain assessment.

Surface-Water Quality. Samples of stream waters in the Yucca Mountain region have been collected and analyzed for their general chemical characteristics. Because surface-water flows are rare and in immediate response to storms, data from sampling events are sparse. Results of the surface-water sample analyses (Table 3-10) bear some resemblance to those from groundwater samples, as discussed in Section 3.1.4.2.2, because both contain bicarbonate as a principal

Table 3-10. Chemistry of surface water in the Yucca Mountain region.[a]

Chemical[b]	Range of chemical composition
pH	6.2 - 8.7
Total dissolved solids (milligrams per liter)	45.0 - 122
Calcium (milligrams per liter)	5.3 - 28.0
Magnesium (milligrams per liter)	0.2 - 4.0
Potassium (milligrams per liter)	3.0 - 11.0
Sodium (milligrams per liter)	2.4 - 46.0
Bicarbonate (milligrams per liter)	32.0 - 340.0
Chloride (milligrams per liter)	1.3 - 13.0
Sulfate (milligrams per liter)	2.8 - 26.0
Silica (milligrams per liter)	4.5 - 48.0

a. Source: TRW (1998a, Table 6.2-5a); TRW (1999h, page 2-8).
b. Based on samples from 15 different surface-water locations (12 involve a single sampling event, 2 involve two sampling events, and 1 involves three sampling events) collected from 1984 to 1995. One milligram per liter is equivalent to one part per million.

component. However, in general, the groundwaters have a higher mineral content, suggesting more interaction between rock and water.

3.1.4.2 Groundwater

This section discusses groundwater, first on a regional basis and then in the Yucca Mountain vicinity. Many studies have been conducted on the groundwater system under and surrounding Yucca Mountain. These studies provide a firm basis of understanding of the hydrology of the region. However, because groundwater systems are complex and difficult to study, there are differences of opinion among experts related to interpreting available data and describing certain aspects of the Yucca Mountain groundwater system. Therefore, this section also discusses the various views on the groundwater system under Yucca Mountain, where viewpoints differ.

3.1.4.2.1 *Regional Groundwater*

The groundwater flow system of the Death Valley region is very complex, involving many aquifers and confining units. Over distance, these layers vary in their characteristics or even their presence. In some areas confining units allow considerable movement between aquifers; in other areas confining units are sufficiently impermeable to support artesian conditions (where water in a lower aquifer is under pressure in relation to an overlying confining unit; when intersected by a well, the water will rise up the borehole).

In general, the principal water-bearing units of the Death Valley groundwater basin are grouped in three types of saturated hydrogeologic units: basin-fill alluvium (or alluvial aquifer), volcanic aquifers, and carbonate aquifers (TRW 1998a, pages 5.2-4 to 5.2-9). An alluvial aquifer is in a permeable body of sand, silt, gravel, or other detrital material deposited primarily by running water. Volcanic and carbonate aquifers are in permeable units of igneous (of volcanic origin) and carbonate (limestone or dolomite) rock, respectively. The mountainous area that makes up the north portion of the Death Valley hydrologic basin that includes the Yucca Mountain region is often underlain by volcanic rocks and associated volcanic aquifers. The basin areas to the south and southeast of Yucca Mountain contain alluvial aquifers, including those beneath the Amargosa Desert. Carbonate aquifers are regionally extensive and generally occur at large depths below volcanic aquifers or alluvial aquifers (TRW 1998a, page 5.2-8). The discussion of groundwater at Yucca Mountain describes the position of the various aquifers and confining units in relation to each other and to stratigraphic units.

HYDROGEOLOGIC TERMS

Permeability: Describes the ease or difficulty with which water passes through a given material. Permeable materials allow fluids to pass through readily, while less permeable materials inhibit the flow of fluids.

Aquifer: A permeable water-bearing unit of rock or sediment that yields water in a usable quantity to a well or spring.

Confining unit (or aquitard): A rock or sediment unit of relatively low permeability that retards the movement of water in or out of adjacent aquifers.

Inflow: Sources of water flow into a groundwater system such as surface infiltration (recharge) or contributions from other aquifers.

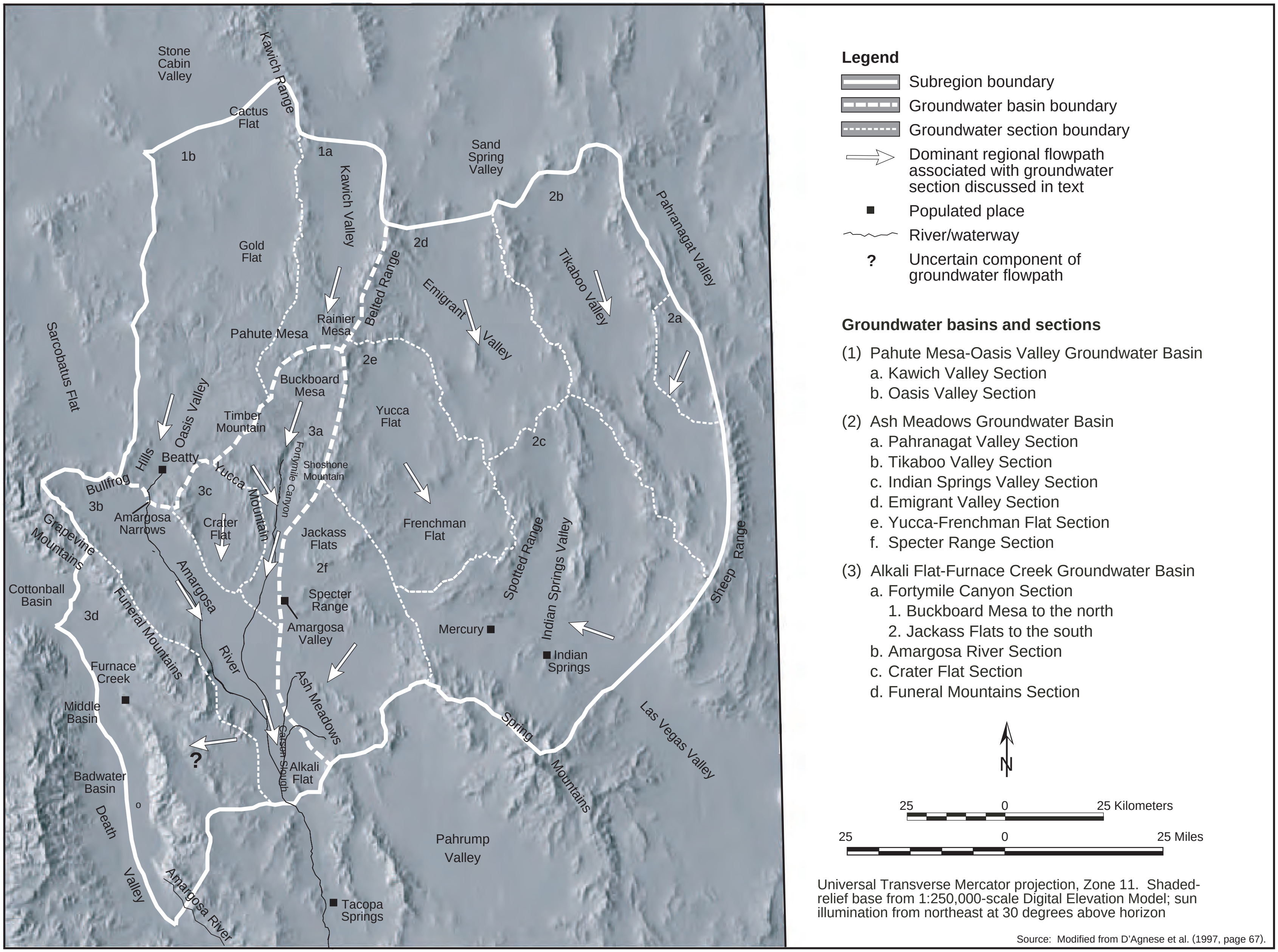
The alluvial aquifers below the Amargosa Desert receive underflow (groundwater movement from one area to another) from sub-basins to the north as well as from sub-basin areas to the east and, therefore, contain a mixture of water from several different aquifers. For example, the volcanic aquifers beneath Yucca Mountain are believed to provide inflow to the alluvial aquifers beneath the Amargosa Desert. In addition, the springs in the Ash Meadows area are fed in part by the carbonate aquifers (Winograd and Thordarson 1975, page C53) and what is not discharged through the springs flows into groundwater moving through the alluvial aquifers at the southeast end of the Amargosa Desert and then discharges at Alkali Flat (Franklin Lake Playa) or continues as groundwater into Death Valley. There is also evidence that indicates a carbonate aquifer might be present below the volcanic sequence, extending from eastern Yucca Mountain south into the Amargosa Desert (Luckey et al. 1996, pages 32 and 40).

Basins. The Death Valley regional groundwater flow system, or basin, covers about 41,000 square kilometers (16,000 square miles) (Harrill, Gates, and Thomas 1988, sheet 1 of 2). Straddling the Nevada-California border, this flow system includes several prominent valleys (Amargosa Desert, Pahrump Valley, and Death Valley) and their separating mountain ranges and extends north to the Kawich Valley, encompassing all of the Nevada Test Site. The major recharge areas are mountains in the east and north portions of the basin. The discharge points are primarily to the south and include the southernmost discharge points in Death Valley and intermediate points such as Ash Meadows in the Amargosa Desert and Alkali Flat. Therefore, flow is primarily to the west or south.

Hydrologic investigations of the Death Valley region date back to the early 1900s, with early work performed primarily by the U.S. Geological Survey (D’Agnese et al. 1997, page 4). More recently, studies by both the U.S. Geological Survey and the State of Nevada have included efforts to collect and compile water-level data from regional wells (TRW 1998a, pages 5.2-17 to 5.2-21). DOE has collected groundwater-level data from wells at Yucca Mountain and in neighboring areas on a routine basis since 1983, and has used the levels to which water rises in these wells—called the *potentiometric surface*—to map the slope of the groundwater surface and to determine the direction of flow. Based on these and other data, groundwater in aquifers below Yucca Mountain and in the surrounding region flows generally south toward discharge areas in the Amargosa Desert and Death Valley (Figure 3-13). The area around Yucca Mountain is in the central portion of the regional groundwater basin, and this portion has three sub-basins: (1) Ash Meadows, (2) Alkali Flat-Furnace Creek Ranch, and (3) Pahute Mesa-Oasis Valley (Rush 1970, pages 10 and 11; Waddell 1982, pages 13 to 20; Luckey et al. 1996, pages 28-30; and D’Agnese et al. 1997, page 65). The aquifers below Yucca Mountain have been included in the Alkali Flat-Furnace Creek Ranch sub-basin because of evidence that the groundwater discharges mainly at Alkali Flat (Franklin Lake Playa) and potentially to the Furnace Creek Wash area of Death Valley.

The Ash Meadows sub-basin is the easternmost of the three sub-basins that make up the Central Death Valley subregion. It underlies eastern portions of the Nevada Test Site (Yucca Flat, Frenchman Flat, Mercury Valley, Rock Valley), parts of Shoshone Mountain, Rainier Mesa to the north, and the Ash Meadows area of the Amargosa Desert in the south. Inflow is principally from the Spring Mountains, Pahranagat Range, Sheep Range, and Pahranagat Valley in the eastern portion of the sub-basin (D’Agnese et al. 1997, pages 67 and 68). Outflow is basically in the form of discharge to the surface and underflow to the lower portion of the Alkali Flat-Furnace Creek Ranch sub-basin. The primary discharge point for this sub-basin is Ash Meadows, where springs occur in a line along a major fault. Estimates of discharge at Ash Meadows range from 21 million to 37 million cubic meters (17,000 to 30,000 acre-feet) per year (Walker and Eakin 1963, page 24; D’Agnese et al. 1997, page 46).

The Pahute Mesa-Oasis Valley sub-basin includes the western portion of Pahute Mesa, Gold Flat, and Oasis Valley. Recharge comes primarily from the north at Black Mountain, Quartz Mountain, and Pahute Mesa, and along the Amargosa River and its tributaries. Subsurface outflow is into the Amargosa Desert



Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northeast at 30 degrees above horizon

Source: Modified from D'Agnese et al. (1997, page 67).

Figure 3-13. Groundwater basins and sections of the Central Death Valley subregion.

of the Alkali Flat-Furnace Creek Ranch sub-basin, and has been estimated at about 0.49 million cubic meters (400 acre-feet) per year (Malmberg and Eakin 1962, page 26).

The Alkali Flat-Furnace Creek Ranch sub-basin is bordered on the northwest by the Pahute Mesa-Oasis Valley sub-basin and on the east by the Ash Meadows sub-basin. This sub-basin includes portions of the Nevada Test Site (parts of Rainier Mesa, Pahute Mesa, and Buckboard Mesa to the north, Shoshone Mountain, Yucca Mountain, and Jackass Flats in the southern half), Crater Flat in the west, and part of Death Valley and the central part of the Amargosa Desert in the south (D'Agnese et al. 1997, pages 67 to 69).

In the immediate vicinity of Yucca Mountain, sources of recharge to the groundwater include Fortymile Wash and precipitation that infiltrates the surface. However, these local sources are not among the primary sources of recharge in the region that makes up the Alkali Flat-Furnace Creek Ranch sub-basin. The primary sources of surface recharge in this region are infiltration on Pahute Mesa, Timber Mountain, and Shoshone Mountain to the north, and the Grapevine and Funeral Mountains to the south (D'Agnese et al. 1997, page 68). One numerical model of infiltration for Yucca Mountain used energy- and water-balance calculations to obtain an average infiltration rate of 6.5 millimeters (0.3 inch) a year over the potential repository area for the current climate. This represents about 4 percent of an average annual precipitation rate of about 170 millimeters (7 inches) at Yucca Mountain. In comparison, areas such as Pahute Mesa, Timber Mountain, and Shoshone Mountain receive more precipitation (DOE 1997e, Plate 1) and have higher estimated percentages of precipitation infiltrating deep into the ground and eventually becoming recharge to the aquifer.

Water infiltrating at Yucca Mountain and becoming recharge to the groundwater would join with water in the Jackass Flats hydrographic area. From there the general direction of groundwater flow is to the Amargosa Desert basin and then Death Valley. There have been many estimates of the amount of groundwater moving along this path. One study (NDCNR 1971, page 50) that is still used extensively by the State of Nevada in its groundwater planning efforts estimated annual groundwater movement of 10 million cubic meters (8,100 acre-feet) from the Jackass Flats basin to the Amargosa Desert basin and 23.4 million cubic meters (19,000 acre-feet) from the Amargosa Desert basin to Death Valley. DOE studies indicate that the quantity of water that might move through a repository area of 10 square kilometers (2,500 acres) under the low thermal load, assuming 6.5 millimeters (0.3 inch) of infiltration per year, would be about 0.3 percent of the estimated 23.4 million cubic meters (19,000 acre-feet) that moves from the Amargosa Desert to Death Valley on an annual basis.

As water in the Alkali Flat-Furnace Creek Ranch sub-basin moves south through the Amargosa Desert, eastern portions of the flow are joined by underflow from the Ash Meadows sub-basin (DOE 1998a, Volume 1, pages 2-56 to 2-58). The line of springs formed by discharge from the Ash Meadows sub-basin provides much of the boundary between the two sub-basins. In this area there is a marked decline [about 37 meters (120 feet)] in water table elevation between Ash Meadows and the Amargosa Desert area to the west and south (Dudley and Larson 1976, page 23). This elevation decline indicates that the potential groundwater flow is from Ash Meadows toward the Alkali Flat-Furnace Creek Ranch sub-basin, rather than the opposite. The primary groundwater discharge point for this sub-basin is Alkali Flat (Franklin Lake Playa) as indicated by the potentiometric surface (or slope) of the groundwater and hydrochemical data. A small portion could move toward discharge points in the Furnace Creek area of Death Valley.

Different researchers have speculated that the general flow boundaries of the three sub-basins in the Central Death Valley groundwater basin are in slightly different locations (D'Agnese et al. 1997, page 59). Some studies [for example, Waddell (1982, page 15)] have placed the Kawich Valley area in the Alkali Flat-Furnace Creek Ranch sub-basin rather than in the Pahute Mesa-Oasis Valley sub-basin as shown in Figure 3-13. This uncertainty in general flow boundaries is a reflection of the complex groundwater flow systems in the Death Valley region. The differing interpretations of the sub-basin boundaries do not, however, disagree on the relative location of the aquifers below Yucca Mountain, which are consistently placed in the central Alkali Flat-Furnace Creek Ranch sub-basin.

Use. Table 3-11 summarizes groundwater use in the Yucca Mountain region. The hydrographic areas listed in the table are basically a finer division of the basins and sub-basins discussed above; their locations are consistent with the hydrographic areas shown in Figure 3-13. DOE has been using small amounts of Jackass Flats hydrographic area groundwater for Nevada Test Site operations, and Yucca Mountain activities have contributed to water use from this source. Most water use in the Alkali Flat-Furnace Creek sub-basin, however, occurs south of Yucca Mountain, from the Amargosa Desert alluvial aquifer. Between 1985 and 1992, water use in the Amargosa Desert from this aquifer averaged 8.1 million cubic meters (6,600 acre-feet) a year for agriculture, mining, livestock, and domestic purposes. As Table 3-11 indicates, water use averaged about 17.5 million cubic meters (14,000 acre-feet) a year from 1995 through 1997. As listed in Table 3-11, groundwater in the Amargosa Desert is heavily appropriated—at much higher levels than is actually withdrawn. The Ash Meadows area of the Amargosa Desert has restrictions on groundwater withdrawal as a result of a U.S. Supreme Court decision (Cappaert v. United States 1976, all) to protect the water level in Devils Hole.

Table 3-11. Perennial yield and water use in the Yucca Mountain region.

Hydrographic area[a]	Perennial yield[b,c] (acre-feet per year)[d]	Current appropriations[e,c] (acre-feet per year)	Average annual withdrawals 1995-1997 (acre-feet)	Chief uses
Jackass Flats (Area 227a)	880[f] - 4,000	500[g]	340[h]	Nevada Test Site programs and site characterization of Yucca Mountain. Minor amounts of water are also discharged for tests at Yucca Mountain.
Crater Flat (Area 229)	220 - 1,000	1,200[i]	140[j]	Mining, site characterization of Yucca Mountain
Amargosa Desert (Area 230)	24,000 - 34,000	27,000	14,000[j]	Agriculture, mining, livestock, municipal, wildlife habitat
Oasis Valley (Area 228)	1,000 - 2,000	1,700	N/A[k]	Agriculture, municipal

a. A specific area in which the State of Nevada allocates and manages the groundwater resources. See Figure 3-17.
b. An estimate of the quantity of groundwater that can be withdrawn annually from a basin without depleting the reservoir.
c. Sources: Thiel (1997, pages 5-12); perennial yield values only, DOE (1996f, pages 4-117 and 4-118).
d. An acre-foot is a commonly used hydrologic measurement of water volume equal to the amount of water that would cover an acre of ground to a depth of 1 foot. To convert acre-feet to cubic meters, multiply by 1,233.49; to convert to gallons, multiply acre-feet by 325,851.
e. The amount of water that the State of Nevada authorizes for use; the amount used might be much less. These appropriations do not cover Federal Reserve Water Rights held by the Nevada Test Site or Air Force.
f. The low estimate for perennial yield from Jackass Flats breaks the quantity down further into 300 acre-feet for the eastern third of the area and 580 acre-feet for the western two-thirds.
g. Area 227a appropriations include about 370 acre-feet for Yucca Mountain characterization activities.
h. Source of Area 227a withdrawals: Bauer et al. (1996, page 702) and Bostic et al. (1997, page 592) for withdrawals from wells J-12 and J-13 at the Nevada Test Site.
i. Area 229 appropriations include temporary mining rights and 61 acre-feet for Yucca Mountain characterization activities.
j. Sources of Area 229 and 230 withdrawals: La Camera, Westenburg, and Locke (1996, page 74) and La Camera and Locke (1997, page 77).
k. N/A = not available.

Table 3-11 lists water volumes (perennial yield, appropriations, and withdrawals) in acre-feet. This unit of volume is common in hydrology and water resource planning. This EIS describes water volumes in both metric (cubic meters) and English (acre-feet) units.

Groundwater Quality. The U.S. Geological Survey has accumulated and evaluated almost 90 years of groundwater data for the Yucca Mountain region and, in more recent years, has periodically collected and analyzed groundwater quality samples. A recent sampling effort (Covay 1997, all) looked for a wide range of inorganic and organic constituents, as well as general water quality properties. This effort collected samples from five groundwater sources in the Amargosa Desert region and three from the immediate vicinity of Yucca Mountain (as discussed in Section 3.1.4.2.2). The regional sampling locations included two wells in the central Amargosa Desert, one well in the Ash Meadows area, and two springs along the border between the Alkali Flat-Furnace Creek Ranch sub-basin and the Ash Meadows sub-basin.

ENVIRONMENTAL PROTECTION AGENCY DRINKING WATER QUALITY STANDARDS

Primary standards are health-based and enforceable for all public drinking water supply systems (including the existing system at the site of the proposed repository).

Secondary standards control substances that primarily affect aesthetic qualities (such as taste, odor, and color). They are not Federally enforceable and, if exceeded, would generally not cause health problems.

The U.S. Geological Survey effort compared the regional groundwater quality measurements to the primary and secondary drinking water standards established by the Environmental Protection Agency [EPA 1993, all; see also the Safe Drinking Water Act, as amended, 42 USC 300(f) *et seq.*]. Though drinking water standards are for public water supply systems, it is common to compare results from groundwater sampling and analysis to these standards for an indication of groundwater quality. The findings indicated that the five groundwater sources met primary drinking water standards, but that a few sources exceeded secondary and proposed standards. Specifically, four of the wells exceeded a proposed standard for radon (Section 3.1.8.2 discusses the natural occurrence of radon in the Yucca Mountain region) and one of those four exceeded secondary standards for sulfate and total dissolved solids and a proposed standard for uranium. Overall, however, regional groundwater quality is generally good and consistent with the State of Nevada description that most groundwater aquifers in the State are suitable, or marginally suitable, for most uses (NDWP 1999a, all). Additional water quality data for wells on the Nevada Test Site are available in the *Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada* (DOE 1996f, pages 4-124 to 4-126). Section 3.1.4.2.2 discusses radiological parameters, including results from regional sample locations.

3.1.4.2.2 *Groundwater at Yucca Mountain*

Groundwater at Yucca Mountain occurs in an unsaturated zone and a saturated zone. This section describes these zones and the characteristics of the groundwater in them.

Unsaturated Zone

Water Occurrence. The unsaturated zone at Yucca Mountain extends down from the crest of the mountain 500 to 750 meters (about 1,600 to 2,500 feet) to the water table (the upper surface of the saturated zone). The primary emplacement area (the upper block) of the proposed repository would be in the unsaturated zone, between about 175 and 365 meters (570 and 1,200 feet) above the present water table. The excavation of the Exploratory Studies Facility encountered very limited quantities of water, and no dripping water or water in sufficient quantities to collect. Some moist areas were observed during excavations through the Paintbrush nonwelded tuff (Figure 3-14) (Peters 1999, all). Boreholes in the

SUBSURFACE FORMATIONS CONTAINING WATER

Unsaturated zone: The zone of soil or rock between the land surface and the *water table*.

Saturated zone: The region below the *water table* where rock pores and *fractures* are completely saturated with *groundwater*.

Perched water bodies: Saturated lenses (thin layers of water) surrounded by unsaturated conditions.

unsaturated zone identified water in the rock matrix, along faults and other fractures, and in isolated saturated zones of perched water (Figure 3-14). The water found in the pores of the rock matrix is chemically different from water found in fractures, perched water, or water in the saturated zone. Perched water in Yucca Mountain occurs where fractured rock overlies rock of low permeability such as unfractured rock, and upslope from faults where permeable or fractured rock lies against less permeable rock and fault fill material. Perched water bodies occur approximately 100 to 200 meters (330 to 660 feet) below the proposed repository horizon (TRW 1998a, page 5.3-236) near the base of the Topopah Spring welded tuff unit (Figure 3-14). Water flow along fractures probably is responsible for recharging the perched water bodies. The apparent age of the perched water based on carbon-14 dating indicates this recharge occurred during the past 6,000 years. Although there are limitations in the use of carbon-14 dating on water (such as knowing the initial activity of carbon-14, estimating sources of losses or gains, and adjusting for postnuclear age contributions), the general conclusion is that the perched water is much too recent to indicate large contributions from pore water in the rock matrix. To learn how recently recharge might have occurred, these dating efforts also looked for the presence of tritium, which would indicate contributions from water affected by atmospheric nuclear weapons tests (after 1952). The results indicate that if tritium has reached the perched water bodies, it is in quantities too small for reliable detection.

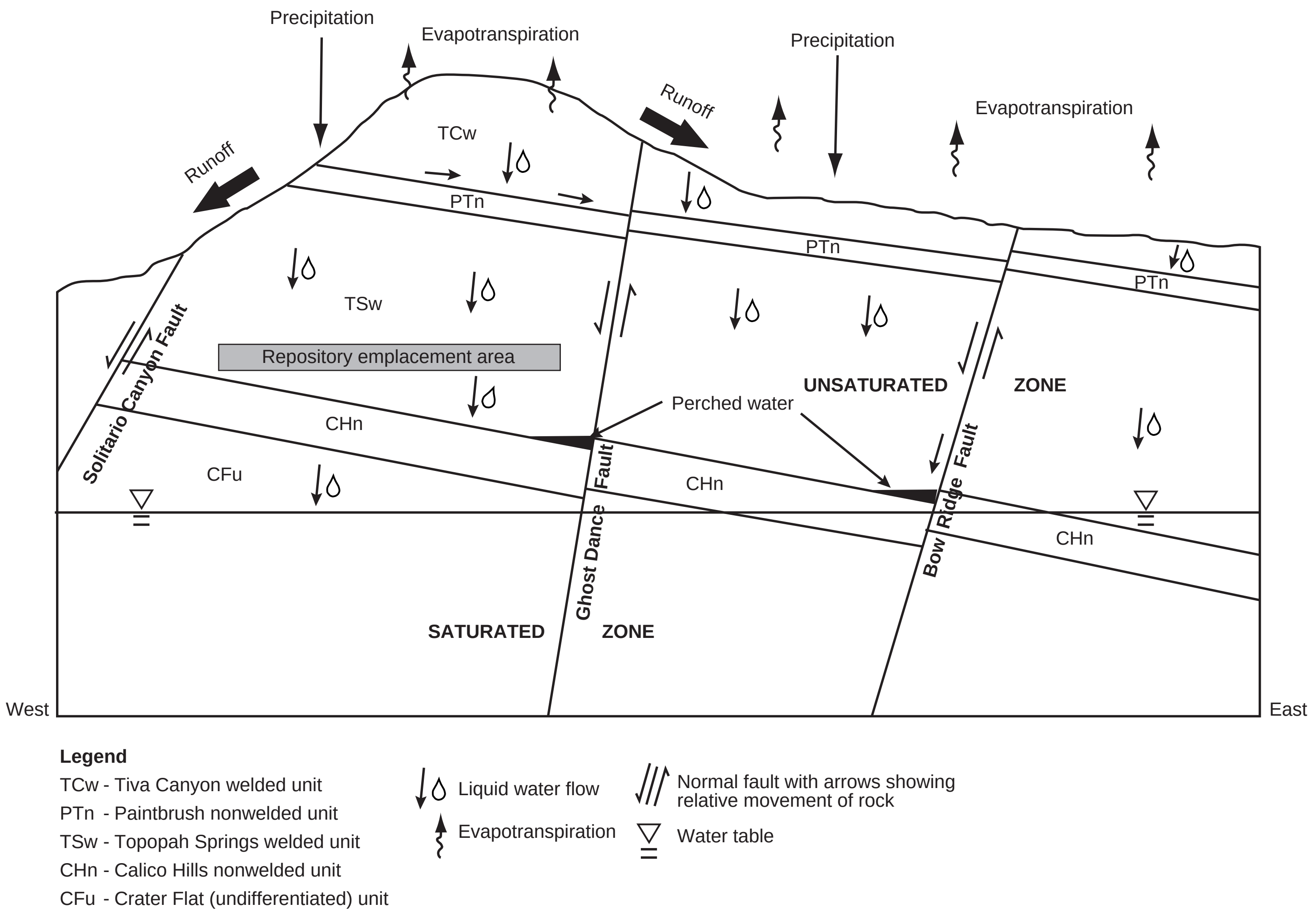
Hydrologic Properties of Rock. The unsaturated zone at Yucca Mountain consists of small areas of alluvium (clay, mud, sand, silt, gravel, and other detrital matter deposited by running water) and colluvium (unconsolidated slope deposits) at the surface underlain by volcanic rocks, mainly fragmented materials called tuffs that have varying degrees of welding. The hydrologic properties of tuffs vary widely. Some layers of tuff are welded and have low matrix porosities, but many contain fractures that allow water to flow more quickly than through the rock. Other layers, such as nonwelded and bedded tuff, have high matrix porosities but few fractures. Some layers have many small hollow bubble-like structures (called lithophysae) that tend to reduce water flow in the unsaturated zone.

TYPES OF TUFF

Welded tuff results when the volcanic ash is hot enough to melt together and is further compressed by the weight of overlying materials.

Non-welded tuff results when volcanic ash cools in the air sufficiently that it does not melt together, yet later becomes rock through compression.

Rock units defined by a set of hydrologic properties do not necessarily correspond to rock units defined by geologic properties and characteristics. For geologic studies, rocks are generally divided on the basis of characteristics that reflect the rock origin and manner of deposition. Hydrogeologic units, on the other hand, reflect the manner in which water moves through the rock. A stratigraphic unit and a hydrogeologic unit commonly do not represent the same layer of rock. For example, a single stratigraphic unit (such as tuff flow) might have been generated by an igneous or volcanic flow. Because of different cooling rates at different depths, a single volcanic flow unit might have layers with different degrees of welding that cause water to move at different rates. The result of this example is a single stratigraphic.



Source: Modified from TRW (1999h, Figure 2-4, page 2-15).

Figure 3-14. Conceptual model of water flow at Yucca Mountain.

unit that includes more than one hydrogeologic unit. Further, because the physical processes of water movement are very different under unsaturated conditions than under saturated conditions, the hydrogeologic units defined in the unsaturated zone can differ from those defined when the same rock sequence is saturated. Figure 3-15 shows the relationship between the stratigraphic units discussed in Section 3.1.3 and the hydrogeologic units discussed in this section, including the aquifers and confining units that make up the area's groundwater system. Table 3-12 lists the hydrogeologic units in the unsaturated zone at Yucca Mountain.

Table 3-12. Hydrogeologic units in the unsaturated zone at Yucca Mountain.[a]

Unit and characteristics[b]	Thickness (meters)[c]
Quaternary alluvium/colluvium Unconsolidated stream deposits beneath valleys and loose slump deposits beneath slopes; porosity and permeability medium to high.	0 - 30
Tiva Canyon welded unit (TCw) Mainly pyroclastic flow tuffs; porosity typically 10 to 30 percent; saturation commonly 50 to 80 percent.	0 - 150
Paintbrush nonwelded unit (PTn) Includes the Yucca Mountain and Pah Canyon Tuffs and uppermost part of the welded Topopah Spring Tuff; porosity generally high, 30 to 60 percent; matrix saturation, 30 to 60 percent.	20 - 100
Topopah Spring welded unit (TSw) Mainly devitrified ash flow tuff; porosity generally low, less than 20 percent, but up to 40 percent in glassy zones; matrix saturation generally greater than 40 percent, commonly greater than 80 percent.	290 - 360
Calico Hills nonwelded unit (CHn) Made up of four subunits, the lower three of which contain zeolites; the unit also includes Prow Pass Tuff (pyroclastic flow) of the Crater Flat Group; porosity variable, 10 to 40 percent; matrix saturation 20 to 90 percent, commonly near 100 percent in zeolitic zones.	100 - 400
Crater Flat undifferentiated unit (CFu) Consists of welded Bullfrog Tuff (stratigraphically above) and nonwelded Tram Tuff (stratigraphically below); is below water table in much of the area, but is unsaturated beneath western part of Yucca Mountain; Bullfrog Tuff has low porosity, less than 20 percent, and high matrix saturation, close to 100 percent; Tram Tuff has porosity 20 to 40 percent; and high matrix saturation.	0 - 200

a. Source: TRW (1999h, pages 2-12 and 2-13).
b. Letters in parentheses are used in Figures 3-14 and 3-15.
c. To convert meters to feet, multiply by 3.2808.

Water Source and Movement. When precipitation falls on Yucca Mountain, part leaves as runoff, part evaporates, and part infiltrates the ground. Some of the water that infiltrates the ground eventually evaporates in the arid climate or passes to plants; the remainder percolates into the ground as infiltration. Some of the infiltration remains at shallow levels, some eventually rises to the surface as vapor, and some (called *net infiltration*) moves deeper into the unsaturated zone. The estimated net infiltration for the current climate is 4.5 millimeters (0.2 inch) per year in a study area of about 230 square kilometers (89 square miles) that includes Yucca Mountain and 6.5 millimeters (0.3 inch) per year in the potential repository area (Flint, Hevesi, and Flint 1996, page 91). These are estimates of average net infiltration for fairly large surface areas. Because of the arid climate, the sporadic nature of storms, and the variation in topography, the actual amount of annual infiltration varies widely from year to year and across the area. Net infiltration varies over segments of the larger areas based, in part, on the amount of unconsolidated material present. The estimated net infiltration ranges from zero where alluvium is more than 6 meters (20 feet) thick to 8 centimeters (3 inches) and more where thin alluvium overlies highly permeable bedrock. On a year-to-year basis, the average net infiltration can range from 0 to 2 centimeters (0.8 inch).

Geologic Age		Stratigraphic unit	Approximate range of thickness (meters)	Hydrogelogic units		Comments
				Unsaturated	Saturated	
Cenozoic Era	Quaternary and Tertiary Periods	Alluvium, colluvium, eolian deposits, spring deposits, basalt lavas, lacustrine deposits, playa deposits	0-30	QAL, alluvium	QTa, Valley-fill aquifer; QTc, valley-fill confining unit	QAL restricted to stream channels on Yucca Mountain; QTa occurs mainly in Amargosa Desert; major water-supply source
	Tertiary Period	Timber Mountain Group Rainier Mesa Tuff				Minor erosional remnants at Yucca Mountain
		Paintbrush Group Tiva Canyon Tuff	0-150	TCw Tiva canyon welded unit		Mainly densely welded; caprock on Yucca Mountain; not known in saturated zone at or near Yucca Mountain
		(bedded tuff) Yucca Mountain Tuff Pah Canyon Tuff	20-100	PTn Paintbrush nonwelded unit		Includes bedded and nonwelded tuffs between basal part of Tiva Canyon Tuff and upper part of Topopah Spring Tuff.
		Topopah Spring Tuff (vitrophyre and non-welded tuffs at base)	290-360	TSw Topopah Spring welded unit	uva, Upper volcanic	About 300 meters of densely welded tuff in unsaturated zone; host rock for repository; in saturated zone where downfaulted to east, south, and west of site
		Calico Hills Formation	100-400	CHn Calico Hills nonwelded unit	uvc, Upper volcanic confining unit	Mainly nonwelded tuff, with thin rhyolite lavas in northern site area; varies from vitric in southwest site area to zeolitic where near or below water table
		Crater Flat Group Prow Pass Tuff Bullfrog Tuff Tram Tuff	0-200	CFu Crater Flat undifferentiated unit	mva Middle volcanic aquifer units	Small occurrence in unsaturated zone; widespread in saturated zone; variably welded ash-flow tuffs and rhyolite lavas; commonly zeolitized; most permeable zones are fracture-controlled
		Unnamed flow breccia Lithic Ridge Tuff	1,000-2,000		mvc, Middle volcanic confining unit	Nonwelded tuff, pervasively zeolitized
		Volcanics of Big Dome			lva, Lower volcanic aquifer	Lava flows and welded tuff; not known at Yucca Mountain
	(Lower Tertiary?)	Older volcanics			lvc, Lower volcanic confining unit	Nonwelded tuff, pervasively zeolitized; tuffaceous sediments in lower part
Paleozoic Era	Permian/ Pennsylvanian Periods	Bird Spring Formation Tippipah Limestone	1,000 ±		uca, Upper carbonate aquifer	Limited distribution in saturated zone north and east of Yucca Mountain
	Mississipian/ Devonian Periods	Eleana Formation (Chainman Shale)	2,500 ±		ecu, Eleana confining unit	Argillite (mudstone) and siltstone; occurrence inferred beneath volcanics of northern Yucca Mountain
	Devonian Silurian Ordovician Cambrian Periods	Devils Gate Limestone, Nevada Formation, Ely Springs Dolomite, Eureka Quartzite, Pogonip Group, Nopah Formation, Dunderberg Shale, Bonanza King Formation, Upper Carrara Formation	7,500 ±		lca, Lower carbonate aquifer	Mainly limestone and dolomite with relatively thin shales and quartzites; major regional aquifer, more than 5 kilometers (3.1 miles) thick
		Lower Carrara Formation			zcu, Precambrian confining unit	Dolomite, shale
Proterozoic (Upper Precambrian)		Proterozoic rocks				Quartzite, slate, marble; fractures commonly healed by mineralization

Source: Modified from TRW (1999h, Figure 2-3, pages 2-10 and 2-11).

Figure 3-15. Correlation of generalized stratigraphy with unsaturated and saturated hydrogeologic units in the Yucca Mountain vicinity.

Groundwater movement in the unsaturated zone at Yucca Mountain occurs in the pore space (matrix) of rock units and along faults and fractures of rock units. Water movement through the pore space of rock units is a relatively slow (or stagnant) process compared with flow through faults and fractures. Water movement through faults and fractures is believed to be episodic in nature (occurring at discrete times related to periods of high surface infiltration), is capable of traveling rapidly through rock units, and is the likely source of perched water in the unsaturated zone.

The characteristics of groundwater movement through specific rock units differ based on their hydrogeologic properties. Water that infiltrates into the Tiva Canyon welded unit can often be transported as deep as the underlying Paintbrush nonwelded unit. Due to its high porosity and low fracture density, the Paintbrush unit tends to slow the downward velocity of water flow dramatically in relation to highly fractured units such as the Tiva Canyon unit. However, isotopic (chlorine-36) analysis has identified isolated pathways that provide relatively rapid water movement through the Paintbrush nonwelded unit to the top of the underlying Topopah Springs welded unit where, due to increased fracturing, it has the potential to travel quickly through the unit.

CHLORINE-36 STUDIES

These studies use the fact that a very small portion of chlorine in the atmosphere consists of the radioactive isotope chlorine-36. The production of chlorine-36 (caused in part by interactions between argon molecules and high-energy protons and neutrons in the atmosphere) is sufficiently balanced with the rate of its removal as atmospheric fallout that the ratio of chlorine-36 to stable chlorine (chlorine-35) at any given location remains fairly constant in atmospheric salts deposited on land, such as that dissolved in rainwater. Once chlorine is isolated from the surface environment (as when dissolved in water percolating down through the soil and subsurface rocks), subsequent changes in the chlorine-36-to-total-chlorine ratio can be attributed to decay of the chlorine-36 (Levy et al. 1997, page 2) (that is, if the residence times are long enough in relation to the 301,000-year half-life of this radionuclide). Measuring the chlorine-36-to-total-chlorine ratio in underground water or in residues it leaves behind, and knowing what the ratio was at the time of recharge provides a means of estimating the age of the water. In reality, slight variations over time in the atmospheric ratio and the potential for some minor production of chlorine-36 in the subsurface has made the use of this technique for water dating difficult, and its use is still under investigation. However, the atmospheric ratio of chlorine-36 to total chlorine has increased by orders of magnitude as a result of above-ground nuclear testing during the past 50 years. As a consequence, the technique has been very successful in tracing underground water or water residues that originated at the surface within the past 50 years, with the so-called *bomb-pulse signal* indicating very young water.

DOE has used the ratio of chlorine-36 (a naturally occurring isotope) to total chlorine to determine where and when moisture has moved in the unsaturated zone at Yucca Mountain. High enough chlorine-36 ratios indicate waters exposed to very small amounts of fallout associated with above-ground nuclear weapons testing (called bomb-pulse water). The methodology used in these studies is complicated and is still under investigation; however, findings thus far have been valuable in reaching certain conclusions.

Chlorine-36 analyses at Yucca Mountain have identified locations where water has moved fairly rapidly (in several decades) from the surface to the depth of the proposed repository and also where it has moved very slowly (thousands to tens of thousands of years). The chlorine-36 studies included one study that collected 247 rock samples along the 8-kilometer (5-mile) Exploratory Studies Facility tunnel. About 70 percent of the samples were from areas thought to be more likely to show evidence of rapid water movement [that is, areas of broken rock such as faults, fractures, or breccia zones (areas where rock composed of fragments of older rocks melded together)].

Most of the samples (87 percent) had ratios that were ambiguous in that they fell within the range over which the chlorine-36-to-total-chlorine ratio has varied over the last 50,000 years or more. Results of these samples indicate that the groundwater travel times from the surface to the repository depth in most areas probably are thousands to tens of thousands of years. This is because there is little evidence for measurable radioactive decay of the chlorine-36 signal in the subsurface. However, a few samples indicated ratios low enough to suggest the possible presence of zones of relatively old or stagnant water (TRW 1998a, page 5.3-176). Further, the data indicate that, away from fault zones, travel times to the repository horizon correlate with the thickness of the overlying nonwelded Paintbrush unit. The shortest travel times (less than 10,000 years) occur in the southern part of the Exploratory Studies Facility where the unit is thinnest.

About 13 percent of the samples (31 samples) had high enough chlorine-36-to-total-chlorine ratios to indicate the water originated from precipitation occurring in the past 50 years (that is, nuclear age precipitation) (TRW 1998a, page 5.3-176). Locations where bomb-pulse water occurred were correlated with the physical conditions in the mountain and on the surface that could lead to, or otherwise affect, the findings. The conclusion to date of these ongoing studies is that relatively fast transport of water through the mountain is controlled by the following factors (Fabryka-Martin et al. 1998, page 3-2):

- The presence of a continuous fracture path from the surface: The limiting factor is a fracture or fault cutting the Paintbrush nonwelded bedded tuffs (PTn) hydrogeologic unit (this prominent unit is above the repository horizon; see Figure 3-14 and Table 3-12). Fracture pathways are normally available in the welded portions of the overlying Tiva Canyon and underlying Topopah Spring units. This is consistent with hydrologic modeling of percolation through this nonwelded bedded tuff, which indicates that there must be fracture pathways due to faulting or other disturbances for water to travel through this unit in 50 years or less. Section 3.1.3 discusses fault locations inside Yucca Mountain.

- The magnitude of surface infiltration: There must be enough infiltration to sustain a small component of flow along the connected fracture pathway.

- The residence time of water in the soil cover: This time must be less than 50 years; to achieve this, the depth of the soil overlying the fracture pathway must be less than an estimated 3 meters (10 feet).

Water percolating to the depth of the repository and beyond is affected not only by fractures but also by the nature of the hydrogeologic units it encounters. Pressure testing in boreholes indicates that fractures in the Topopah Spring tuff (the rock unit in which DOE would build the repository) are very permeable and extensively interconnected. Below the repository level, low-permeability zeolite zones impede the vertical flow of water near the Topopah Spring welded unit and its contact with the underlying Calico Hills nonwelded unit, forming perched water bodies. The primary source of the perched water is water traveling down along faults and fractures. In the dipping or sloped strata beneath Yucca Mountain, perched water bodies require vertical impediments such as fault zones where less permeable rock and fault-gouge material block the lateral flow of water (Figure 3-14). If these conditions do not exist at the fault zone, the fault can provide a downward pathway. Even in cases where fault zones are barriers to lateral water flow, they can be very permeable to gas and moisture flow along the fault plane and permit the rapid vertical flow of water from the land surface to great depth. Studies of heat flux above and below the perched water zone appear to indicate more water percolation above the perched water than below. This is consistent with the concept that some of the water moves laterally on top of the zeolite zone before it resumes its downward course to the saturated zone.

Unsaturated Zone Groundwater Quality. DOE has analyzed water from the unsaturated zone, both pore water from the rock matrix and perched water, to obtain information on the mechanisms of recharge and the amount of connection between the two. The preceding sections discuss some of the relevant findings.

Table 3-13 summarizes the chemical composition of perched and pore water samples from the vicinity of Yucca Mountain.

Table 3-13. Water chemistry of perched and pore water samples in the vicinity of Yucca Mountain.[a]

	Ranges of chemical composition	
Constituent	Perched	Pore
pH	7.6 - 8.7	7.7 - 8.4
Total dissolved solids (milligrams per liter)	140 - 330	320 - 360
Calcium (milligrams per liter)	2.9 - 45	1.1 - 62
Magnesium (milligrams per liter)	0 - 4.1	0 - 4.5
Potassium (milligrams per liter)	1.7 - 10	N/A[b]
Sodium (milligrams per liter)	34 - 98	49 - 140
Bicarbonate (milligrams per liter)	110 - 220	170 - 230
Chloride (milligrams per liter)	4.1 - 16	26 - 90
Bromide (milligrams per liter)	0 - 0.41	0
Nitrate (milligrams per liter)	0 - 34	11 - 17
Sulfate (milligrams per liter)	4 - 220	14 - 45

a. Source: Striffler et al. (1996, Table 2).
b. N/A = not available.

The smaller concentrations of dissolved minerals, particularly chloride, in perched water in comparison to those in pore water is a primary indicator of differences between the two. This difference in dissolved mineral concentrations indicates that the two types of water do not interact to a large extent and that the perched water reached its current depth with little interaction with rock. This, in turn, provides strong evidence that flow through faults and fractures is the primary source of the perched water.

Saturated Zone

Water Occurrence. The saturated zone at Yucca Mountain has three aquifers and two confining units. The aquifers are commonly referred to as the upper volcanic aquifer, the lower volcanic aquifer, and the lower carbonate aquifer. The interlayered aquitards (low permeability units that retard water movement) that separate the aquifers are called the upper volcanic confining unit and the lower volcanic confining unit (see Figure 3-15). The upper volcanic aquifer is composed of the Topopah Spring welded tuff, which occurs in the unsaturated zone near the repository but is present beneath the water table to the east and south of the proposed repository. The upper volcanic confining unit includes the Calico Hills nonwelded unit and the uppermost unstructured end of the Prow Pass tuff where they are saturated. The lower volcanic aquifer includes most of the Crater Flat Group, and the lower volcanic confining unit includes the lowermost Crater Flat Group and deeper tuff, lavas, and flow breccias. An upper carbonate aquifer, though regionally important, is not known to occur beneath Yucca Mountain. (The lower volcanic aquifer discussed here corresponds to the middle volcanic aquifer shown in Figure 3-15. The lower volcanic aquifer in Figure 3-15 has not been identified in the area of the proposed repository.)

South of the proposed repository site, downstream in the groundwater flow path from Yucca Mountain, the Tertiary volcanic rocks (and the volcanic aquifers) pinch out and groundwater moves into the valley-fill sediments of the Amargosa Desert (TRW 1998a, page 5.3-7). In the Amargosa Desert south of Yucca Mountain, the most important source of water is an aquifer formed by valley-fill deposits.

The lower carbonate aquifer is more than 1,250 meters (4,100 feet) below the proposed repository horizon. This aquifer, which consists of lower Paleozoic carbonate rocks (limestone and dolomite) that have been extensively fractured during many periods of mountain building (see Section 3.1.3), forms a regionally extensive aquifer system through which large amounts of groundwater flow. Evidence indicates that water in the lower carbonate aquifer is at least as old as most of the water in the volcanic aquifers (with apparent ages in the range of 10,000 to 20,000 years) and, similarly, was recharged during a wetter and cooler climate. Some of the limited carbonate aquifer sample results indicate older water ages (30,000 years and greater), but use of carbon-14 dating on this water has an additional limitation due to the probable contribution of "dead carbon" (nonradioactive) dissolved from the carbonate rock. Limited data show that the level to which water rises in a well that penetrates the lower carbonate aquifer is about 20 meters (66 feet) higher than the water levels in the overlying volcanic aquifers. This indicates that, in the vicinity of Yucca Mountain, water from the lower carbonate aquifer is pushing up against a confining layer with more force than the water in the upper aquifers is pushing down. This suggests that water in the volcanic aquifers does not flow down into the lower carbonate aquifer at Yucca Mountain because it would be moving against a higher upward pressure and that, if mixing occurs, it would be from carbonate to volcanic and not the reverse.

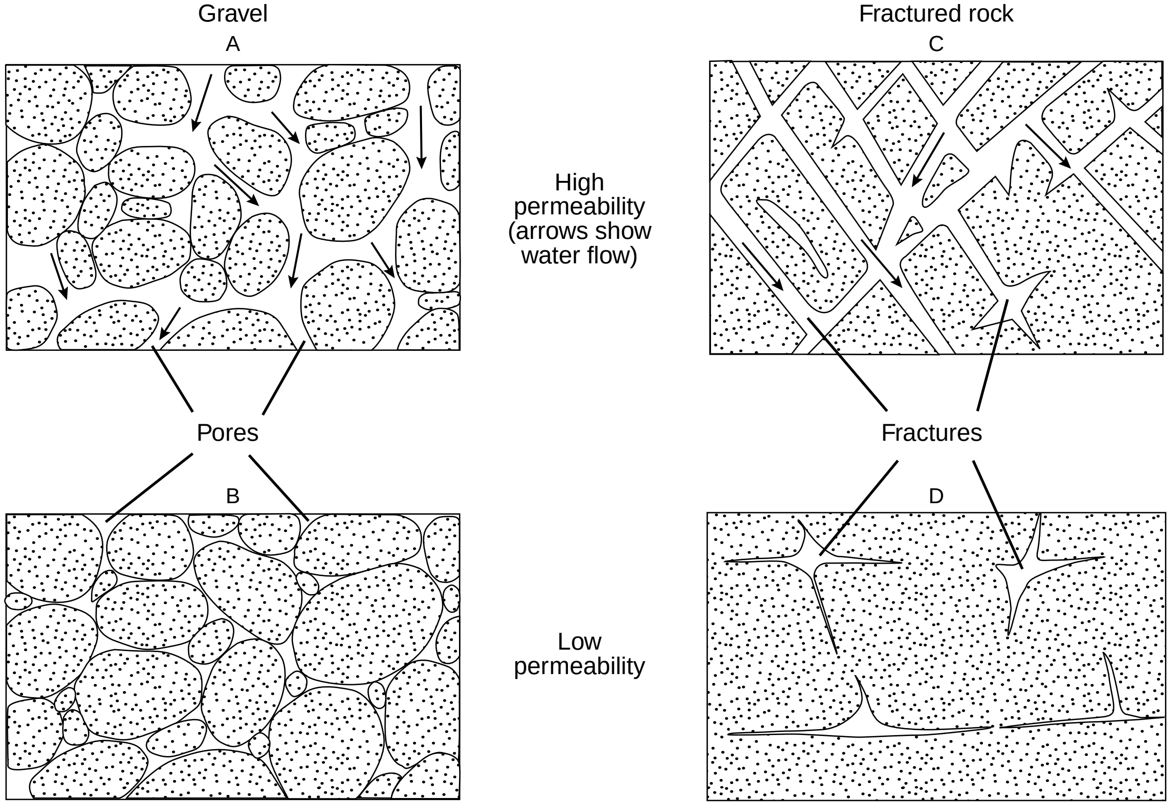
Paleoclimatic (referring to the climate during a former period of geologic time) studies have identified six wetter and cooler periods in the southern Great Basin during late Pleistocene time. These periods occurred 10,000 to 50,000 years ago; 60,000 to 70,000 years ago; 120,000 to 170,000 years ago; 220,000 to 260,000 years ago; 330,000 to 400,000 years ago; and 430,000 to 470,000 years ago. They represent the sequencing of glacial (cooler and wetter) to interglacial (warmer and drier) and back to glacial climates (TRW 1998a, page 4.2-24). During the wetter periods, the elevation of the saturated zone was as much as about 100 meters (330 feet) higher than it is today. The repository would be above this historic maximum elevation (see Section 2.1). Calcite veins and opal were deposited along fractures during the wetter periods. The calcite and opal coatings have been dated by the uranium series method; the calcites have also been dated by the carbon-14 method. The youngest vein deposits are 16,000 years old. The *Yucca Mountain Site Description* (TRW 1998a, pages 4.2-1 to 4.2-41) provides additional information, including supporting evidence, on the timing, magnitude, and character of past climate changes in the Yucca Mountain region.

Several investigators have suggested that the water table in the vicinity of Yucca Mountain has risen dramatically higher than 100 meters (330 feet) above the current level, even reaching the land surface in the past (Szymanski 1989, all). If such an event occurred, it would affect the performance of the proposed repository. These concerns originated in the early- to mid-1980s when surface excavations performed as part of site investigations exposed vein-like deposits of calcium carbonate and opaline silica (TRW 1998a, page 3.4-20). Szymanski (1989, all) hypothesized that the carbonate and silica were deposited by hydrothermal fluids, driven to the surface by pressurization of groundwater by earthquakes (a mechanism called *seismic pumping*) or by thermal processes that occurred in the Yucca Mountain vicinity. A number of investigators and groups, including a National Academy of Science panel specifically designated to look at the issue (National Research Council 1992, all), have examined the model on which this position is based and have rejected its important aspects (Luckey et al. 1996, pages 76-77). The National Research Council panel concluded that the evidence cited as proof of groundwater upwelling in Yucca Mountain and in its vicinity could not reasonably be attributed to that process. In addition, the panel stated its position that the proposed mechanism for upwelling water was inadequate to raise the water table more than a few tens of meters (DOE 1998a, Volume 1, page 2-26). Finally, the panel concluded that the carbonate-rich depositions in fractures were formed from surface water from precipitation and surface processes (TRW 1998a, page 3.4-29).

Another alternative interpretation of past groundwater levels at Yucca Mountain occurs in Dublyansky (1998, all). This study involved the examination of tiny pockets of water (known as *fluid inclusions*) trapped in the carbonate-opal veinlets deposited in rock fractures at Yucca Mountain. According to the report, an analysis of samples collected from the Exploratory Studies Facility includes evidence of trace quantities of hydrocarbons and evidence that the fluid inclusions were formed at elevated temperatures. These findings, and others, are used to support the report's conclusion that the carbonate-opal veinlets were caused by warm upwelling water and not by the percolation of surface water. DOE, given the opportunity to review a preliminary version of the report, arranged for review by a group of independent experts, including U.S. Geological Survey personnel and a university expert. This review group did not concur with the conclusion in the report by Dublyansky (1998, all), which now contains an appendix with the DOE-arranged review comments and the author's responses. Although DOE has disagreed with some of the central scientific conclusions presented in this report, both parties have agreed that additional research is needed to resolve the issues. DOE and the State of Nevada are continuing to evaluate these and other alternative conceptual models and data interpretations.

Hydrologic Properties of Rock. This section discusses the hydrologic properties of rock in the saturated zone, and specifically the aquifers and confining units at Yucca Mountain. As discussed above, these properties depend in part on whether the rocks are saturated. In general, the amount and speed at which water flows through an aquifer depend chiefly on the transmissivity and effective porosity of the rock. *Transmissivity* is a measure of how much water an aquifer can transfer and is equal to the average hydraulic conductivity of the aquifer multiplied by the thickness of the aquifer that is saturated. *Porosity* is the ratio of the rock's void (open) space to its total volume; *effective porosity* is the ratio of interconnected void space to total volume.

Figure 3-16 shows the types of conditions that might exist in gravel and rock aquifers that would make them more or less permeable to water movement. The empty spaces between gravel fragments or in the rock fractures represent the porosity. Although not necessarily representative of conditions at Yucca Mountain, the figure shows that the manner in which void spaces are interconnected, more than their size



A. Gravel with interconnected pore space having relatively high permeability.
B. Gravel with limited interconnected pore space having relatively low permeability.
C. Rock with interconnected fractures having relatively high permeability.
D. Rock with few interconnected fractures having relatively low permeability.

Source: Modified from USGS (1993, page 2).

Figure 3-16. Aquifer porosity and effects on permeability.

or quantity, determines how water can move through the material. At Yucca Mountain, conditions are often such that the rock with the highest porosity is also the rock with the fewest fractures. Because the void spaces are not interconnected very well, such a high-porosity rock has low transmissivity. Because a large portion of the groundwater flow at Yucca Mountain is probably along fractures, representative transmissivity values are difficult to measure. Measurements can vary greatly depending on the nature of the fractures that happen to be intercepted by the borehole and the location in the borehole at which measurements are made. This is reflected in the wide range of transmissivity values listed in Table 3-14, which also lists the characteristics, thicknesses, apparent hydraulic conductivities, and porosities of the three aquifers and two confining units beneath Yucca Mountain. For the lower carbonate aquifer, the table lists a single transmissivity value because there was only a single test for that unit. Similarly, only one apparent hydraulic conductivity value, which is a measure of the aquifer’s capacity to transport water, is provided for the lower carbonate aquifer unit because it is based on tests in a single well at Yucca Mountain. However, the value is an average of measurements taken from that well. This and the other hydraulic conductivity values are called *apparent* because they are all based on single-borehole tests. Such measurements, which are believed to represent conditions at a limited distance around the well, could vary greatly depending on whether there are water-bearing fractures in the well zone being tested. When such fractures are present, hydraulic properties measured in a single-borehole test probably reflect conditions only in isolated locations rather than in the overall rock matrix in the test zone.

Table 3-14. Aquifers and confining units in the saturated zone at Yucca Mountain.

Unit	Typical thickness (meters)[a,b,c]	Transmissivity (square meters per day)[d,e]	Apparent hydraulic conductivity (meters per year)[e]	Porosity[f,g] (ratio)
Upper volcanic aquifer Densely welded and densely fractured part of Topopah Spring Tuff	300	120 - 1,600	47 - 6,900	0.036 - 0.16
Upper volcanic confining unit Basal vitrophyre of Topopah Spring Tuff, Calico Hills Formation Tuff, and uppermost nonwelded part of Prow Pass Tuff	90 - 330	2.0 - 26	7.3 - 95	0.17 - 0.35 (Calico Hills)
Lower volcanic aquifer Most of Prow Pass Tuff and underlying Bullfrog and Tram Tuffs of Crater Flat Group	370 - 700	1.1 - 3,200	< 1.4 - 4,700	0.26 - 0.33 (Prow Pass Tuff) 0.12 - 0.26 (Bullfrog Tuff)
Lower volcanic confining unit Bedded tuffs, lava flows, and flow breccia beneath Tram Tuff	370 - > 750	0.003 - 23	0.002 - 40.2	N/A[h]
Lower carbonate aquifer Cambrian through Devonian limestone and dolomite	N/A	120	69	N/A

a. Source: Luckey et al. (1996, Table 2 and Figure 7).

b. To convert meters to feet, multiply by 3.2808.

c. Typical thickness ranges for the upper volcanic confining unit, the lower volcanic aquifer, and the lower volcanic confining unit are based on measurements from 13 boreholes. With respect to the lower volcanic confining unit, only one penetrated and showed a unit thickness of about 370 meters (1,200 feet); of the others, about 750 meters (2,500 feet) was the deepest penetration without passing through. Water was detected in the rock unit that elsewhere makes up the upper volcanic aquifer unit in only one of the 13 boreholes. (Beneath the center of Yucca Mountain, the upper volcanic aquifer is above the saturated zone.) The typical thickness shown here for this unit is based on Figure 7 from Luckey et al. (1996, Figure 7).

d. To convert square meters to square feet, multiply by 10.764.

e. Source: TRW (1998a, Tables 5.3-35 and 5.3-36).

f. Source: TRW (1999h, Table 2-2, page 2-40).

g. Ranges are for means of several hydrogeological subunits.

h. N/A = not available.

Water Source and Movement. Section 3.1.4.2.1 describes the direction of water movement (Figure 3-13), the nature of the rock through which it moves, and where local recharges to and discharges from the aquifer might occur.

When undisturbed by pumping, groundwater levels at Yucca Mountain have been very stable, with long-term measurements generally varying less than 0.1 meter (0.3 foot) since 1983. These small variations are probably due to changes in barometric pressure and Earth tides. In addition, short-term fluctuations in groundwater elevations also have been attributed to apparent recharge events and earthquakes. Water levels in wells have fluctuated by as much as 2.2 meters (7 feet) in response to earthquake events, but the fluctuations are typically of short duration with water levels returning to the pre-earthquake conditions within minutes to a few hours. An exception to this occurred in response to earthquakes in the summer of 1992, when water levels in specific wells at Yucca Mountain fluctuated over several months. At the northern end of Yucca Mountain, the apparent potentiometric surface slopes steeply southward, dropping almost 300 meters (980 feet) in a horizontal distance of 2.5 kilometers (1.6 miles). Experts reviewing the data have suggested several credible reasons for this steep gradient, including that it results from an undetected geological feature with low permeability, that it is caused by groundwater draining to deep aquifers, or that it is a perched water table being encountered in this area (Geomatrix and TRW 1998, pages 3-5 and 3-6). However, there are no obvious geologic reasons for the steep gradient, and it is still under investigation.

The north-trending Solitario Canyon fault, on the west side of Yucca Mountain, apparently impedes the eastward flow of groundwater in the saturated zone. West of the fault, the water table slopes moderately about 20 meters (66 feet) in 0.4 kilometer (0.25 mile), while east of the fault the water table slopes very gently. West of the Solitario Canyon fault groundwater probably flows southward either along the fault or beneath Crater Flat.

The gentle southeastward groundwater gradient east of the Solitario Canyon fault underlies the proposed repository horizon and extends beneath Fortymile Wash and probably farther east into Jackass Flats. This gentle gradient might indicate that the rocks through which the water flows are highly transmissive, that only small amounts of groundwater flow through this part of the system, or a combination of both. This gentle southeastward gradient is a local condition in the regional southward flow of the groundwater.

In an opposing viewpoint about the stability of groundwater levels at Yucca Mountain, Davies and Archambeau (1997, pages 33 and 34) suggests that a moderate magnitude earthquake at the site could cause a southward displacement of the large hydraulic gradient to the north of the proposed repository, resulting in a water table rise of about 150 meters (490 feet) at the site. In addition, that report proposed that a severe earthquake could cause a rise of about 240 meters (790 feet) in the water table, flooding the repository. As part of its study of groundwater flow in the saturated zone, DOE elicited expert opinions on various issues from a panel of five experts in the fields of groundwater occurrence and flow. Among the issues put to the panel were those raised by Davies and Archambeau (1997, all). The panel reviewed the Davies and Archambeau paper and received briefings by project personnel and outside specialists. The consensus of the panel was that a rise of the groundwater to the level of the proposed repository was essentially improbable and that changes to the water table associated with earthquakes would be neither large nor long-lived (Geomatrix and TRW 1998, page 3-14).

Inflow to Volcanic Aquifers at Yucca Mountain. There are four potential sources of inflow to the volcanic aquifers in the vicinity of Yucca Mountain: (1) lateral flow from volcanic aquifers north of Yucca Mountain, (2) recharge along Fortymile Wash from occasional stream flow, (3) precipitation at Yucca Mountain, and (4) upward flow from the underlying carbonate aquifer. The actual and relative amounts of inflow from each source are not known.

North of Yucca Mountain, the potentiometric surface rises steeply toward probable recharge areas on Pahute Mesa (Figure 3-13) and Rainier Mesa. Chemical data indicate that some recharge to the groundwater has occurred everywhere in the Yucca Mountain vicinity during the past 10,000 years, but that most recharge occurred between 10,000 and 20,000 years ago (based on apparent carbon-14 ages) during a wetter climate. From west to east across Yucca Mountain, the age of water in the saturated zone decreases from about 19,000 years to 9,100 years (Benson and McKinley 1985, page 4).

The estimated annual recharge along the 150-kilometer (93-mile) length of Fortymile Wash averages about 4.22 million cubic meters (3,400 acre-feet). Much of the recharge occurs during and after heavy precipitation when water flows in the wash. On rare occasions, Fortymile Wash carries water to Jackass Flats and into the Amargosa Desert. After several periods of flow in Fortymile Wash during 1992 and 1993, water levels in nearby wells rose substantially. Earlier studies found that shallow water in some wells was younger than water deeper in the wells, indicating that recharge was occurring. Paleoclimatic evidence suggests that a perennial stream might have existed in Fortymile Wash 25,000 to 50,000 years ago, and that substantial recharge might have occurred as recently as 15,000 years ago.

Recharge to the saturated zone below Yucca Mountain from precipitation is probably small in comparison to inflow from volcanic aquifers to the north or recharge along Fortymile Wash (see the unsaturated zone discussion). An average net infiltration of 4.5 millimeters (0.2 inch) over a 220-square-kilometer (85-square-mile) vicinity around Yucca Mountain would produce a quantity of recharge less than one quarter of the estimated annual recharge along Fortymile Wash.

Monitoring well data collected during the site characterization effort have shown that the potentiometric surface of the carbonate aquifer (that is, the level to which water rises in wells tapping this aquifer), at least in the immediate vicinity of Yucca Mountain, is higher than the water level in the overlying volcanic aquifer. Based on this and other considerations, studies suggest that, provided structural pathways exist, the lower carbonate aquifer might provide upward flow to the volcanic aquifer beneath the proposed level of the repository and farther south. The amount of inflow, if it occurs, is not known.

Outflow from Volcanic Aquifers at and Near Yucca Mountain. Pathways by which water might leave the volcanic aquifers in the Yucca Mountain vicinity include (1) downgradient movement into other volcanic aquifers and alluvium in the Amargosa Desert, (2) downward movement into the carbonate aquifer (though evidence indicates that this does not occur), and (3) upward movement into the unsaturated zone. In addition, water is pumped from wells for a variety of uses, as described in Section 3.1.4.2.1. With the exception of well withdrawals, the actual and relative amounts of outflow from each source are not known.

The regional slope of the potentiometric surface indicates that much of the groundwater flowing southward beneath Yucca Mountain discharges about 80 kilometers (50 miles) to the south at Alkali Flat (Franklin Lake Playa) and in Death Valley. Death Valley, more than 80 meters (260 feet) below sea level, is the final sink for surface water and groundwater in the Death Valley groundwater basin (Figure 3-13); as such, water leaves only by evapotranspiration. Therefore, the pathway for groundwater beneath Yucca Mountain, as indicated by the potentiometric surface, is southerly where it traverses portions of the volcanic aquifers before encountering the basin-fill alluvium and carbonate rock that underlie the Amargosa Valley.

Outflow from the volcanic aquifers into the underlying carbonate aquifer might occur, but direct evidence for this does not exist. Studies suggest that the steeply sloping potentiometric surface at the north end of Yucca Mountain could be explained by a large outflow from the volcanic aquifers to the carbonate aquifer. However, in the vicinity of Yucca Mountain, data available on the potentiometric head of the carbonate aquifer indicate that the opposite condition (that is, outflow from the carbonate aquifer up to the volcanic aquifer) is more likely.

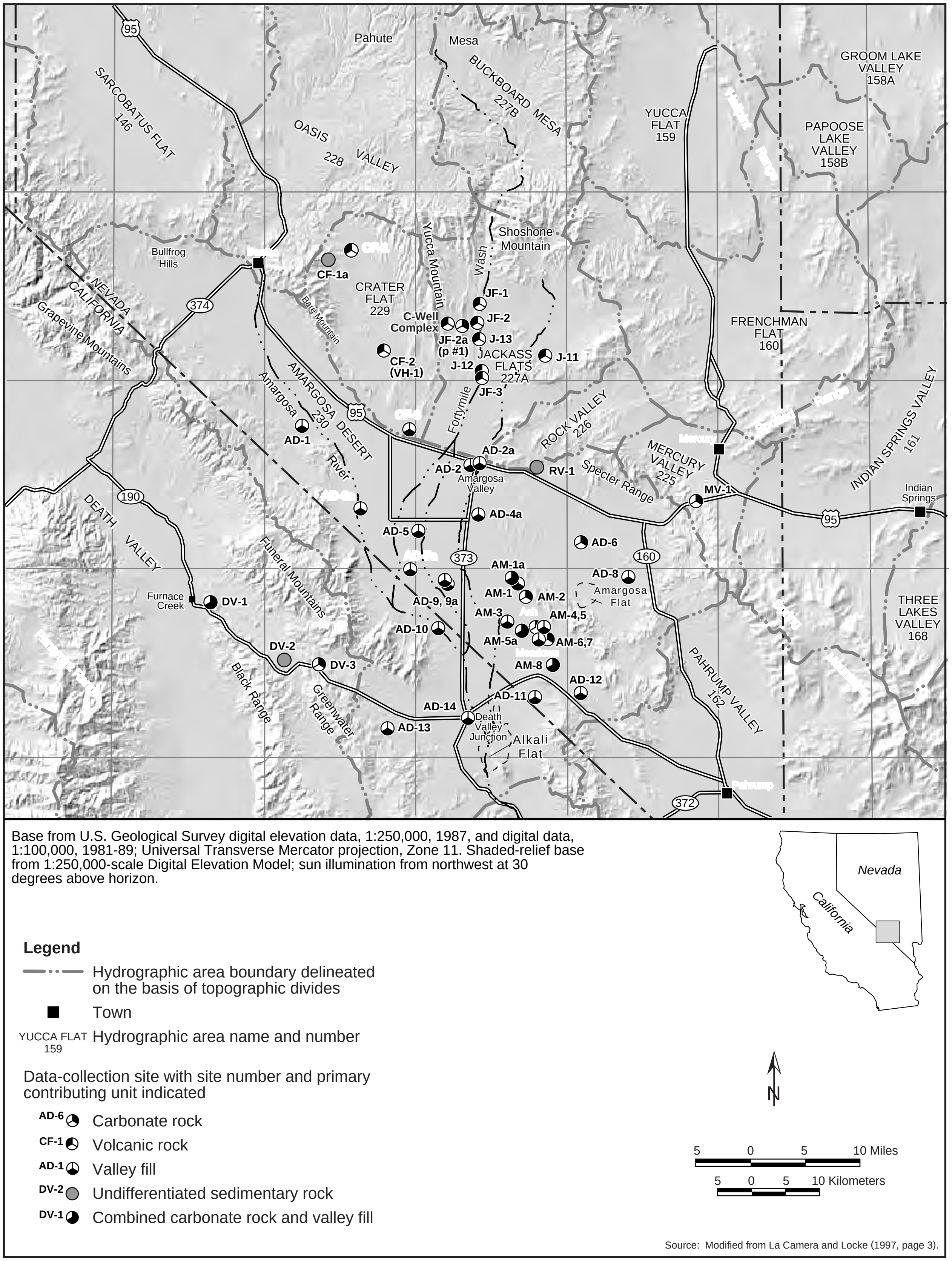
The third possible pathway of outflow from the volcanic aquifer (that is, upward movement to the unsaturated zone), if present, has not been quantified. However, consistent with the above discussion of net infiltration, DOE believes that there is a net downward movement of water in the unsaturated zone in the vicinity of Yucca Mountain.

Use. Two wells, J-12 and J-13 (shown in Figure 3-17), are part of the water system for site characterization activities at Yucca Mountain. These are the nearest production wells to Yucca Mountain and they support water needs for Area 25 of the Nevada Test Site and for Exploratory Studies Facility activities. Both of these wells withdraw groundwater from the Jackass Flats hydrographic area, as listed in Table 3-11. Groundwater has also been pumped from the Jackass Flats area from various boreholes for hydraulic testing, and most recently from the C-well complex, which consists of three separate wells grouped in an area just east of the South Portal Operations Area (Luckey et al. 1996, Figure 17). In addition, water has been pumped occasionally from borehole USW VH-1 (also designated CF-2) in support of Yucca Mountain characterization activities. But the volume pumped from this well, which is in the Crater Flat hydrographic area, is small (Luckey et al. 1996, page 70).

The Yucca Mountain Site Characterization Project has received water appropriation permits (Numbers 57373, 57374, 57375, and 57376) from the State of Nevada for wells J-12, J-13, VH-1 (also known as F-2), and the C-Well complex (Numbers 58827, 58828, and 58829), and a Potable Water Supply permit (NY-0867-12NCNT) for the distribution system. The permits allow a maximum pumping rate of about 0.028 cubic meter (1 cubic foot) a second, with a maximum yearly withdrawal of about 530,000 cubic meters (430 acre-feet). The permit limits apply to site characterization water use. Table 3-15 lists historic and projected water use from wells J-12 and J-13 from 1992 to 2005 for the Exploratory Studies Facility and Concrete Batch Plant, and from the C-Wells, which is pumped and then reinjected as part of aquifer testing. It also lists the total amount of water pumped from wells J-12 and J-13 for both Yucca Mountain and the Nevada Test Site. The difference between the quantities pumped from wells J-12 and J-13 for Yucca Mountain activities and the total withdrawals from these wells represents the quantities used for Nevada Test Site activities in the area. The water-use projections in Table 3-15 are through the end of site characterization activities; Section 4.1.3 discusses water demand projections for the proposed repository.

The U.S. Geological Survey, in support of Yucca Mountain characterization efforts and in compliance with the State permits, has kept records of the amount of water pumped from the J-12 and J-13 wells and of measured water elevation levels in those and other wells in their immediate area since 1992 (La Camera and Locke 1997, pages 1 and 2). One of the objectives of keeping these records is to detect and document changes in groundwater resources during the Yucca Mountain investigations. Therefore, the Survey effort included the collection of historic water elevation data to establish a baseline. Results from these efforts have been documented in annual reports. The report for 1997 (La Camera, Locke, and Munson 1999, all) includes a summary of 1996 results and detailed results for 1997. Table 3-16 summarizes the changes observed in median groundwater elevations in seven wells in Jackass Flats. The second column of the table identifies the historic or baseline elevation for each well against which the annual median values are being compared. In addition, the table lists the average deviation of measured water levels during the period from which the baseline was generated.

The elevation changes listed in Table 3-16 are different from the short-term fluctuations described above that are a response to changes in barometric pressure and Earth tides. The differences in comparison of annual median values should indicate water level trends, if there are any. The data show that a decline in



Base from U.S. Geological Survey digital elevation data, 1:250,000, 1987, and digital data, 1:100,000, 1981-89; Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northwest at 30 degrees above horizon.

Source: Modified from La Camera and Locke (1997, page 3).

Figure 3-17. Selected groundwater data-collection sites in the Yucca Mountain region.

Table 3-15. Water withdrawals (acre-feet)[a] from wells in the Yucca Mountain vicinity.

Year	J-12 and J-13 Yucca Mountain characterization[b]	J-12 and J-13 total withdrawals[c]	C-wells[b]
1992	18	120	0
1993	80	210	0
1994	75	280	0
1995	94	260	19
1996	66	220	180
1997	63	150	190
1998	63[d]	N/A[e]	190[f]
1999	63	N/A	N/A
2005	63	N/A	N/A

a. To convert acre-feet to cubic meters, multiply by 1233.49.

b. Source: TRW (1999j, page 4).

c. Source: Clary et al. (1995, page 660); Bauer et al. (1996, page 702); Bostic et al. (1997, page 592); Bonner et al. (1998, page 606); La Camera, Locke, and Munson (1999, all); withdrawals for 1992 and 1993 were estimated from figures in La Camera and Locke (1997, page 51).

d. Assumed to remain constant from 1997 through 2005.

e. N/A = not available.

f. Assumed to remain constant from 1997 to 1998.

Table 3-16. Differences between annual median elevations and baseline median elevations.[a]

	Baseline elevations		Difference (in centimeters[b]) baseline					
Well	Median (meters[c] above sea level)	Average deviation about the median (centimeters)	1992	1993	1994	1995	1996	1997
JF-1	729.23	± 6	–3	0	–6	0	–6	–3
JF-2	729.11	± 9	+3	0	+3	+9	0	–3
JF-2a[d]	752.43	± 12	0	+6	+12	+15	+21	+27
J-13	728.47	± 6	–3	–3	–9	–6	–12	–12
J-11	732.19	± 3	0	0	+3	+6	+6	+12
J-12	727.95	± 3	0	0	–3	–3	–9	–9
JF-3	727.95	± 3	N/A[e]	N/A	–6	–6	–9	–9

a. Source: La Camera, Locke, and Munson (1999, Table 10).

b. To convert centimeters to inches, multiply by 0.3937.

c. To convert meters to feet, multiply by 3.2808.

d. Well JF-2a is also known as UE-25 p#1, or P-1.

e. N/A = not available.

groundwater elevation has been seen in some, but not all, of the local wells. Specifically, the data show the following:

- Two wells, JF-1 and JF-2, stayed within the band of elevations characteristic of the baseline data.

- Two wells, JF-2a (also known as UE-25 p#1, or P-1) and J-11, indicated elevation increases of 15 and 9 centimeters (about 5.9 and 3.5 inches), respectively, above the band of elevations characteristic of the baseline data (and even higher above the median of the baseline data as listed in the table).

- Three wells, J-13, J-12, and JF-3, each indicated an elevation decrease of 6 centimeters (about 2.4 inches) below the band of elevations characteristic of the baseline data (and even further below the median of the baseline data as listed in the table).

In its discussion of groundwater levels, the U.S. Geological Survey (La Camera and Locke 1997, page 22) indicated that monitoring of water levels in the seven wells should continue to see if additional decreases occur and if they can be correlated to periods of withdrawal. In regard to overall groundwater levels in the Jackass Flats area, the data do not appear to show any definitive trend in elevation change, either up or down. However, the three wells showing a water decline are either being pumped (J-12 and J-13) or, in the case of JF-3, are close to a production well. Five of these wells (see Figure 3-17) are in or very close to Fortymile Wash and the two wells (JF-2a and J-11) that are farthest from the wash are those wells that have shown a water level increase.

Table 3-17. Water chemistry of volcanic and carbonate aquifers at Yucca Mountain (milligrams per liter).[a]

	Chemical composition	
Chemical constituent	Volcanic aquifers[b]	Lower carbonate aquifer[c]
Calcium	1 - 20	100
Magnesium	0.01 - 2	39
Potassium	1 - 5	12
Sodium	38 - 100	150
Bicarbonate	110 - 280	570
Chloride	5 - 10	28
Sulfate	40 - 57	160
Silica	40 - 57	41

a. Source: TRW (1999h, pages 2-43 to 2-44).
b. Based on samples from 12 wells.
c. Based on samples from one well.

Saturated Zone Groundwater Quality. Groundwater quality for the aquifers beneath Yucca Mountain was addressed by the Geological Survey sampling and analysis effort described above for regional groundwater quality. This effort included the collection and analysis of samples from three wells in the Jackass Flats area (including J-12 and J-13); the results indicated that the concentrations of dissolved substances in local groundwater were below the numerical criteria of the primary drinking water standards set by the Environmental Protection Agency for public drinking water systems (Covay 1997, all). However, samples from each of the wells exceeded the secondary standard for fluoride, as was a proposed standard for radon. Both of these constituents occur naturally in the rock through which the groundwater flows. Overall, local groundwater quality is generally good.

Investigations of the chemical and mineral composition of groundwater at Yucca Mountain have provided an indication of the differences between the aquifers beneath the site. The chemical composition of groundwater depends on the chemistry of the recharge water and the chemistry of the rocks through which the water travels. Water in the volcanic aquifers and confining units at Yucca Mountain has a relatively dilute sodium-potassium-bicarbonate composition that probably results from the dissolution of volcanic tuff (Table 3-17). The chemistry of water from the lower carbonate aquifer is very different (a generally more concentrated calcium-magnesium-bicarbonate composition), which would be expected from water traveling through and dissolving carbonate rock (Table 3-17).

As part of the Yucca Mountain project, well and spring monitoring activities performed during 1997 aided the establishment of a baseline for radioactivity in groundwater near the site of the proposed repository (TRW 1998b, all). The quarterly sampling included six wells and two springs that were selected to ensure that at least two were representative of each of the three general aquifers (carbonate, volcanic, and alluvial) in the region. Samples were analyzed for gross alpha, gross beta, total uranium, and concentrations of selected beta and gamma-emitting radionuclides. Table 3-18 lists the results from this monitoring as average values from the quarterly sampling events for each well or spring. The table lists the location of each well or spring, including the data collection site designations shown on Figure 3-17, the contributing aquifer, and a comparison, if applicable, to Maximum Contaminant Levels established by the Environmental Protection Agency for water supplied by public drinking water systems. As indicated in the table, the sites sampled include locations outside the Alkali Flat-Furnace Creek sub-basin in which Yucca Mountain is located. The Cherry Patch location is in the Ash Meadows sub-basin and Crystal Pool and Fairbanks Spring are on the border between the two sub-basins, but are fed by flow

Table 3-18. Results of 1997 groundwater sampling and analysis for radioactivity.[a]

Site name and location description[b]	Contributing aquifer	Average combined radium-226 and -228 (picocuries per liter)	Average gross alpha (picocuries per liter)	Average total uranium[c] (micrograms per liter)	Average gross beta (picocuries per liter)
J-12 Fortymile Wash, SE of Yucca Mtn.	Volcanic	0.18±0.31	BDL[d]	0.52±0.05	6.23±0.86
J-13 Fortymile Wash, SE of Yucca Mtn.	Volcanic	0.45±0.36	BDL	0.51±0.04	5.84±0.85
C-3 (C-well complex) By South Portal, SE of Yucca Mtn.	Volcanic	0.58±0.36	1.34±1.05	1.04±0.09	3.59±0.76
Crystal Pool (Spring) (AM-5a) Ash Meadows	Carbonate/ alluvial[e]	0.93±0.20	BDL	2.64±0.23	14.0±1.28
Fairbanks Spring (AM-1a) Ash Meadows	Carbonate/ alluvial	0.80±0.36	BDL	2.23±0.19	11.1±1.17
Nevada Department of Transportation Well (AD-2a) Amargosa Valley	Alluvial	0.32±0.33	BDL	2.55±0.22	5.95±0.93
Gilgans South Well (AD-9a) Amargosa Desert	Alluvial	0.19±0.31	BDL	0.63 ± 0.05	9.14±0.97
Cherry Patch Well (AD-8) NE of Ash Meadows	Alluvial	0.22±0.33	9.19±4.35	13.1 ± 1.16	18.7±1.65
Drinking water Maximum Contaminant Levels[f]		5	15	NA[g]	NA

a. Source: TRW (1998b, pages 12 to 21).
b. Figure 3-18 shows the locations of the wells.
c. To convert total uranium concentrations in micrograms per liter to picocuries per liter, multiply by 0.68 (TRW 1998b, page 15).
d. BDL = below detection limit.
e. Alluvium is identified as valley fill in TRW (1999h, pages 1-7 and 1-8).
f. Drinking water Maximum Contaminant Levels are set by the Environmental Protection Agency in 40 CFR Part 141.
g. NA = not applicable.

through Ash Meadows. The location variety supports area comparisons as well as comparisons between the different contributing aquifers.

Table 3-18 indicates that Maximum Contaminant Levels for combined radium-226 and radium-228 and for gross alpha were not exceeded by the average values from any of the sampling sites or by the maximum values reported for those parameters (TRW 1998b, pages 12 to 21). The samples were analyzed for other beta- or gamma-emitting radionuclides, specifically tritium, carbon-14, chlorine-36, nickel-59, strontium-89, strontium-90, technetium-99, iodine-129, and cesium-137. The table does not list the results for these parameters because they are below minimum detectable activity (TRW 1998b, page 13). As a conservative measure, however, DOE used the values reported by the laboratory to calculate dose contributions (TRW 1998b, Appendix F). Water from each sampling location was shown to have exposure values well below the 4-millirem-per-year total body (or any internal organ) dose limit set as the Maximum Contaminant Level for beta- or gamma-emitting radionuclides.

There is no indication that DOE activities at the Nevada Test Site have contaminated the groundwater beneath Yucca Mountain. This is consistent with studies performed on the Nevada Test Site. Nimz and Thompson (1992, all) documented about a dozen instances in which radionuclides have migrated into the groundwater from areas of nuclear weapons testing at the Nevada Test Site in 40 years. The maximum distance of tritium migration is believed to be several kilometers; less mobile radioactive constituents, which include a wide variety of isotopes (DOE 1996f, pages 4-126 to 4-129), have migrated no more than about 500 meters (1,600 feet). There has, however, been recent evidence of plutonium migration from one below-groundwater test at Pahute Mesa. Groundwater monitoring results indicate plutonium has migrated at least 1.3 kilometers (0.8 mile) from this site in 28 years and is apparently associated with the movement of very small particles called colloids (Kersting et al. 1999, page 56). None of the nuclear testing occurred in Area 25 where the Yucca Mountain Repository facilities would be. However, the flow of groundwater from areas on Pahute and Buckboard Mesas where DOE conducted 81 and 2 nuclear tests, respectively, could be to the south toward Yucca Mountain. The distance is about 40 kilometers (25 miles) to Pahute Mesa and about 30 kilometers (19 miles) to Buckboard Mesa (Figure 3-17). Because of these distances, there is no reason to believe that radionuclides from nuclear tests could migrate as far as Yucca Mountain during the active life of the repository. Chapter 8 discusses the potential for long-term migrations of radionuclides to result in cumulative radiation from nuclear testing contamination eventually migrating through the groundwater system under the repository.

3.1.5 BIOLOGICAL RESOURCES AND SOILS

DOE used available information and studies on plants and animals at the site of the proposed repository and the surrounding region to identify baseline conditions for biological resources. This information included land cover types, vegetation associations, and the distribution and abundance of plant and animal species in the region of influence (the analyzed land withdrawal area) and in the broader region. The plants and animals in the Yucca Mountain region are typical of species in the Mojave and Great Basin Deserts.

DOE has surveyed the region for naturally occurring wetlands and has studied soil characteristics (thicknesses, water-holding capacity, texture, and erosion hazard) in the region. This section summarizes this information and describes existing soil conditions in relation to potential contaminants. Unless otherwise noted, this information is from the *Environmental Baseline File for Biological Resources* (TRW 1999k, all) or the *Environmental Baseline File for Soils* (TRW 1999l, all).

The State of Nevada (NWPO 1997, all) has expressed the opposing view that there was no systematic, interdisciplinary, environmental program before investigations began in 1982 to characterize the unique and fragile desert environment at Yucca Mountain before potential irreversible alterations (Lemons and Malone 1989, pages 435 to 441). However, after site investigations started and impacts might have occurred, DOE began studies of sensitive species, archaeology, airborne particulates, and groundwater (Lemons and Malone 1989, pages 435 to 441), and established an environmental baseline from these data for use in the preparation of the EIS (Malone 1989, pages 77 to 95). Many of the studies conducted to establish the baseline and evaluate impacts, particularly those on plants and animals (Malone 1995, pages 271 to 284), did not use an integrated ecosystem approach and, therefore, are of little value for evaluating impacts of the repository.

Studies initiated after the start of site investigations are suitable for establishing the baseline needed for this EIS. The purpose of studies of the impacts of site characterization activities on plants and animals was not to evaluate potential impacts from a repository, but rather to focus on the appropriate level of ecological organization for the types of impacts that occurred during characterization activities. DOE used the results of those studies in the EIS analysis to understand and predict possible impacts from similar activities during repository construction and operation (for example, habitat destruction).

3.1.5.1 Biological Resources

3.1.5.1.1 *Vegetation*

Broad categories of land cover types (based primarily on predominant vegetation) have been identified and mapped across the State of Nevada (Utah State University 1996, GAP Data) and at the site of the proposed Yucca Mountain Repository (TRW 1998c, page 9). Land cover types typical of the Mojave and

Great Basin Deserts occur in the analyzed land withdrawal area; they include creosote-bursage (56 percent), blackbrush (14 percent), hopsage (13 percent), Mojave mixed scrub (10 percent), salt desert scrub (4 percent), sagebrush (3 percent), and pinyon-juniper (much less than 1 percent) (Figure 3-18). None of the more than 210 plant species known to occur in the analyzed land withdrawal area is endemic to the area; that is, they all occur in other places.

Plant species typical of the Mojave Desert dominate the vegetation at low elevations in the analyzed land withdrawal area. Low-elevation valleys, alluvial fans, and large washes are dominated by white bursage (*Ambrosia dumosa*), creosotebush (*Larrea tridentata*), Nevada jointfir (*Ephedra nevadensis*), littleleaf ratany (*Krameria erecta*), and pale wolfberry (*Lycium pallidum*). Low-elevation hillsides are dominated by similar species, with the addition of shadscale (*Atriplex confertifolia*), California buckwheat (*Eriogonum fasciculatum*), and spiny hopsage (*Grayia spinosa*).

At higher elevations, generally at the northern end of the analyzed land withdrawal area, species typical of the Great Basin Desert are dominant. Ridge tops and slopes are dominated by blackbrush (*Coleogyne ramosissima*), heathgoldenrod (*Ericameria teretifolius*), Nevada jointfir, broom snakeweed (*Gutierrezia sarothrae*), green ephedra (*Ephedra viridis*), and California buckwheat. On some steep north-facing slopes, big sagebrush (*Artemisia tridentata*) is predominant.

3.1.5.1.2 *Wildlife*

Wildlife at Yucca Mountain is dominated by species associated with the Mojave Desert, with some species from the Great Basin Desert at higher elevations.

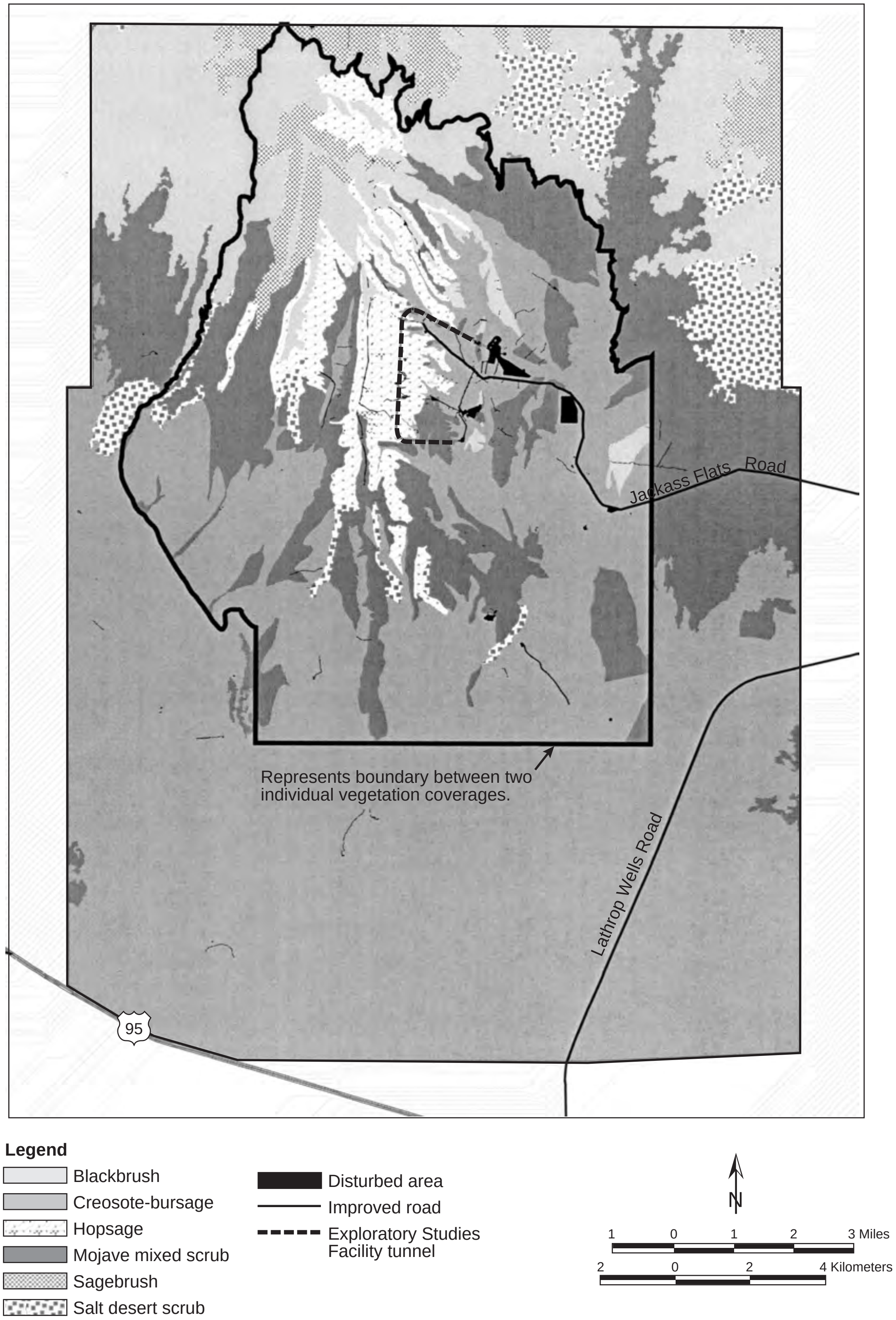
The 36 species of mammals that have been observed in the analyzed Yucca Mountain land withdrawal area include 17 species of rodents, seven species of bats, three species of rabbits and hares, and nine species of large mammals such as coyote *(Canis latrans)*, mule deer *(Odocoileus hemionus)*, and burros (*Equus asinus*). The most abundant species are long-tailed pocket mice *(Chaetodipus formosus*) and Merriam’s kangaroo rats (*Dipodomys merriami*).

The 27 species of reptiles include 12 species of lizards, 14 species of snakes, and the desert tortoise (*Gopherus agassizii*). The most abundant lizard is the side-blotched lizard (*Uta stansburiana*), while the western whiptail (*Cnemidophorus tigris*) is common. The most abundant snakes are the coachwhip (*Masticophis flagellum*) and the long-nosed snake (*Rhinocheilus lecontei*). No amphibians have been found at Yucca Mountain.

There have been no formal attempts to quantify the birds present at Yucca Mountain, but at least 120 species have been sighted in or near the analyzed land withdrawal area, including 14 species that nest there. Transient and resident species have been recorded including species typical of the desert, migrating water birds and warblers, and raptors. Black-throated sparrows (*Amphispiza bilineata*) are the most common resident birds and mourning doves (*Zenaida macroura*) are seasonally common.

Researchers have collected invertebrates from 18 orders and 53 families at Yucca Mountain. Members of the insect orders Lepidoptera (butterflies and moths), Hymenoptera (bees, wasps, and ants), and Coleoptera (beetles) were the most numerous of those collected.

Several game species and furbearers (see Nevada Administrative Code 503.125) have been observed in the analyzed land withdrawal area, including (1) three species of game birds—Gambel’s quail (*Callipepla gambelii*), chukar (*Alectoris chukar*), and mourning doves, (2) mule deer (*Odocoileus*



Source: Adapted from Utah State University (1996, all) and TRW (1998c all).

Figure 3-18. Vegetation types in the analyzed land withdrawal area.

hemionus), and (3) three species of furbearers—kit foxes (*Vulpes velox*), mountain lions (*Puma concolor*), and bobcats (*Lynx rufus*).

3.1.5.1.3 *Special Status Species*

SPECIAL STATUS SPECIES

An **endangered species** is classified under the Endangered Species Act as being in danger of extinction throughout all or a significant part of its range.

A **threatened species** is classified under the Endangered Species Act as likely to become an endangered species in the foreseeable future.

Candidate species are species for which the Fish and Wildlife Service has enough substantive information on biological status and threats to support proposals to list them as threatened or endangered under the Endangered Species Act. Listing is anticipated but has been precluded temporarily by other listing activities.

The State of Nevada has also designated special status species as endangered, threatened, protected, and sensitive. Species with these classifications are protected under Nevada Administrative Code Chapter 503.

Bureau of Land Management **sensitive species** include species designated by the Bureau's State Director in addition to those listed, proposed, or candidates under the Endangered Species Act or listed by the State of Nevada as endangered or otherwise protected.

No plant species listed as threatened or endangered or that are proposed or candidates for listing under the Endangered Species Act occur in the analyzed land withdrawal area. No plant species classified as sensitive by the Bureau of Land Management are known to occur in the analyzed land withdrawal area. Several species of cacti and yucca, all of which are protected by the State of Nevada from commercial collection, are scattered throughout the region, including the analyzed land withdrawal area.

One animal species that occurs at Yucca Mountain, the desert tortoise, is listed as threatened under the Endangered Species Act. Yucca Mountain is at the northern edge of the range of the desert tortoise (Rautenstrauch, Brown, and Goodwin 1994, page 11), and the abundance of tortoises at Yucca Mountain is low or very low in comparison to other portions of its range. Aspects of the ecology of the desert tortoise population at Yucca Mountain have been studied extensively (TRW 1999k, all).

Individual threatened bald eagles (*Haliaeetus leucocephalus)* or endangered peregrine falcons (*Falco peregrinus)* occasionally migrate through the region; these species have been seen once each at the Nevada Test Site. Both species are rare in the region and have not been seen at Yucca Mountain. The State of Nevada has classified both birds as endangered.

No other Federally listed threatened or endangered species or candidates for listing under the Endangered Species Act occur at Yucca Mountain.

Five species classified as sensitive by the Bureau of Land Management occur at Yucca Mountain. Two species of bats—the long-legged myotis (*Myotis volans*) and the fringed myotis (*M. thysanodes*)—have been observed near the site. Three other species, the western chuckwalla (*Sauromalus obesus*), burrowing owl (*Speotyto cunicularia*), and Giuliani's dune scarab beetle (*Pseudocotalpa giulianii*), occur in the analyzed land withdrawal area. The chuckwalla, one of the largest lizards in Nevada, is locally common and widely distributed in rocky habitats throughout the analyzed land withdrawal area and the surrounding region. The seldom-seen burrowing owl generally occurs in valley bottoms and is known to be a year-round resident at the Nevada Test Site. Giuliani's dune scarab beetle has been found near the cinder cones north of U.S. Highway 95 at the south end of Crater Flat.

Ash Meadows is about 39 kilometers (24 miles) south of Yucca Mountain. Although Ash Meadows is outside the region of influence for biological resources, it contains a number of special status species that an evaluation of regional biological resources should consider. Of the eight endemic plant species at Ash Meadows, one is listed as endangered (Amargosa alkali plant, *Nitrophila mohavensis*) and six are listed as threatened (Spring-loving centaury, *Centaurium namophilum*; Ash Meadows milkvetch, *Astragalus phoenix*; Ash Meadows naked stem sunray, *Enceliopsis nudicaulis* var. *corrugata*; Kings Mousetail, *Ivesia kingii* var. *eremica*; Ash Meadows gumweed, *Grindelia fraximopratensis*; and Ash Meadows blazing star, *Mentzelia leucophylla*) (50 *FR* 20777, May 20, 1985). Four endemic fish species occur in the springs and pools. The Fish and Wildlife Service and the State of Nevada list these species—the Ash Meadows Amargosa speckled dace (*Rhinichthys osculus nevadensis*), Ash Meadows Amargosa pupfish (*Cyprinodon nevadensis mionectes*), Devils Hole pupfish (*C. diabolis*), and Warm Springs Amargosa pupfish (*C. nevadensis pectoralis*)—as endangered. The springs also provide habitat for a number of endemic riffle beetles, springsnails, and other invertebrates, including the threatened Ash Meadows naucorid bug (*Ambrysus amargosus*).

3.1.5.1.4 *Wetlands*

There are no naturally occurring jurisdictional wetlands (wetlands that are regulated under Section 404 of the Clean Water Act) at Yucca Mountain. Four manmade ponds in the Yucca Mountain region have riparian vegetation. Fortymile Wash and some of its tributaries might be classified as waters of the United States as defined by the Clean Water Act. Jurisdictional wetlands associated with Ash Meadows are outside the region of influence for the Proposed Action.

3.1.5.2 Soils

Researchers have conducted a soil survey centered on Midway Valley (the location of the proposed North Portal facilities) and the ridges to the west (Resource Concepts 1989, all), and a more general soil survey of the entire Yucca Mountain region (DOE 1997f, all). The survey that centered on Midway Valley identified 17 soil series and seven map units (Table 3-19) at Yucca Mountain (Resource Concepts 1989, all); none of these series is classified as prime farmland. Based on a wetlands assessment at the Nevada Test Site (Hansen et al. 1997, all), there are no hydric soils at Yucca Mountain. Yucca Mountain soils are derived from underlying volcanic rocks and mixed alluvium dominated by volcanic material, and in general have low water-holding capacities.

SOIL TERMS

Prime farmland: Land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops, and is available for these uses (urban areas are not included). It has the soil quality, growing season, and moisture supply needed for the economic production of sustained high yields of crops when treated and managed (including water management) according to acceptable farming methods (Farmland Protection Policy Act of 1981, 7 CFR 7.658).

Piedmont: Land lying along or near the foot of a mountain. For example, a fan piedmont is a fan-shaped landform between the mountain and the basin floor.

Table 3-19. Soil mapping units at Yucca Mountain.[a]

Map unit	Percent	Geographic setting	Soil characteristics
Upspring-Zalda	11	Mountain tops and ridges. Soils occur on smooth, gently sloping ridge tops and shoulders and on nearly flat mesa tops. Rhyolite and tuffs are parent materials for both soil types.	Typically shallow (10 - 51 cm[b]) to bedrock, or to thin duripan[c] over bedrock. They are well to excessively drained, have low available water-holding capacity, medium to rapid runoff potential, and slight erosion hazard.
Gabbvally-Downeyville-Talus	8	North-facing mountain sideslopes. Talus is stone-sized rock occurring randomly throughout unit in long, narrow, vertically oriented accumulations.	Shallow (10 - 36 cm) to bedrock. Permeability is moderate to moderately rapid. They have moderate to rapid runoff potential, are well drained, and have low available water-holding capacity and moderate erosion hazard.
Upspring-Zalda-Longjim	27	Mountain sideslopes. Soils occur on south-, east-, and west-facing slopes, and on moderately sloping alluvial deposits below sideslopes.	Shallow (10 - 51 cm) to bedrock or to thin duripan over bedrock. They are well to excessively drained and have moderately rapid to rapid permeability and runoff potential, very low available water-holding capacity, and slight erosion hazard.
Skelon-Aymate	22	Alluvial fan remnants. Soils occur on gently to strongly sloping summits and upper sideslopes.	Moderately deep (51 - 102 cm) to indurated[d] duripan or petrocalcic[e] layer with low to very low available water-holding capacity, moderately rapid permeability, slow runoff potential, and slight erosion hazard.
Strozi variant-Yermo-Bullfor	7	Alluvial fan remnants. Soils occur on gently to moderately sloping alluvial fan remnants and stream terraces adjacent to large drainages.	Moderately deep (51 - 102 cm) to deep (102 cm). They are well drained and have rapid permeability, very low available water-holding capacity, slow runoff potential, and slight erosion hazard.
Jonnic variant-Strozi-Arizo	12	Dissected alluvial fan remnants. Soils occur on fan summits, moderately sloping fan sideslopes, and inset fans. They are formed in alluvium from mixed volcanic sources.	Moderately deep (36 - 43 cm) to deep (more than 102 cm), sometimes over strongly cemented duripan. They have slow or rapid permeability, slow or moderate runoff potential, very low available water-holding capacity, and slight erosion hazard.
Yermo-Arizo-Pinez	13	Inset fans and low alluvial sideslopes in mountain canyons; and drainages between fan remnants. Soils occur on moderately to strongly sloping inset fans near drainages, adjacent to lower fan remnants, and below foothills.	Deep (more than 102 cm), sometimes over indurated duripan. They are well drained and have very low available water holding-capacity, moderately slow to rapid permeability, slow to medium runoff potential, and slight erosion hazard.

a. Source: TRW (1999l, pages 3 and 4).
b. To convert centimeters (cm) to inches, multiply by 0.3937.
c. Duripan: A subsurface layer cemented by silica, usually containing other accessory cements.
d. Indurated: Hardened, as in a subsurface layer that has become hardened.
e. Petrocalcic: A subsurface layer in which calcium carbonate or other carbonates have accumulated to the extent that the layer is cemented or indurated.

The shallow soils on ridge tops at Yucca Mountain often consist of a thin *hardpan* (hardened or cemented soil layer) on top of bedrock and range from *well drained* to *excessively drained*, which means that water drains readily to very rapidly. The soil has a topsoil layer typically less than 15 centimeters (6 inches) thick and, in some instances, a subsoil layer 5 to 30 centimeters (2 to 12 inches) thick. Soil textures range from gravelly to cobbly, loamy sands to sandy loams. Soils are calcareous (high in calcium carbonate), with lime coatings on the undersides of rocks in the subsoil layer. The soils are moderately to strongly alkaline, with a pH ranging from 8.0 to 8.6. Rock fragments ranging in size from gravel to cobbles dominate 45 to 65 percent of the ground surface.

Soils on fan piedmonts and in steep, narrow canyons are relatively deep and are *well drained* (water is drained readily, but not rapidly). These soils developed from residues of volcanic parent material, with a component of calcareous eolian sand. Soils formed from the volcanic parent material generally range from *moderately shallow* [50 to 75 centimeters (20 to 30 inches)] to *moderately deep* [75 to 100 centimeters (30 to 40 inches)] over a thin hardpan on top of bedrock. The topsoil layers are generally less than 25 centimeters (10 inches) thick, with a subsoil layer thickness of 25 to 50 centimeters (10 to 20 inches). The mixed soils, containing residues from volcanic parent material and calcareous eolian sand, are often *deep* [100 to 150 centimeters (40 to 60 inches)] or moderately deep, having a well-cemented hardpan. The topsoil layers are less than 15 centimeters (6 inches) thick, with the layer of soil parent material as deep as 150 centimeters (60 inches). Soil textures are gravelly, sandy loams with 35 to 70 percent rock fragments. Soils are generally calcareous and moderately to strongly alkaline.

Soils on alluvial fans and in stream channels are *very deep* [greater than 150 centimeters (60 inches)] and range from well drained to excessively drained. The topsoil layers are generally less than 20 centimeters (8 inches) thick, with the layer of soil parent material as deep as 150 centimeters. Soil textures are very gravelly, with fine sands to sandy loams and abundant rock fragments. The soils are calcareous and moderately alkaline.

The Yucca Mountain site characterization project has sampled and analyzed surface soils for radiological constituents. In addition, records of spills or releases of nonradioactive materials have been maintained to meet regulatory requirements and to provide a baseline for the Proposed Action. A recent summary of existing radiological conditions in soils is based on 98 surface samples collected within 16 kilometers (10 miles) of the Exploratory Studies Facility. The results of that analysis, when compared to other parts of the world, indicate average levels of the naturally occurring radionuclide uranium-238 series decay products and above-average levels of the naturally occurring radionuclides potassium-40 and thorium-232 series decay products. The higher-than-average radionuclide values might be due to the origin of the soil at the site from tuffaceous igneous rocks. The studies also detected concentrations of the manmade radionuclides strontium-90, cesium-137, and plutonium-239 from worldwide nuclear weapons testing.

3.1.6 CULTURAL RESOURCES

Cultural resources include any prehistoric or historic district, site, building, structure, or object resulting from or modified by human activity. Cultural resources could also include potential traditional cultural properties. Under Federal regulation, cultural resources designated as historic properties warrant consideration with regard to potential adverse impacts resulting from proposed Federal actions. A cultural resource is an historic property if its

CULTURAL RESOURCES

Archaeological site: The location of a past event, a prehistoric or historic occupation or activity, or a building or structure, whether standing, ruined, or vanished, where the location itself maintains archaeological value.

Traditional cultural property: A property associated with the cultural practices or beliefs of a living community that are (1) rooted in that community's history, and (2) important in maintaining the cultural identity of the community.

attributes make it eligible for listing or it is formally listed on the *National Register of Historic Places*. For this analysis, DOE has evaluated the importance of historic and archaeological resources according to National Register eligibility criteria.

Cultural resources at Yucca Mountain include archaeological resources that are prehistoric or historic, and other resources important to Native American tribes and organizations, such as potential traditional cultural properties. DOE has collected information on the various types of archaeological sites, detailing their purposes and the kinds of artifacts typically present. DOE also has focused on Native American interests in the region's cultural resources. Section 3.1.6.2 summarizes these issues in discussions of Native American views of the affected environment.

Unless otherwise indicated, the information in this section is derived from either the summary of past archaeological projects at Yucca Mountain (TRW 1999m, all) or from *American Indian Perspectives on the Yucca Mountain Site Characterization Project and the Repository Environmental Impact Statement* (AIWS 1998, all).

3.1.6.1 Archaeological and Historic Resources

Site characterization efforts have led to a number of archaeological investigations at Yucca Mountain over the past two decades, including an archaeological field survey of a 44-square-kilometer (about 11,000-acre) parcel that proposed repository activities probably would affect. The field survey was followed by limited test excavations at 29 sites to determine their scientific importance and to develop management strategies for the protection of archaeological resources. Additional archaeological surveys have been conducted along nearby Midway Valley and Yucca Wash and in lower Fortymile Canyon just east of the Yucca Mountain site.

Concurrent with these investigations, DOE directed archaeological surveys and data-recovery projects before beginning planned ground-disturbing activities specific to the Yucca Mountain Project. Limited data-recovery efforts at 18 archaeological sites support a model for a local cultural sequence that includes a pattern of linear-shaped sites along major drainages dating as far back as 7,000 years, and a shift to a more dispersed pattern of sites about 1,500 years ago. A site monitoring program designed to examine human and natural impacts to cultural resources through time began in 1991 and is continuing at Yucca Mountain.

Decades of cultural resource investigations at Yucca Mountain and at the Nevada Test Site have revealed archaeological features and artifacts. Based on archaeological site file searches at the Desert Research Institute in Las Vegas and Reno and at the Harry Reid Center at the University of Nevada, Las Vegas, approximately 826 archaeological sites have been discovered in the analyzed land withdrawal area. Most of the known archaeological sites are small scatters of lithic (stone) artifacts, usually comprised of fewer than 50 artifacts with few formal tools and no temporally or culturally diagnostic artifacts in the inventory. None of the sites has been listed on the *National Register of Historic Places*, but 150 are potentially eligible for nomination (see Table 3-20). Several reports describe the specific procedures used to study and protect these cultural sites (Buck and Powers 1995, all; DOE 1992a, all). DOE (1988b, all) describes how the Department meets its responsibilities under Section 106 of the National Historic Preservation Act and the American Indian

Table 3-20. Sites in the Yucca Mountain region potentially eligible for the *National Register of Historic Places.*

Type	Number
Temporary camps	43
Extractive localities	14
Processing localities	9
Localities	77
Caches	2
Stations	1
Historic sites	4
Total	**150**

Religious Freedom Act, and interactions with the Advisory Council on Historic Preservation and the Nevada State Historic Preservation Officer.

This EIS separates archaeological sites into two broad groups, prehistoric and historic, separated by the first contact between Native Americans and Euroamericans; in the Great Basin, this contact occurred in the early 1800s. The oldest prehistoric sites in southern Nevada are about 11,000 years old. These sites include one or more of the following features: temporary campsites, rock art, scattered lithic artifacts, quarries, plant-processing remains, hunting blinds, and rock alignments. The sites are categorized as temporary camps, extractive localities, processing localities, localities, caches, and stations. Historic sites include mining sites, ranching sites, transportation and communication sites, and some Cold War facilities. The following paragraphs define eligible types of sites at Yucca Mountain in each group (Table 3-20).

Temporary Camps. When occupied by a group of people, a temporary camp was a hub of activity for raw materials processing, implement manufacturing, and maintenance and general living activities. Camp artifacts typically include debris and discards from the making of stone tools, projectile points, bifacial stone tools, cores, milling stones, pottery, specialized tools, hearths, shelters, structures, and art. The nature and diversity of artifacts and features are the basis for designating a site as a temporary camp.

Extractive Localities. These were sites for specific extractive or resource-procurement tasks. They probably were occupied for short periods and for such limited activities as toolstone quarrying, hunting, and seed gathering. A single locality can contain isolated artifacts or large quantities of artifacts that reflect specific activities. In comparison to temporary camps, extractive localities have a low diversity of artifacts. Extractive locality artifacts include isolated projectile points or bifacial stone tools where hunting occurred, toolstone quarries with thousands of flakes, diffuse scatters of lithic flakes where plant materials were gathered, hunting blinds, and *tinajas* or water-catchment basins.

Processing Localities. Specific resource-processing tasks occurred at processing localities. These localities probably were occupied only for short periods and for limited activities such as butchering, milling, and roasting. A single site can contain an isolated artifact or large quantities of artifacts that reflect specific activities. Like extractive localities, processing localities have a low diversity of artifacts. Examples of processing localities include stone tool manufacturing stations, milling stations for processing food, diffuse scatters containing stone tools for processing meat and hides, hearths, and roasting pits.

Localities. This category includes sites that might have been either extractive or processing localities but for which there is not enough information to determine if such activities occurred.

Caches. Caches are temporary places for storing resources or artifacts. They include sealed rock shelters, rock piles, rock rings without evidence of habitation, rock alignments, brush piles held in place by rocks, and storage pits. A cache can also be an association of similar artifacts such as heat-treated bifacial stone tools, projectile points, and snares, or such resources as toolstone blanks and firewood in or on a natural feature such as at the base of a tree, in a rock shelter, or in a mountain saddle. Caches are distinguished from localities as places for storing resources, rather than as places of procurement or processing.

Stations. Stations are sites where groups gathered to exchange information about such things as game movement, routes of travel, and ritual activities. Examples of stations are rock cairns marking routes of travel, isolated petroglyphs and pictographs, geoglyphs, and observation points and overlooks.

Historic Sites. Historic sites are contemporaneous with or postdate the introduction of European influences in the region. Historic archaeological sites are few in number in the project area, usually represented by a small scatter of artifacts (cans and bottles). These short-term activities were related to mining, ranching, and transportation.

3.1.6.2 Native American Interests

3.1.6.2.1 *Yucca Mountain Project Native American Interaction Program*

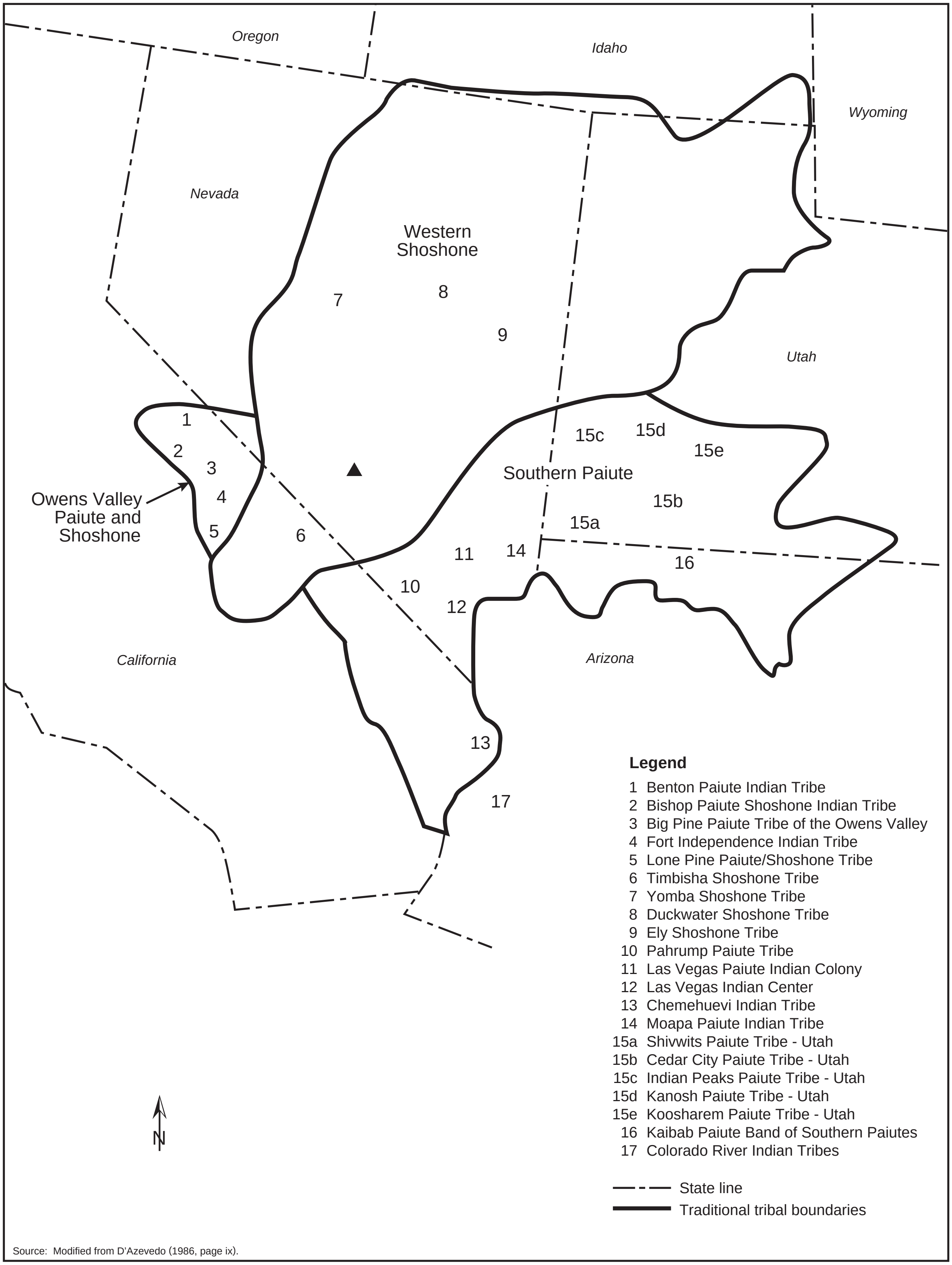
In 1987, DOE initiated the Native American Interaction Program to consult and interact with tribes and organizations on the characterization of the Yucca Mountain site and the possible construction and operation of a repository. These tribes and organizations—Southern Paiute, Western Shoshone, and Owens Valley Paiute and Shoshone people from Arizona, California, Nevada, and Utah—have cultural and historic ties to the Yucca Mountain area.

The Native American Interaction Program concentrates on the protection of cultural resources at Yucca Mountain and promotes a government-to-government relationship with the tribes and organizations. Its purpose is to help DOE comply with various Federal laws and regulations, including the American Indian Religious Freedom Act, the Archaeological Resources Protection Act, the National Historic Preservation Act, the Native American Graves Protection and Repatriation Act, DOE Order 1230.2 (*American Indian and Tribal Government Policy*), and Executive Orders 13007 (*Indian Sacred Sites*) and 13084 (*Consultation and Coordination with Indian Tribal Governments*). These regulations mandate the protection of archaeological sites and cultural items and require agencies to include Native Americans and Federally recognized tribes in discussions and interactions on major Federal actions.

Initial studies identified three tribal groups—Southern Paiute, Western Shoshone, and Owens Valley Paiute and Shoshone—whose cultural heritage includes the Yucca Mountain region (Stoffle 1987, page 5-13). Additional ethnographic efforts eventually identified 17 tribes and organizations involved in the Yucca Mountain Project Native American and cultural resource studies. Figure 3-19 shows the traditional boundaries and locations of the 17 tribes and organizations.

Of the 17 tribal groups, 15 are Federally recognized tribes. The Pahrump Paiute Indian Tribe, which consists of a group of Southern Paiutes living in Pahrump, Nevada, has applied for Federal tribal recognition but to date has not received it. In addition, the Las Vegas Indian Center is not a Federally recognized tribe, but DOE included it in the Native American Interaction Program because it represents the urban Native American population of Las Vegas and Clark County, Nevada (Stoffle et al. 1990, page 7).

The 17 tribes and organizations have formed the Consolidated Group of Tribes and Organizations, which consists of officially appointed tribal representatives who are responsible for presenting their respective tribal concerns and perspectives to DOE. The primary focus of this group has been the protection of cultural resources and environmental restoration at Yucca Mountain. Members of the group have participated in many ethnographic interviews and have provided DOE valuable insights into Native American cultural and religious values and beliefs. These interactions have produced several reports that record the regional history of Native American people and the interpretation of Native American cultural resources in the Yucca Mountain region (Stoffle, Evans, and Harshbarger 1989, pages 30 to 74; Stoffle et al. 1990, pages 11 to 25; Stoffle, Olmsted, and Evans 1990, pages 23 to 49). In addition, tribal representatives have identified and discussed traditional and current uses of plants in the area (Stoffle et al. 1989, pages 22 to 139).



Source: Modified from D'Azevedo (1986, page ix).

Figure 3-19. Traditional boundaries and locations of tribes in the Yucca Mountain region.

3.1.6.2.2 *Native American Views of Affected Environment*

During the EIS scoping process, DOE visited many tribes to encourage their participation. Members of the Consolidated Group of Tribes and Organizations designated individuals who represented the three tribal groups (Southern Paiute, Western Shoshone, and Owens Valley Paiute and Shoshone) to document their viewpoints on the Yucca Mountain area. This group, the American Indian Writers Subgroup, prepared a resource document that provides Native American perspectives on the repository (AIWS 1998, all). This report also describes the relationship between Native American people and DOE and discusses impacts of the Proposed Action while recommending impact mitigation approaches for reducing potential impacts to Native American resources and other heritage values in the Yucca Mountain region. In addition to the general and specific cultural resources issues, which are summarized in the following paragraphs, the report covers other critical topics, including concerns for occupational and public health and safety, environmental justice and equity issues, and social and economic issues. The report also provides recommendations for the conduct of appropriate consultation procedures for the repository and associated activities, and requests Native American participation in development of project resource management approaches to enable the incorporation of accumulated centuries of ethnic knowledge in long-term cultural resource protection strategies.

Native American people believe that they have inhabited their traditional homelands since the beginning of time. Archaeological surveys have found evidence that Native American people used the immediate vicinity of Yucca Mountain on a temporary or seasonal basis (Stoffle et al. 1990, page 29). Native Americans emphasize that a lack of abundant artifacts and archaeological remains does not mean that their people did not use a site or that the land is not an integral part of their cultural ecosystem. Native Americans assign meanings to places involved with their creation as a people, religious stories, burials, and important secular events. The traditional stories of the Southern Paiute, Western Shoshone, and Owens Valley Paiute and Shoshone peoples identify such places, including the Yucca Mountain area. Native Americans believe that cultural resources are not limited to the remains of native ancestors but include all natural resources and geologic formations in the region, such as plants and animals and natural landforms that mark important locations for keeping their historic memory alive and for teaching their children about their culture. Equally important are the water resources and minerals in the Yucca Mountain region. Native Americans used traditional quarry sites to make tools, stone artifacts, and ceremonial objects; many of these sites are *power places* associated with traditional healing ceremonies. Despite the current physical separation of tribes from Yucca Mountain and neighboring lands, Native Americans continue to value and recognize the meaningful role of these lands in their culture and continued survival. Many areas in the Yucca Mountain region are important to them. Fortymile Canyon was an important crossroad where a number of traditional trails from such distant places as Owens Valley, Death Valley, and the Avawtz Mountain came together. Oasis Valley was an important area for trade and ceremonies. Native Americans believe that Prow Pass was an important ceremonial site and, because of this religious importance, have recommended that DOE conduct no studies in this area. Other areas are important based on the abundance of artifacts, traditional-use plants and animals, rock art, and possible burial sites.

According to Native American people, the Yucca Mountain area is part of the holy lands of the Western Shoshone, Southern Paiute, and Owens Valley Paiute and Shoshone peoples. Native Americans generally do not concur with the conclusions of archaeological investigators that their ancestors were highly mobile groups of aboriginal hunter-gatherers who occupied the Yucca Mountain area before Euroamericans began using the area for prospecting, surveying, and ranching. They believe that these conclusions overlook traditional accounts of farming that occurred before European contact. Yucca Mountain and nearby lands were central in the lives of the Western Shoshone, Southern Paiute, and Owens Valley Paiute and Shoshone peoples, who shared them for religious ceremonies, resource uses, and social events. Native Americans value the cultural resources in these areas, viewing them in a holistic manner. They believe that the water, animals, plants, air, geology, and artifacts are interrelated and dependent on each other for existence.

3.1.7 SOCIOECONOMICS

To define the existing conditions for the socioeconomic environment in the Yucca Mountain region, DOE determined the current economic and demographic status in a well-defined region (called the *region of influence*) near the site of the proposed repository. DOE based its definition of the socioeconomic region of influence on the distribution of the residences of current employees of the Department and its contractors who work on the Yucca Mountain Project or at the Nevada Test Site. The region of influence, therefore, consists of the counties where about 90 percent of the DOE workforce lives. The Department used the residential distribution, which reflects existing commuting patterns, to estimate the future distribution of direct workers associated with the Proposed Action and the No-Action Alternative. Unless otherwise noted, the *Yucca Mountain Site Characterization Project Environmental Baseline File for Socioeconomics* (TRW 1999n, all) is the basis for the information in this section.

DOE received numerous reports from affected units of local government providing socioeconomic baseline environmental information. The reports contain information that characterizes the existing community environment, provides assessments of economic development, or includes basic economic and demographic trends. DOE reviewed these reports and determined that the information provided was consistent with the information used in this EIS.

The socioeconomic region of influence for the Proposed Action consists of Clark, Lincoln, and Nye Counties in southern Nevada (Figure 3-20). Clark County contains the City of Las Vegas and its suburbs. Based on a count of respondents to a 1994 survey, an estimated 79 percent of Yucca Mountain Project and Nevada Test Site onsite employees live in Clark County (Table 3-21). The region of influence includes Lincoln County because of the possibility that DOE could build and operate an intermodal transfer station there.

Table 3-21. Distribution of Yucca Mountain Project and Nevada Test Site onsite employees (survey respondents) by place of residence.[a]

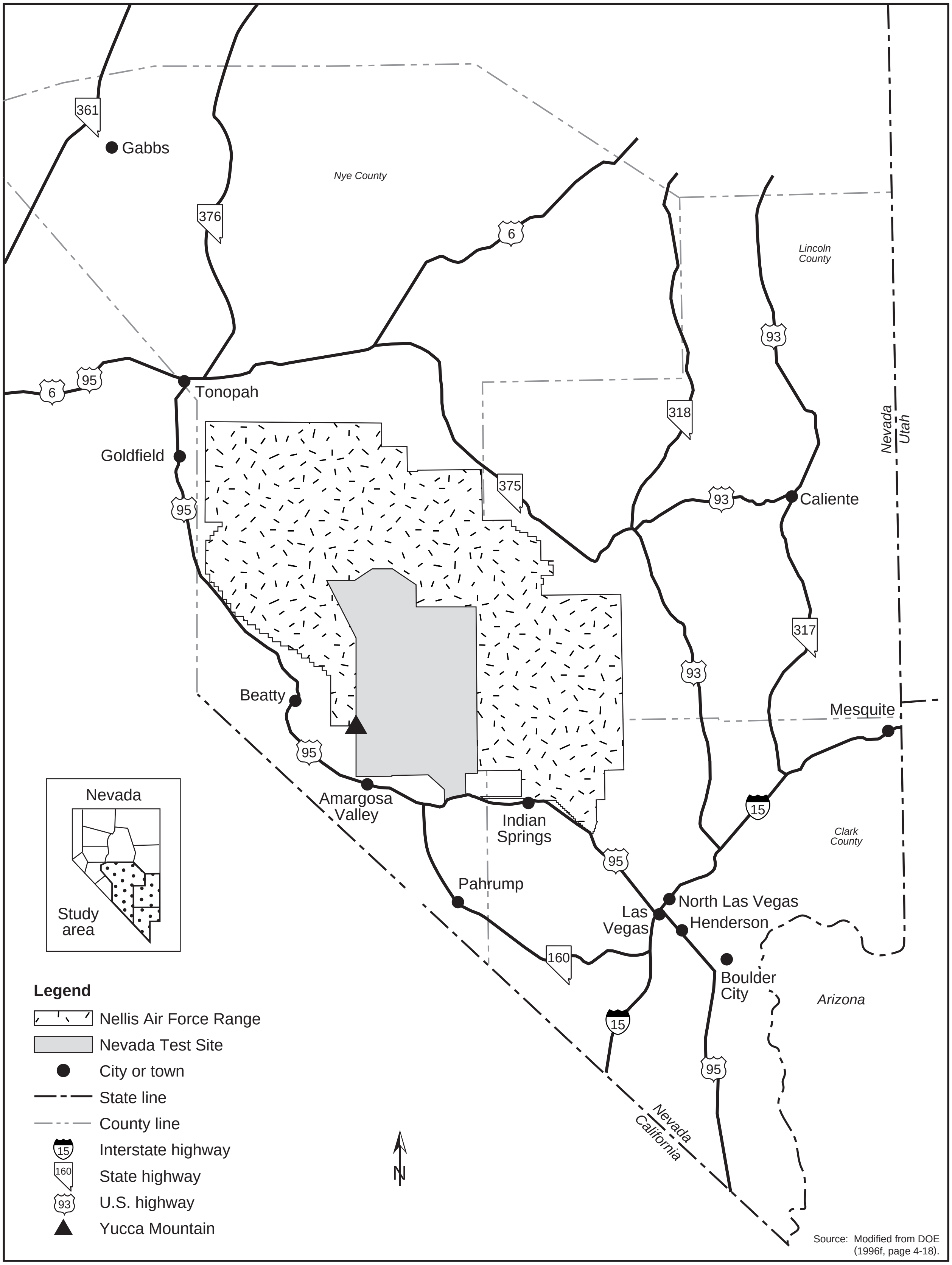
Place of residence	Onsite workers	Percent of total
Clark County	1,268	79
Lincoln County	5	0.3
Nye County	310	19
Total region of influence	**1,583**	**98**
Outside region of influence	31	2
Total respondents	***1,614***	***100.0***

a. Source: TRW (1994a, all).

3.1.7.1 Population

DOE used the Regional Economic Models, Inc. (REMI) model to estimate baseline socioeconomic conditions at the conclusion of site characterization (Treyz, Rickman, and Shao 1992, all).

Southern Nevada has been and continues to be one of the fastest-growing areas in the country. During the 1980s, the population of the region of influence had an average annual growth rate of 4.8 percent, adding more than 29,000 people annually and reaching 780,000 residents in 1990. In comparison to the State of Nevada, which had a average annual growth rate of 4 percent between 1980 and 1990, the United States had a growth rate of less than 1 percent during the same period (Bureau of the Census 1999, all). This trend has increased during the 1990s. From 1990 to 1997, the region of influence had an annual growth rate of 5.5 percent, averaging 51,000 new residents annually. In 1997, the population of the region increased 5.4 percent and added 57,000 new residents, bringing the estimated population to about 1.14 million. Led by Clark County, Nevada is the fastest growing state in the country. From 1990 to 1997, Nevada had an annual growth rate of 4.5 percent compared to the 1-percent annual growth rate of the United States.



Source: Modified from DOE (1996f, page 4-18).

Figure 3-20. Socioeconomic region of influence.

Las Vegas and the immediate surrounding area dominate the Clark County population. The Las Vegas economy is driven by the growth of the hotel and gaming industry. As the popularity of gaming grew in the 1970s and 1980s, Las Vegas evolved as one of the country's major tourism and convention destinations. In 1997, Las Vegas hosted 30.5 million visitors, contributing $25 billion to the local economy (LVCVA 1999, all). The tourism trend is expected to continue well into the next century. The relatively inexpensive land, Sunbelt climate, and favorable business conditions have also contributed to commercial and residential growth.

Another factor influencing strong growth is the number of retirees moving to communities in the region of influence. The pleasant climate, abundance of recreational opportunities, and Nevada's favorable tax structure have attracted retirees from across the United States.

Nye County, which has been the site of booms and busts due to fluctuating mining activity and the recent decline of Nevada Test Site employment, is home to approximately 19 percent of the Yucca Mountain Project workforce (Table 3-21). Pahrump, in southern Nye County, is experiencing growth caused primarily by inmigrating retirees.

In 1997, Nye County had about 26,000 residents, and it has experienced a 3.7-percent annual growth rate in the 1990s. The 1997 population in Lincoln County was about 4,200, up from about 3,800 in 1990. Although the annual growth rate of the region of influence is likely to slow, the population should increase 2 to 4 percent a year in the next decade. Clark County should lead the population growth in the foreseeable future in the region of influence.

The region of influence includes a number of incorporated cities as well as unincorporated towns (Table 3-22). The largest city in Clark County is Las Vegas, followed by Henderson. In 1997, Las Vegas had a population of about 430,000 compared to Henderson, which had about 150,000 residents. Nye County has one incorporated city, but the largest community is unincorporated Pahrump, which had an estimated population of about 19,000 in 1997. Lincoln County also has only one incorporated city, Caliente, which is the largest community. In 1997, Caliente had a population of about 1,100.

Table 3-22. Population of incorporated cities and selected unincorporated towns, 1991 to 1997.[a,b]

Jurisdiction	1991	1995	1997
Clark County			
Boulder City	13,000	14,000	14,000
Henderson	77,000	120,000	150,000
Indian Springs[c]	N/A[d]	N/A	1,200
Las Vegas	290,000	370,000	430,000
Mesquite	2,100	5,100	9,300
North Las Vegas	51,000	78,000	93,000
Nye County			
Amargosa Valley[c]	N/A	N/A	990
Beatty[c]	N/A	N/A	1,600
Gabbs	680	360	400
Pahrump[c]	N/A	N/A	19,000
Tonopah[c]	N/A	N/A	2,800
Lincoln County			
Caliente	1,100	1,200	1,100

a. Source: TRW (1999n, all).
b. Population numbers have been rounded to two significant figures.
c. Selected unincorporated towns.
d. N/A = not available.

3.1.7.2 Employment

Of the three counties that comprise the region of influence, Clark County has by far the largest economy; in 1995, the estimated employment was about 620,000. This constituted 98 percent of the regional employment and about 64 percent of the State employment. During the same year Nye County had an employment of about 11,000, and the Lincoln County employment was about 2,100. Clark County should continue to outpace the growth of the other counties in the region.

Between 1980 and 1990, Clark County added an average of 19,000 jobs a year (Table 3-23). Since 1990 that pace has increased to more than 30,000 new jobs a year with an average annual growth rate of 6.1 percent. Total employment increased 35 percent between 1990 and 1995, adding about 160,000 jobs. By 2000, Clark County is expected to have an employment of about 860,000, continuing to create over 2,000 new jobs a month. The services employment sector is the largest in Clark County, representing 46 percent of the employment in 1995.

Table 3-23. Clark County employment by sector, 1980 to 2000.[a,b]

Sector	1980	1990	1995	2000
Private sector (totals)	*230,000*	*410,000*	*560,000*	*780,000*
Agriculture, forestry, and fisheries	1,300	3,900	6,200	9,000
Mining	590	820	1,200	1,300
Construction	16,000	41,000	53,000	79,000
Manufacturing	7,300	12,000	18,000	20,000
Transportation and public utilities	14,000	21,000	29,000	37,000
Wholesale trade	6,500	14,000	19,000	24,000
Retail trade	44,000	72,000	98,000	130,000
Finance, insurance, and real estate	20,000	32,000	44,000	55,000
Services	120,000	210,000	290,000	420,000
Government (totals)	*38,000*	*51,000*	*62,000*	*79,000*
Federal Government - civilian	4,800	6,900	7,800	7,700
Federal Government - military	11,000	11,000	9,500	10,000
State and local government	22,000	33,000	45,000	11,000
Farm	*420*	*400*	*300*	*310*
Totals	***268,420***	***460,000***	***620,000***	***859,310***

a. Sources: 1980, 1990, and 1995: TRW (1999n, all); 2000: estimated.

b. Employment numbers have been rounded to two significant figures.

Although Nye County's employment increased between 1980 and 1990, it declined to about 11,000 in 1995, a decrease of 15 percent (Table 3-24). The services sector represented the largest in the Nye County economy. In 1995, services comprised 47 percent of the employment. Projections indicate that employment will decline to about 10,000 by 2000. Lincoln County employment also declined between 1990 and 1995 after growth during the 1980s (Table 3-25). In 1995, Lincoln County had a employment of about 2,100, a decline of 13 percent from 1990. As in Clark and Nye Counties, services represented the largest sector of the Lincoln County economy. In 1995, services comprised 39 percent of the employment.

Las Vegas, in Clark County, has one of the fastest growing economies in the country. The rapid growth of the Las Vegas area is driven by the gaming and tourism industry. For each hotel room constructed, an employment multiplier effect creates an estimated 2.5 direct and indirect jobs. About 14,000 hotel rooms were added between 1996 and 1998. Five new major resorts under construction with completion dates between Spring 1998 and Spring 2000 will add about 14,000 hotel rooms (*Las Vegas Sun* 1998, all). Despite an inventory of more than 100,000 rooms, hotels consistently operate at 90 percent occupancy, reaching to 97 percent on weekends.

Table 3-24. Nye County employment by sector, 1980 to 2000.[a,b]

Sector	1980	1990	1995	2000
Private sector (totals)	*6,900*	*12,000*	*9,600*	*11,000*
Agriculture, forestry, and fisheries	50	70	110	120
Mining	1,100	2,000	1,400	1,000
Construction	410	390	560	1,000
Manufacturing	88	160	250	290
Transportation and public utilities	[210]	[280]	280	380
Wholesale trade	25	49	100	150
Retail trade	530	960	1,200	1,800
Finance, insurance, and real estate	[360]	[290]	450	490
Services	4,100	7,700	5,200	5,500
Government (totals)	*770*	*1,200*	*1,500*	1,700
Federal Government - civilian	130	200	200	*200*
Federal Government - military	100	77	53	79
State and local government	540	930	1,200	1,400
Farm	*220*	*260*	*210*	210
Totals	***7,890***	***13,360***	***11,310***	***12,910***

a. Sources: 1980, 1990, and 1995: TRW (1999n, all), except estimates in [brackets] appear wherever data suppression by TRW (1999n) was indicated by zeros; 2000: estimated.

b. Employment numbers have been rounded to two significant figures.

Table 3-25. Lincoln County employment by sector, 1980 to 2000.[a,b]

Sector	1980	1990	1995	2000
Private sector (totals)	*1,300*	*1,712*	*1,380*	*1,558*
Agriculture, forestry, and fisheries	[4]	[30]	22	24
Mining	310	30	18	14
Construction	75	47	44	24
Manufacturing	12	[10]	10	37
Transportation and public utilities	96	88	62	62
Wholesale trade	12	10	[17]	41
Retail trade	310	250	[270]	386
Finance, insurance, and real estate	51	47	68	74
Services	380	[1,200]	[869]	846
Government (totals)	*400*	*537*	*607*	*573*
Federal Government - civilian	25	45	39	34
Federal Government - military	12	12	*8*	9
State and local government	360	480	560	530
Farm	*160*	*180*	*150*	*149*
Totals	***1,860***	***2,429***	***2,137***	***2,280***

a. Sources: 1980, 1990, and 1995: TRW (1999n, all), except estimates in [brackets] appear wherever data suppression by TRW (1999n) was indicated by zeros; 2000: estimated.

b. Individual employment numbers have been rounded to two significant figures.

Because of the thousands of new jobs added to the economy each month, the Las Vegas area has a low unemployment rate. In 1997, Clark and Nye Counties had unemployment rates below the Nevada and national rates at 4.0 percent and 3.9 percent, respectively. The planned closing of the Bullfrog Mine in Nye County will increase unemployment. In 1997, the Bullfrog Mine employed approximately 290 workers; however, it will probably close in 2000 (Meyers 1998, all). Lincoln County had an unemployment rate above the national average at 7.8 percent (Reel 1998, all). The State of Nevada had an unemployment rate of 4.1 percent and the United States had a rate of 4.9 percent (NDETR 1999, all). Onsite employment levels at the Exploratory Studies Facility remained relatively constant between 1995 and 1997, and are not likely to fluctuate substantially through the end of site characterization activities.

In 1997, an average of about 1,600 workers (140 on the site and 1,460 off the site) worked on the Yucca Mountain Project. Most offsite workers are in the Las Vegas area (TRW 1998d, all). The employment projection for 2000 reflects expected changes due to new hotel construction, closure of the Bullfrog Mine, and Yucca Mountain Project employment.

3.1.7.3 Payments Equal to Taxes

Another issue of interest is the DOE Payments-Equal-To-Taxes Program. Section 116(c)(3)(A) of the Nuclear Waste Policy Act of 1982, as amended, requires the Secretary of Energy to "…grant to the State of Nevada and any affected unit of local government an amount each fiscal year equal to the amount such State or affected unit of local government, respectively, would receive if authorized to tax site characterization activities…." The Yucca Mountain Site Characterization Office is responsible for implementing and administering this program for the Yucca Mountain Project. DOE acquired data from the project organizations that purchase or acquire property for use in Nevada, have employees in Nevada, or use property in Nevada. These organizations include Federal agencies, national laboratories, and private firms. Not all of them have a Federal exemption, so they pay the appropriate taxes. The purchases (sales and use tax), employees (business tax), and property (property or possessory use taxes) of the Yucca Mountain Project organizations that exercise a Federal exemption are subject to the Payments-Equal-To-Taxes Program (NLCB 1996, all).

The estimated sales and use taxes, property taxes, and Nevada business taxes Yucca Mountain Project organizations paid from May 1986 through June 1996 have been totaled. These organizations paid sales or use taxes of $2.25 million for purchases consumed in Clark County and $3.8 million in Nye County, paid property or possessory taxes of about $110,000 in Clark County and $37,355 in Nye County, and paid Nevada business taxes of about $460,000 (NLCB 1996, all).

The Payments-Equal-To-Taxes for sales or use taxes from May 1986 through June 1996 was about $1.68 million for purchases consumed in Clark County and $240,000 in Nye County. For property taxes it was about $200,000 in Clark County, $14.8 million in Nye County, $8,000 in Lincoln County, $3,700 in Esmeralda County, and $24,000 in Inyo County. For Nevada business taxes, about $95,000 has been paid.

3.1.7.4 Housing

Spurred by the rapid population growth and soaring employment opportunities, the residential housing market is strong and steady in the Las Vegas area. From 1992 to 1996, annual sales of new homes exceeded 16,000 units. In 1996, a record 19,000 units were sold. More than 400 residential developers sell properties in the Las Vegas area, leading to a highly competitive market. The competition has kept price increases to the rate of inflation. Eighty-five percent of the new homes sold were priced between $100,000 and $190,000. The average home sold for about $131,000 in 1996. Large master-planned communities are common, and average about 30 percent of the total home sales. Steady employment and population growth should continue to spur demand for housing. Sustained growth will depend on further development of large-scale resort and gaming projects.

The housing stock of Clark County in 1990 was about 320,000 units, which consisted of about 150,000 single-family units, 130,000 multifamily units, and 33,000 mobile homes or other accommodations. About 290,000 of these units were occupied, resulting in 2.5 persons per household (Bureau of the Census 1998, all). Assuming that the persons per household and occupancy rate remain the same, the expected number of households in Clark County in 2000 is about 570,000.

The housing stock of Nye County in 1990 was about 8,100 units, which consisted of about 2,300 single-family units, 560 multifamily units, and 5,200 mobile homes or other accommodations. About 6,700 of these units were occupied, resulting in 2.5 persons per household (Bureau of the Census 1998, all). Assuming that the persons per household and occupancy rate remain the same, the expected number of households in Nye County in 2000 is about 12,000.

The housing stock of Lincoln County in 1990 was about 1,800 units, which consisted of about 1,000 single-family units, 160 multifamily units, and 600 mobile homes or other accommodations. About 1,300 of these units were occupied, resulting in 2.6 persons per household (Bureau of the Census 1998, all). Assuming that the persons per household and occupancy rate remain the same, the expected number of households in Lincoln County in 2000 is about 1,800.

Because most population and employment growth in the region of influence will occur in Clark County, most housing growth also will occur there. The only other area in the region likely to see large growth is Pahrump in southern Nye County. Housing changes in Lincoln County probably will be minimal in the foreseeable future.

3.1.7.5 Public Services

Education. In the 1996-1997 school year, the region of influence contained about 180 elementary and middle schools, 34 high schools, 13 alternative schools, and 4 special education schools. The average pupil-teacher ratio was about 21-to-1 for elementary schools and 19-to-1 for secondary schools (Clark County 1997a, all; NDE 1997, page 4). In 1997, the national pupil-teacher ratio was about 19-to-1 for elementary schools and 15-to-1 for secondary schools (USDE 1999, all). Clark County has the tenth-largest school district in the country; during the 1996-1997 school year, Clark County had about 210 schools and nearly 180,000 students (Table 3-26). During the same period, Nye County had 16 schools and fewer than 5,000 students, and Lincoln County had nine schools and about 1,000 students (Clark County 1997a, all; TRW 1999n, all; NDE 1997, page 4).

Because Clark County is experiencing rapid growth, voters have passed three bond issues totaling $1.85 billion dollars since 1988 to renovate existing schools and build new schools. The most recent was a $643 million bond in 1996. Eleven new schools—six elementary, three middle, and two high schools—were scheduled to open during the 1997-1998 school year (Clark County 1998, all). Nye County was scheduled to seek approval in a 1998 bond issue to build a new middle and elementary school over the next few years (Harge 1997, page 18).

Table 3-26. Enrollment by school district and grade level.[a,b]

District	Actual 1996-1997[c]	Projected 2000-2001[d]
Clark County[e]		
Prekindergarten	1,000	1,300
Kindergarten	15,000	19,000
Elementary (grades 1-6)	90,000	110,000
Secondary (grades 7-12)	73,000	91,000
District totals	**179,000**	**221,300**
Nye County[f]		
Prekindergarten	43	44
Kindergarten	310	380
Elementary (grades 1-6)	2,300	2,400
Secondary (grades 7-12)	2,200	2,300
District totals	**4,853**	**5,124**
Lincoln County[g]		
Prekindergarten	22	20
Kindergarten	57	51
Elementary (grades 1-6)	400	360
Secondary (grades 7-12)	630	570
District totals	**1,109**	**1,001**

a. Figures include ungraded students who are enrolled in school for special education and students who cannot be assigned to a grade because of the nature of their condition; Prekindergarten refers to 3- and 4-year-old minors receiving special education.
b. Enrollment numbers have been rounded to two significant figures.
c. Enrollments for the 1996-1997 school year are as of the end of the first school month.
d. Projected enrollment for the 2000-2001 school year is based on the ratio of actual 1996-1997 figures to the 1996 population estimate multiplied by the 2000 population forecast.
e. Source: Clark County (1997a, all).
f. Source: NDE (1997, page 4).
g. Source: TRW (1999n, all).

Health Care. Health care services in the region of influence are concentrated in Clark County, particularly in the Las Vegas area. In 1995, Clark County had seven hospitals and four specialized care facilities. Although Nye County has one hospital in Tonopah, most people in the southern part of the county use local clinics or go to hospitals in Las Vegas. Lincoln County has one hospital in Caliente (Rodefer et al. 1996, all). Table 3-27 lists hospital use in the region of influence.

Table 3-27. Hospital use by county in the region of influence.[a,b]

County	1990	1995	2000
Clark			
Population	750,000	1,000,000	1,310,000
Average number of beds	2,000	2,100	2,900[c]
Beds per 1,000 residents	2.6	2.2	2.2[d]
Patient-days	490,000	530,000	700,000[e]
Nye			
Population	18,000	24,000	26,000
Average number of beds	21	21	22[c]
Beds per 1,000 residents	1.2	0.86	0.86[d]
Patient-days	1,800	1,900	2,000[e]
Lincoln			
Population	3,800	3,900	3,400
Average number of beds	5	4	4[c]
Beds per 1,000 residents	1.3	1.0	1.0[d]
Patient-days	520	360	310[e]

a. Source: Rodefer et al. (1996, pages 214 to 216).
b. All numbers have been rounded to two or three significant figures.
c. Calculated assuming number of beds per 1,000 residents remained constant.
d. Held constant at 1995 levels.
e. 2000 patient-days calculated by multiplying 2000 population by 1995 ratio of patient-days to population.

Medical services are available at the Nevada Test Site for Exploratory Studies Facility personnel; these services include two paramedics and an ambulance in Area 25. Backup services are on call from other Test Site locations. In addition, the Nevada Test Site provides medical services for Yucca Mountain Project workers at a clinic in Mercury, which has no overnight capability. When patients need urgent care, the Yucca Mountain Project relies on the helicopter "Flight for Life" and "Air Life" operations from Las Vegas. In emergencies, Area 25 can call on Nellis Air Force Base or Nye County for help.

Law Enforcement. The Las Vegas Metropolitan Police Department is responsible for law enforcement in Clark County with the exceptions of the Cities of North Las Vegas, Henderson, Boulder City, and Mesquite, which have their own police departments. The Las Vegas police department is the largest law enforcement agency in Nevada; in 1996, it had about 1,200 employees, a ratio of about 1.2 employees per 1,000 residents. In 1996, the Nye County Sheriff Department had 110 employees, a ratio of 4.4 employees per 1,000 residents, and Lincoln County had 14 sheriff department employees, a ratio of 3.7 employees per 1,000 residents. In comparison, the national officer-to-population ratio is 2.4 officers per 1,000 residents, (FBI 1996, pages 1 to 3). Assuming that the number of employees per 1,000 residents remains the same, the expected law enforcement staffing in 2000 will be about 1,600 in Clark County, 120 in Nye County, and 15 in Lincoln County.

Fire Protection and Emergency Management. A combination of fire departments provides protection in the region of influence; these include the Clark County, Las Vegas, and North Las Vegas fire departments and several other city, county, and military departments. In 1992, Clark County had about 1,100 paid, 420 volunteer, and 80 seasonal or inmate firefighters, a ratio of 1.9 firefighters per 1,000 residents. In 1992, Nye County had 150 paid and 330 volunteer firefighters, a ratio of about 25 firefighters per 1,000 residents, and Lincoln County had 73 volunteer firefighters, a ratio of about 19 firefighters per 1,000 residents. The national average is 4.1 firefighters (full and volunteer) per 1,000 residents.

3.1.8 OCCUPATIONAL AND PUBLIC HEALTH AND SAFETY

The public health and safety region of influence consists of the number of persons residing within an 80-kilometer (50-mile) radius of the repository site at the end of site characterization. The estimated population in 2000 is about 28,000. The region of influence encompasses communities in Nye and Clark Counties in Nevada, as well as Inyo County in California (Figure 3-21). Potentially affected workers include those at the repository site and at nearby Nevada Test Site facilities. This section describes the existing radiation environment and the baseline cancer incidence in the region of influence. Unless otherwise noted, the *Environmental Baseline File for Human Health* (TRW 1999o, all) is the basis of the information in this section.

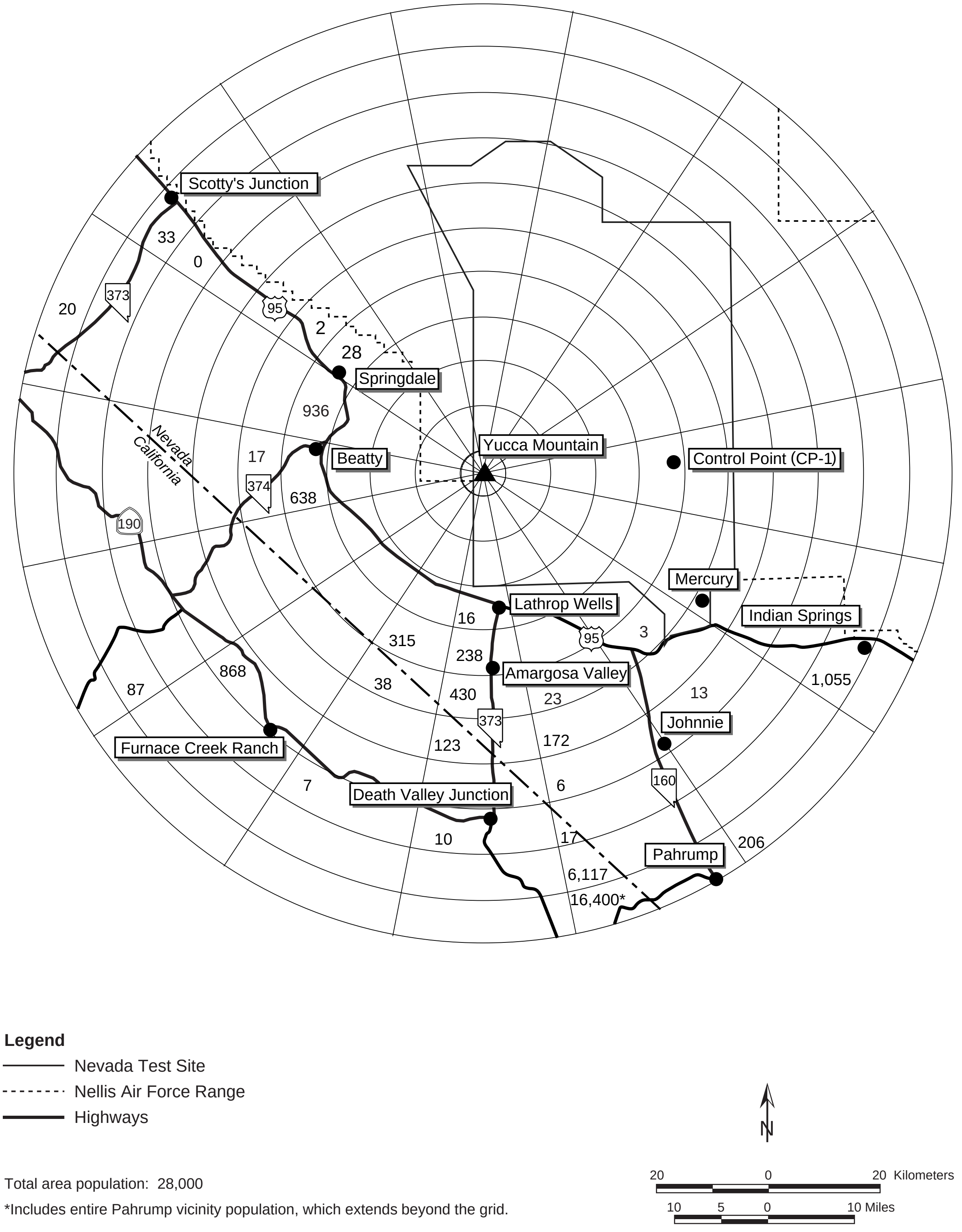
Section 3.1.8.1 describes the various radiation sources that make up the radiation environment. Section 3.1.8.2 describes the existing radiation environment in the Yucca Mountain region. Section 3.1.8.3 describes the health-related mineral issues encountered during site characterization activities. Section 3.1.8.4 describes the worker industrial safety experienced from site characterization activities.

3.1.8.1 Radiation Sources in the Environment

There are ambient levels of radiation at and around the site of the proposed repository just as there are around the world. All people are inevitably exposed to the three sources of ionizing radiation: those of *natural* origin unaffected by human activities, those of natural origin but affected by human activities (called *enhanced natural* sources), and *manmade* sources. Natural sources include cosmic radiation from space, *terrestrial* radiation from natural radioactive sources in the ground (radon, for example), radiation from radionuclides naturally present in the body, and inhaled and ingested radionuclides of natural origin. Enhanced natural sources include those that can increase exposure as a result of human actions, deliberate or otherwise. For example, air travel, especially at very high altitudes, increases exposure to cosmic radiation, and tunneling through rock (as at Yucca Mountain) increases worker exposure to naturally occurring sources. A variety of exposures result from manmade materials and devices such as radiopharmaceuticals and X-rays in medicine, and consumer products such as some smoke detectors. Exposures can also result from episodic events, such as uncontained nuclear weapons tests.

External background radiation comes from two sources of approximately equal magnitude: cosmic radiation from space and terrestrial gamma radiation from radionuclides in the environment, mainly from the Earth itself. In the case of cosmic radiation, charged particles (primarily protons from extraterrestrial sources) have sufficiently high energies to generate secondary particles that have direct and indirect ionizing properties. The three main contributors to the terrestrial gamma radiation field are potassium-40 and the members of the thorium and uranium decay series. Most terrestrial gamma radiation comes from the top 20 centimeters (8 inches) of soil, with a small contribution from airborne radon decay products.

Cosmogenic radionuclides are produced by interactions of cosmic particles with certain atoms in the atmosphere or in the Earth. There are four cosmogenic radionuclides of interest for internal doses: tritium (hydrogen-3), beryllium-7, carbon-14, and sodium-22. With the exception of beryllium-7, all are isotopes of important elements in the human body. The dose rates from natural cosmic, cosmogenic, and terrestrial radiation vary throughout the world depending on such factors as altitude and geology. Natural background radiation is the largest contributor to the average radiation dose to individuals and is the most variable component of background radiation. Table 3-28 lists estimated radiation doses from natural sources to individuals in the region of influence and other locations.



Total area population: 28,000

*Includes entire Pahrump vicinity population, which extends beyond the grid.

This map shows the population around the proposed repository site. The grid consists of 16 sectors. The circles shown start at 4 kilometers from the mountain and are spaced equally at 8 kilometers.

Source: Modified from DOE (1998a, Volume 3, Figure 3-76, page 3-153).

Figure 3-21. Population distribution within 80 kilometers (50 miles) of the proposed repository site, year 2000 estimate.

Table 3-28. Radiation exposure from natural sources (millirem per year).[a]

	Annual dose (effective dose equivalent)					
					Region of influence	
Source	U.S. average	Aiken[b]	Oak Ridge[c]	Las Vegas	Amargosa Valley	Beatty
Cosmic and cosmogenic	28	33	29	(d)	40	(d)
Terrestrial	28	43	38	89	56	150
Radon in homes (inhaled)[e]	200	200	200	200	200	200
In body	40	40	40	40	40	40
Totals[f]	**300**	**320**	**310**	**330**	**340**	**390**

a. Sources: Bechtel (1998, page 4-31); DOE (1995e, pages 4-211 and 4-394); NCRP (1987, Section 2).
b. Aiken, South Carolina, is the location of the DOE Savannah River Site.
c. Oak Ridge, Tennessee, is the location of the DOE Oak Ridge National Laboratory.
d. Included in the terrestrial source.
e. Value for radon is an average for the United States.
f. Totals might differ from sums due to rounding.

The effect of radiation on people depends on the kind of radiation exposure (alpha and beta particles, and X-rays and gamma rays), the total amount of tissue exposed to radiation, and the duration of the exposure. The amount of radiant energy imparted to tissue from exposure to ionizing radiation is referred to as *absorbed dose*. The sum of the absorbed dose to each tissue, when multiplied by certain quality and weighting factors that take into account radiation quality and different sensitivities of the various tissues, is referred to as *effective dose equivalent* and is measured in rem. The Code of Federal Regulations contains further discussion of DOE radiation protection standards and methods of dose assessment (10 CFR Part 835).

An individual can be exposed to radiation from outside or inside the body because radioactive materials can enter the body by ingestion or inhalation. External dose is different from internal dose in that it is delivered only during the actual time of exposure. An internal dose, however, continues to be delivered as long as the radioactive source is in the body (although both radioactive decay and elimination of the radionuclide by ordinary metabolic processes decrease the dose rate with the passage of time).

TERMS USED IN RADIATION DOSE ASSESSMENT

Curie: A unit of radioactivity equal to 37 billion disintegrations per second; also a quantity of any nuclide or mixture of nuclides having 1 curie of radioactivity.

Picocurie per liter: A unit of measure describing the amount of radioactivity in a liter of a given substance (for example, air or water). A picocurie is one one-trillionth of a curie.

Roentgen: A unit of measure of X-ray or gamma-ray radiation exposure described in terms of the amount of energy transferred to a unit mass of air. One roentgen corresponds to the absorption of 87.7 ergs (about 6.5×10^{-6} foot-pound) per gram of air.

Rem: The dose of an ionizing radiation that will cause the same biological effect as 1 roentgen of X-ray or gamma ray exposure (rem means Roentgen Equivalent in Man).

Radiation can cause a variety of adverse health effects in people. A large dose of radiation can cause prompt death. At low doses, the most important adverse health effect for depicting the consequences of environmental and occupational radiation exposures (which are typically low doses) is the potential inducement of cancers that can lead to death in later years. This effect is referred to as *latent cancer* *fatalities* because the cancer can take years to develop and for death to occur, and might never actually be the cause of death.

The collective dose to an exposed population is calculated by summing the estimated doses received by each member of the exposed population. This is referred to as a *population dose*. The total population dose received by the exposed population is measured in person-rem. For example, if 1,000 people each received a dose of 0.001 rem, the population dose would be 1.0 person-rem (1,000 persons multiplied by 0.001 rem equals 1.0 person-rem). The same population dose (1.0 person-rem) would result if 500 people each received a dose of 0.002 rem (500 persons multiplied by 0.002 rem equals 1 person-rem).

The factor used in this EIS to relate a dose to its potential effect is 0.0004 latent cancer fatality per person-rem for workers and 0.0005 latent cancer fatality per person-rem for individuals among the general population (NCRP 1993a, page 3). The latter factor is slightly higher because some individuals in the public, such as infants, might be more sensitive to radiation than workers. These risk factors have been endorsed by the International Commission on Radiological Protection, Environmental Protection Agency, Nuclear Regulatory Commission, and National Council on Radiation Protection and Measurements. The factors apply if the dose to an individual is less than 20 rem and the dose rate is less than 10 rem per hour. At doses greater than 20 rem, the factors used to relate radiation doses to latent cancer fatalities are doubled. At much higher doses, prompt effects, rather than latent cancer fatalities, might be the primary concern.

These concepts can be used to estimate the effects of exposing a population to radiation. For example, if 100,000 people were each exposed only to background radiation (0.3 rem per year), 15 latent cancer fatalities could occur as a result of 1 year of exposure (100,000 persons multiplied by 0.3 rem per year multiplied by 0.0005 latent cancer fatality per person-rem equals 15 latent cancer fatalities per year).

Calculations of the number of latent cancer fatalities associated with radiation exposure do not normally yield whole numbers and, especially in environmental applications, can yield numbers less than 1.0. For example, if 100,000 people were each exposed to a total dose of only 1 millirem (0.001 rem), the population dose would be 100 person-rem, and the corresponding estimated number of latent cancer fatalities would be 0.05 (100,000 persons multiplied by 0.001 rem multiplied by 0.0005 latent cancer fatality per person-rem equals 0.05 latent cancer fatality).

The *average* number of deaths that would result if the same exposure situation were applied to many different groups of 100,000 people is 0.05. In most groups, nobody (zero people) would incur a latent cancer fatality from the 1-millirem dose each member would have received. In a small fraction of the groups, 1 latent fatal cancer would result; in exceptionally few groups, 2 or more latent fatal cancers would occur. The average number of deaths over all the groups would be 0.05 latent fatal cancer (just as the average of 0, 0, 0, and 1 divided by 4 is 0.25). The most likely outcome is no latent cancer fatalities in these different groups.

The same concepts apply to estimating the effects of radiation exposure on a single individual. Consider the effects, for example, of exposure to background radiation over a lifetime. The “number of latent cancer fatalities” corresponding to a single individual’s exposure to 0.3 rem a year over a (presumed) 70-year lifetime is:

$$\begin{aligned}\text{Latent cancer fatality } &= 1 \text{ person} \times 0.3 \text{ rem per year} \times 70 \text{ years} \\ &\quad \times 0.0005 \text{ latent cancer fatality per person-rem} \\ &= 0.011 \text{ latent cancer fatality.}\end{aligned}$$

Again, this should be interpreted in a statistical sense; that is, the estimated effect of background radiation exposure on the exposed individual would produce a 1.1-percent chance that the individual would incur a latent fatal cancer. The baseline Nevada cancer fatality rate in a population of 100,000 is about 185 deaths per year (ACS 1998, page 6), resulting in a baseline rate of about 50 cancer deaths per year in the region of influence.

3.1.8.2 Radiation Environment in the Yucca Mountain Region

Ambient radiation levels from cosmic and terrestrial sources at Yucca Mountain are higher than the U.S. average. The higher elevation at Yucca Mountain results in higher levels of cosmic radiation due to less shielding by the atmosphere. The U.S. average for cosmic, cosmogenic, and terrestrial radiation exposures is 56 millirem per year (Table 3-28). The exposures at the Yucca Mountain ridge and Yucca Mountain surface facilities are about 160 and 150 millirem per year, respectively. Moreover, there are higher amounts of naturally occurring radionuclides in the soil and parent rock of this region than in some other regions of the United States, which also results in higher radiation doses.

The Yucca Mountain Project and the DOE Nevada Operations Office (in conjunction with the Environmental Protection Agency) conduct environmental surveillances around the Nevada Test Site. This monitoring has identified no radioactivity attributable to current operations at the Test Site. It did detect trace amounts of manmade radionuclides from worldwide nuclear testing in milk, game, and foods and in soil. Even though the monitoring has not detected ongoing releases to the environment related to the Test Site, DOE has made quantitative estimates of offsite doses from releases from past weapons testing activities at the Nevada Test Site (Bechtel 1998, page 7-5). Sources of ongoing releases at the Nevada Test Site include water containment ponds and contaminated soil resuspension. The estimated maximum annual radiation dose to a hypothetical individual in Springdale, Nevada [approximately 16 kilometers (10 miles) north of Beatty on U.S. 95], from airborne radioactivity is 0.09 millirem. The estimated maximum annual radiation dose for a hypothetical individual at the Nevada Test Site boundary is 0.12 millirem. These doses, which are about 1 percent of the 10-millirem-per-year dose limit that the Environmental Protection Agency established for a member of the public from emissions to the air from manmade sources (40 CFR Part 61), are conservative because data from offsite surveillance do not support doses of this magnitude.

Workers in the Exploratory Studies Facility can inhale naturally occurring radon-222 (a radioactive noble gas that is a decay product of naturally occurring uranium in rock) and its radioactive decay products. Radon concentration measurements during working hours, at a location representative of repository conditions, ranged from about 0.22 to 72 picocuries per liter, with a median concentration of about 6.5 picocuries per liter (TRW 1999o, page 12). The median annual dose to involved workers from inhalation of radon and decay products underground was estimated to be about 60 millirem. Appendix F contains additional information on the estimated underground external dose to involved workers from radon.

Workers in the Exploratory Studies Facility are also exposed to external gamma radiation from radon decay products and other naturally occurring radionuclides. Ambient radiation monitoring in this facility indicated a dose rate from background sources of radionuclides in the drift walls of about 40 millirem per year, which is about the same as the cosmic and cosmogenic components from background radiation on the surface in the Amargosa Valley region (see Table 3-28).

Naturally occurring radon-222 and decay products are released from the Exploratory Studies Facility in the exhaust ventilation air. The estimated annual release of radon and decay products is about 80 curies. The estimated annual dose to an individual 20 kilometers (12 miles) south of the repository is about 0.1 millirem. The estimated annual dose to the population within 80 kilometers (50 miles) is about

0.6 person-rem. These doses are small percentages of the dose from natural sources shown in Table 3-28. Appendix G contains additional information on the estimated releases of radon from the repository.

3.1.8.3 Health-Related Mineral Issues Identified During Site Characterization

Certain minerals known to present a potential risk to worker health are present in the volcanic rocks at Yucca Mountain (DOE 1998a, Volume 1, pages 2-24 and 2-25). The risks are generally related to potential exposures caused by inhalation of airborne particulates (dust). Some of the minerals represent a hazard commonly associated with underground construction, whereas others are rare and less well known.

Crystalline silica (silicon dioxide) comes in several forms—among them quartz, tridymite, and cristobalite. Inhaling silica dust causes a disease called *silicosis* that damages an area of the lungs called the air sac (alveoli) (EPA 1996a, all). The presence of silica dust in the alveoli causes a defensive reaction that results in the formation of scar tissue in the lungs. This scar tissue can reduce overall lung capacity.

DOE typically performs evaluations of exposure to crystalline silica at Yucca Mountain for cristobalite that encompass potential impacts from exposure to other forms of crystalline silica. The repository host rock has a cristobalite content ranging from 18 to 28 percent (TRW 1999b, page 4-81). The American Conference of Governmental Industrial Hygienists has established Threshold Limit Values for various forms of crystalline silica (ACGIH 1999, page 61). These limits are based on an 8-hour day and 40-hour week and, therefore, could be exceeded for a short period—as long as the average time spent by a worker is below the limit. The Threshold Limit Values for respirable cristobalite dust and quartz dust are 0.05 and 0.1 milligram per cubic meter, respectively. In addition, crystalline silica has been listed by the World Health Organization as a carcinogen (IARC 1997, page 41).

Normal underground mechanical excavation produces dust when the rock is broken loose from the face. Dust is also generated when the broken rock is transferred to railcars or conveyors, or a storage pile. Dust can also be generated by wind erosion of excavated rock storage piles. Excavation activities during site characterization have caused exceedances of crystalline silica Threshold Limit Values at specific work locations. Workers at these locations were required to wear respirators. DOE will use the experience gained during Experimental Studies Facility activities to design engineering controls to minimize future exposures.

Erionite is an uncommon zeolite mineral that the International Agency for Research on Cancer recognized as a human carcinogen in 1987; at Yucca Mountain, it occurs primarily in the basal vitrophyre of the Topopah Spring tuff and in isolated zones of the Tiva Canyon tuff (see Section 3.1.3). Even at low doses erionite is believed to be a potent carcinogen capable of causing mesothelioma, a form of lung cancer. As a result of its apparent carcinogenicity, erionite could pose a risk if encountered in quantity during underground construction, even with standard modern construction practices. Because erionite appears to be absent or rare at the proposed repository depth and location, most repository operations should not be affected. However, repository workers would take precautions (for example, dust suppression, air filters, personal protective gear) during construction when penetrating horizons in which erionite could occur, such as in the basal vitrophyre of the Topopah Spring tuff.

A number of other minerals present at Yucca Mountain might have associated health risks if prolonged exposures occur; however, there is no evidence suggesting a link to cancer. Therefore, the International Agency for Research on Cancer has ranked these substances not classifiable (IARC 1997, all). Some of the minerals identified and considered in establishing health and safety practices for potential repository operations include the zeolite group minerals mordenite (which is fibrous and similar in some respects to erionite), clinoptilolite, heulandite, and phillipsite. Because there is no known risk associated with the other zeolite minerals, and because they occur primarily in nonwelded units below the repository horizon, they probably do not represent a large risk. The measures implemented to mitigate risk from silica (for example, dust suppression, air filters, personal protective gear) should also protect workers from exposure to other minerals.

3.1.8.4 Industrial Health and Safety Impacts During Construction of the Exploratory Studies Facility

During Yucca Mountain site characterization activities, health and safety impacts to workers have resulted from common industrial hazards (such as tripping and falling). The categories of worker impacts include total recordable incidents, lost workdays, and fatalities. Recordable incidents or cases are occupational injuries or occupation-related illnesses that result in (1) a fatality, regardless of the time between the injury or the onset of the illness and death, (2) lost workday cases (nonfatal), and (3) incidents that result in the transfer of a worker to another job, termination of employment, medical treatment, loss of consciousness, or restriction of motion during work activities.

Site characterization activities at Yucca Mountain have had no involved worker fatalities. DOE has compiled statistics for the other types of health and safety impacts in accordance with the regulations of the Occupational Safety and Health Administration (29 CFR Part 1904) (see Appendix F, Table F.2-3). These statistics cover the 30-month period from the fourth quarter of 1994 through the first quarter of 1997. DOE selected this period because there was high onsite work activity in which the tunnel-boring machine was in operation in the Exploratory Studies Facility. DOE expects this condition to be characteristic of the types of activities that would occur during the construction of the surface facilities and the development of the emplacement drifts. Table 3-29 lists the industrial health and safety loss statistics for industry, general construction, general mining, and the Yucca Mountain site.

Table 3-29. Comparison of health and safety statistics for mining activities from the Bureau of Labor Statistics to those for Yucca Mountain during excavation of the Exploratory Studies Facility.[a]

Statistic	Total industry[b]	General construction[b]	General mining[b]	Yucca Mountain experience from DOE CAIRS data base, involved workers[c]
Total recordable cases rate	7.1	9.5	5.9	6.8
Lost workday cases rate	3.3	4.4	3.7	4.8
Lost workdays rate	Not available	Not available	Not available	100

a. Statistics based on 100 full-time equivalent work years or 200,000 worker hours.
b. Source: BLS (1998, all).
c. Source: Appendix F, Table F.2-3.

3.1.9 NOISE

Noise comes from either natural or manmade sources. DOE has evaluated existing noise conditions in the Yucca Mountain region and has compiled the detected ranges of noise levels at different locations under differing conditions.

3.1.9.1 Noise Sources and Levels

Yucca Mountain is in a quiet desert environment where natural phenomena such as wind, rain, and wildlife account for most background noise. The acoustic environment is typical of other desert environments where average day-night sound-level values range from 22 decibels on calm days to 38 decibels on windy days (Brattstrom and Bondello 1983, page 170).

NOISE MEASUREMENT

What are *sound* and *noise*?

When an object vibrates it possesses energy, some of which transfers to the air, causing the air molecules to vibrate. The disturbance in the air travels to the eardrum, causing it to vibrate at the same frequency. The ear and brain translate the vibration of the eardrum to what we call *sound*. *Noise* is simply unwanted sound.

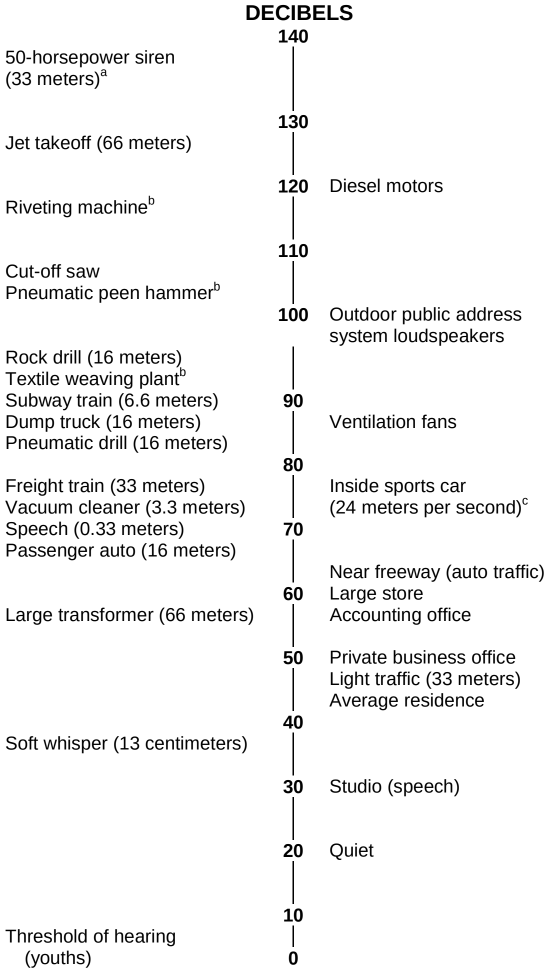
How is sound measured?

The human ear responds to sound pressures over an extremely wide range of values. The range of sounds people normally experience extends from low to high pressures by a factor of 1 million. Accordingly, scientists have devised a special scale to measure sound. The term decibel (abbreviated dB), borrowed from electrical engineering, is the unit commonly used.

Another common sound measurement is the A-weighted sound level, denoted as dBA. The A-weighting accounts for the fact that the human ear responds more effectively to some pitches than others. Higher pitches receive less weighting than lower ones. Most of the sound levels provided in this EIS are A-weighted; however, some are in decibels due to lack of information on the frequency spectrum of the sound. The scale to the right provides common references to sound on the A-weighted sound-level scale.

Source: Modified from DOE (1999g, page 3-39).

TYPICAL A-WEIGHTED SOUND LEVELS



a. To convert meters to feet, multiply by 3.2808.
b. Operator's position.
c. 24 meters per second = about 50 miles per hour.
d. 13 centimeters = about 5 inches.

Manmade noise occurs periodically in the area as vehicles travel to and from Yucca Mountain, from site characterization activities at the operations areas, and from occasional low-flying military jets. Sound-level measurements recorded in May 1997 at areas adjacent to and at the Yucca Mountain operations areas were consistent with noise levels associated with industrial operations [sound levels from 44 to 72 decibels (A-weighted)] (Brown-Buntin 1997, pages 4-6). Table 3-30 lists estimated sound-level values for Yucca Mountain, nearby communities and cities, and other environments.

3.1.9.2 Regulatory Standards

With the exception of prohibiting nuisance noise, neither the State of Nevada nor local governments have established numerical noise standards. Nevertheless, many Federal agencies use average day-night sound

Table 3-30. Estimated sound levels in southern Nevada environments.[a]

Environment	Sound level[b] (decibels)
Calm day at Yucca Mountain	22
Windy day at Yucca Mountain	38
Rural communities (Panaca, Hadley, Rachel, Alamo, Jean, Goodsprings, Sandy)	40 - 47
Small towns or rural communities along busy highways (Beatty, Indian Springs, Pahrump, Lathrop Wells, Caliente, Tonopah, Goldfield, Mercury) and at the intersection of proposed transportation routes to Yucca Mountain	45 - 55
Suburban parts of Las Vegas	52 - 60
Urban parts of Las Vegas	56 - 66
Dense urban parts of Las Vegas with heavy traffic	64 - 74
Under flight path at McCarran International Airport (0.8 to 1.6 kilometers[c] from runway)	78 - 88

a. Source: modified from EPA (1974, page 14); Brattstrom and Bondello (1983, page 170).
b. Day-night average sound level.
c. About 0.5 to 1 mile.

levels as guidelines for land-use compatibility and to assess the impacts of noise on people. Many agencies, including the Environmental Protection Agency, recognize an average day-night sound level of 55 decibels (A-weighted) as an outdoor goal for protecting public health and welfare in residential areas (EPA 1974, page 3). This noise level, which has been established by scientific consensus, is not a regulatory criterion in Nevada, and could protect against activity interference and annoyance. As required, DOE monitors noise levels in worker areas, and a hearing protection program has been in place during site characterization. Hearing protection is used as a supplement to engineering controls, which are the primary method of noise suppression.

3.1.10 AESTHETICS

Visual resources include the natural and manmade physical features that give a particular landscape its character and value as an environmental factor. Sections 3.1.3 and 3.1.5 describe the geologic and biological settings, respectively, at Yucca Mountain.

The region surrounding Yucca Mountain consists of unpopulated to sparsely populated desert and rural lands. Because Yucca Mountain is on the Nevada Test Site and Nellis Air Force Range with restricted public access, public visibility is limited to portions of U.S. Highway 95 near Amargosa Valley.

The Bureau of Land Management uses four visual resource classes in the management of public lands (BLM 1986, all). Classes I and II are the most valued, Class III is moderately valued, and Class IV is of least value. Visual resources fall into one of these classes based on a combination of three factors: (1) scenic quality, (2) visual sensitivity, and (3) distance from travel routes or observation points (BLM 1986, all). There are three scenic quality classes in the Visual Resource Management system. Class A includes areas that combine the most outstanding characteristics of each physical feature category. Class B includes areas in which there is a combination of some outstanding and some fairly common characteristics. Class C includes areas in which the characteristics are fairly common to the region. A visual sensitivity rating for an area is based on the number and types of users, public interest in the area, and adjacent land uses.

The Bureau of Land Management has not assigned a Visual Resource Management class to Yucca Mountain because the Nevada Test Site is not under the Bureau's jurisdiction. However, using the Bureau's method of determining scenic quality, DOE has evaluated the visual resources of the Yucca Mountain region from two observation points—one at Lathrop Wells on U.S. 95 and the other on the Nevada Test Site at a location that provides a clear view of the proposed repository site (TRW 1999p, all).

BUREAU OF LAND MANAGEMENT VISUAL RESOURCE MANAGEMENT CLASS OBJECTIVES
(used in the management of public lands)

Class I	The objective of this class is to preserve the existing character of the landscape. This class provides for natural ecological changes; however, it does not preclude very limited management activity. The level of change to the characteristic landscape should be very low and must not attract attention.
Class II	The objective of this class is to retain the existing character of the landscape. The level of change to the characteristic landscape should be low. Management activities may be seen, but should not attract the attention of the casual observer. Any changes must repeat the basic elements of form, line, color, and texture found in the predominant natural features of the characteristic landscape.
Class III	The objective of this class is to partially retain the existing character of the landscape. The level of change to the characteristic landscape should be moderate. Management activities may attract attention but should not dominate the view of the casual observer. Changes should repeat the basic elements found in the predominant natural features of the characteristic landscape.
Class IV	The objective of this class is to provide for management activities that require major modification of the existing character of the landscape. The level of change to the characteristic landscape can be high. These management activities may dominate the view and be the major focus of viewer attention. However, every attempt should be made to minimize the impact of these activities through careful location, minimal disturbance, and repeating the basic elements.

The visual assessment at both these locations concluded that the scenic quality classification of Yucca Mountain is C.

3.1.11 UTILITIES, ENERGY, AND SITE SERVICES

DOE research into the current consumer demand for utilities and energy in the Yucca Mountain region has yielded information on water and power sources, use, and supply systems. The research included water treatment capabilities. The region of influence for potential impacts to utility and energy supplies consists of Clark, Lincoln, and Nye Counties in Nevada. Sections 3.1.11.1 and 3.1.11.2 contain information on current water and energy suppliers and consumer use. Unless otherwise noted, the *Yucca Mountain Site Characterization Project Environmental Baseline File for Utilities, Energy, and Site Services* (TRW 1999j, all) is the basis of the information in this section.

3.1.11.1 Utilities

Water and sewer utilities in the region could be affected by the Proposed Action as a result of project-related increases in population and the associated increases in water demand and sewage production. DOE anticipates that the predominant project-related increase in population would occur in Clark County, with a smaller increase in Nye County (see Section 3.1.7).

Water. The Southern Nevada Water Authority supplies water to five communities in Clark County: Boulder City, Henderson, Las Vegas (including parts of unincorporated Clark County), Nellis Air Force Base, and North Las Vegas. Eighty-five percent of the water supplied to the Las Vegas Valley comes from the Colorado River through Lake Mead; the remaining 15 percent comes from groundwater (Las Vegas Valley Hydrographic Area; SNWA 1997, page 2). To meet growing water demands, the Water Authority is upgrading current facilities and installing new facilities, such as a second raw water intake at Lake Mead, a second water treatment facility, and additional pipelines and pumping stations.

In southern Nye County, where the repository would be, groundwater is the only source of water. In August 1996, a water supply and demand evaluation for southern Nye County, including Beatty, Amargosa Desert, and Pahrump, was performed (Buqo 1996, all). In Beatty (Oasis Valley Hydrographic Area), the local water utility will have difficulty meeting future water demands due not to a high growth rate but to falling well yields and poor water quality in some wells. Existing pumping capacity is not adequate to meet projected peak demands between 1997 and 2000, and one or more additional wells will be needed. In Amargosa Desert (Amargosa Desert Hydrographic Area), the current committed amount of groundwater appropriations (permits and certificates) is larger than the lower estimate of perennial yield for the applicable groundwater. However, historic pumping amounts have never been higher than the estimates of yield. In Pahrump (Pahrump Valley Hydrographic Area), the total groundwater pumped from the basin in 1995 was almost 30 million cubic meters (24,000 acre-feet). This is about 25 percent higher than the upper end of estimates of the basin's perennial yield, which range from 15 million cubic meters [12,000 acre-feet (NDWP 1992, page 7)] to 23 million cubic meters [19,000 acre-feet (Buqo 1996, page 17)]. Much of Pahrump's water consumption results from about 7,000 domestic water supply wells. Drilling continues at a rate of about two wells a year (Buqo 1999, page 34). Alternatives to address long-term water supply issues in Pahrump Valley include optimizing the locations of new wells, reducing per capita consumption, developing the carbonate aquifer, and importing water from other groundwater basins. Overall groundwater withdrawals in Nye County totaled about 93 million cubic meters (75,000 acre-feet) in 1995. The predominant use of this water was agriculture, accounting for 80 percent of the total; domestic use was responsible for only 7 percent of the total withdrawal (Horton 1997, Table 1).

Sewer. Wastewater treatment needs in the Las Vegas Valley are supported by three major wastewater treatment facilities: one operated by the City of Las Vegas (which also serves the City of North Las Vegas); one operated by the City of Henderson; and one operated by the Clark County Sanitation District. The County Sanitation District includes all the unincorporated areas in Clark County, and it provides services to several outlying communities including Blue Diamond, Laughlin, Overton, and Searchlight (Clark County 1999, all). However, its primary service area is the portion of the Las Vegas Valley south and east of the City of Las Vegas and extending to Henderson. There might be other small wastewater treatment units serving parts of Clark County outside the populous area of the Las Vegas Valley, but septic tank and drainage field systems provide the primary means of wastewater treatment in these outlying areas, particularly for private residences.

Southern Nye County does not have a metropolitan area or a sanitation district comparable to Clark County, and communities in this area rely primarily on individual dwelling or small communal wastewater treatment systems. For example, Pahrump has no community-wide wastewater treatment system. Several wastewater treatment units serve parts of the town, such as the dairy and the jail, but most households have septic tank and drainage field systems. This is likely to be typical of the small communities in southern Nye County.

3.1.11.2 Energy

Electric Power. Three different power distributors—Nevada Power Company, Valley Electric Association, Inc., and Lincoln County Power District No. 1—supply electric power in the region of influence.

Nevada Power Company supplies electricity to southern Nevada in a corridor from southern Clark County, including Las Vegas, North Las Vegas, Henderson, and Laughlin, to the Nevada Test Site in Nye County. In 1996, the power sources were 50 percent company-generated (38 percent coal, 12 percent natural gas), 4 percent Hoover Dam hydroelectric, and 46 percent purchased power. In 1996, Nevada Power Company sold 13.7 million megawatt-hours to its 490,000 customers, with average annual sales per residential customer of about 13,000 kilowatt-hours. In 1996, the peak load was the highest ever at about 3,300 megawatts with a generating capacity and firm purchases of about 3,900 megawatts. Nevada Power Company has an annual customer growth rate of 7.2 percent. To keep pace with demands for electricity, each year Nevada Power must build more substations and transmission and distribution facilities; in 1996, it invested about $180 million in such equipment (NPC 1997, all).

The Valley Electric Association is a nonprofit cooperative that distributes power to southern Nye County, including Pahrump Valley, Amargosa Valley, Beatty, and the Nevada Test Site. The Western Area Power Administration allocates Valley Electric a portion of the lower cost hydroelectric power from the Colorado River dams. The private power market supplies the supplemental power necessary to meet the needs of the members. Since 1995, the amount of power available in the marketplace has been abundant. The amount of energy that Valley Electric sells annually to its members almost tripled in the 11 years from 1985 through 1995. In 1995, Valley Electric sold about 300 million kilowatt-hours to its 8,600 members (McCauley 1997, pages 54 and 55). To meet the power demands of its members, Valley Electric has built a new 230-kilovolt transmission line from Las Vegas to Pahrump and plans to install three new substations in Pahrump.

At present, two commercial utility companies own transmission lines that supply electricity to the Nevada Test Site (Figure 3-22). The electric power for the Yucca Mountain Project in Area 25 comes through the Nevada Test Site power grid. The Test Site buys power at 138 kilovolts at the Mercury Switch Station and at the Jackass Flats Substation. The 138-kilovolt system at the Test Site has nine substations, one switching center, and one tap station, which are connected by approximately 210 kilometers (130 miles) of transmission line. A 138-kilovolt line owned by Nevada Power Company connects the Mercury Switch Station to the Jackass Flats substation, which reduces the power and transmits it to the Field Operations Center and nearby buildings in Area 25 that support the Yucca Mountain Project. A Valley Electric Association 138-kilovolt line also provides power to the Jackass Flats Substation. From the Jackass Flats substation, a 138-kilovolt line feeds the Canyon Substation in Area 25, which provides power to the Exploratory Studies Facility. The Canyon Substation reduces the voltage from 138 to 69 kilovolts, with a capacity of 10 megawatts, and transmits it to the Yucca Mountain substation at the Exploratory Studies Facility.

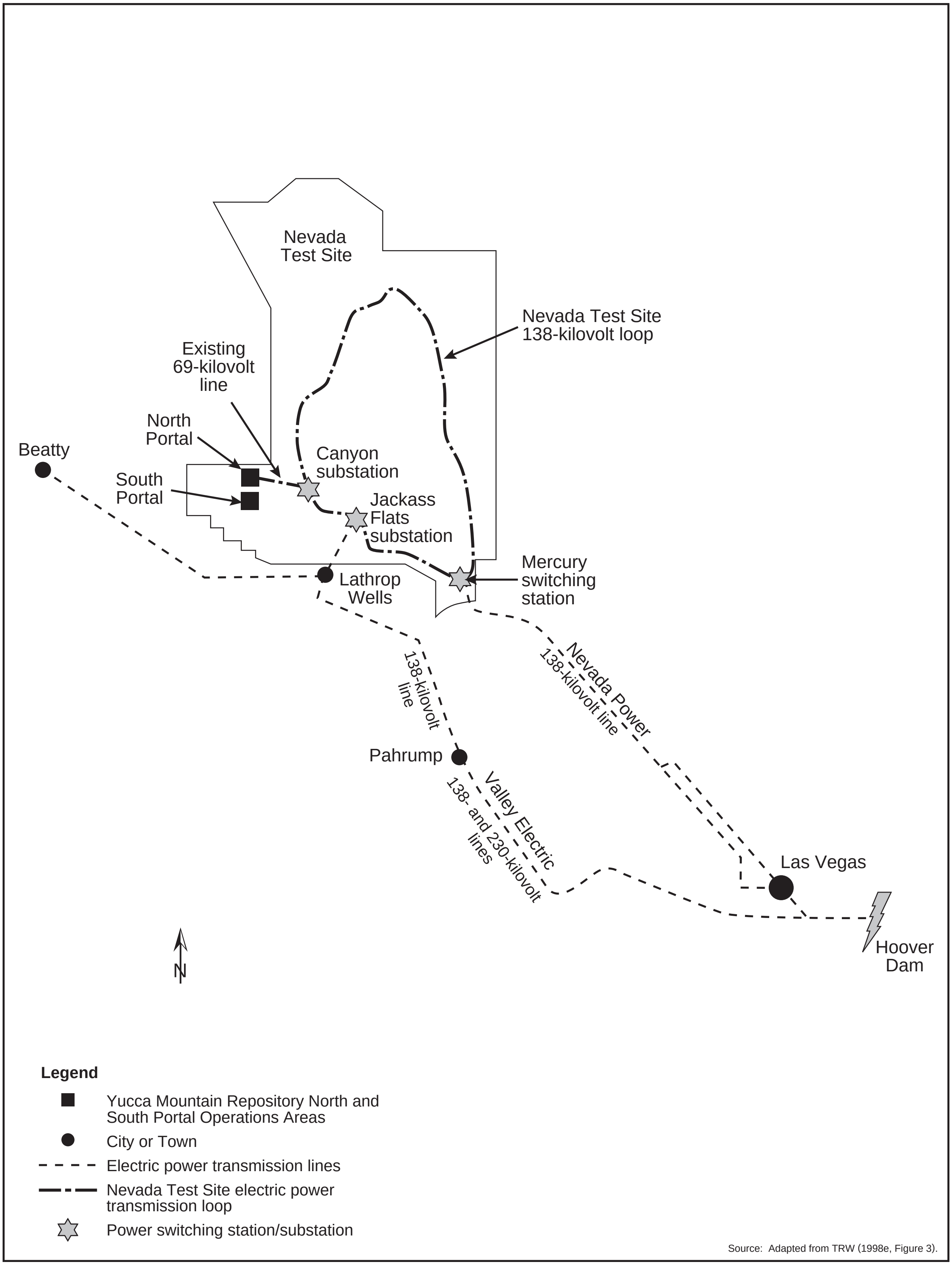
The capacity of the Nevada Test Site grid is 72 megawatts. Since 1990, the historic monthly peak use was about 18,000 megawatt-hours in January 1992, with a peak load of about 37 megawatts (Thurman 1997, page 1).

Table 3-31 lists the combined historic and projected electricity use for the Exploratory Studies Facility and the Field Operations Center for 1995 through 2000. The Exploratory Studies Facility consumed about 70 percent of the listed amounts (Thurman 1997, all). Annual power use and peak demand at the Exploratory Studies Facility would probably decline and stabilize at a lower level than the 1997 use rates because site activity would decline until

Table 3-31. Electric power use for the Exploratory Studies Facility and Field Operations Center.[a,b]

	Power use	
Fiscal Year	Consumption (megawatt-hours)	Peak (megawatts)
1995	9,800	3.5
1996	19,000	4.9
1997	23,000	5.3
1998[c]	21,000	4.2
1999[c]	17,000	4.2
2000[c]	8,700	4.2

a. Source: TRW (1998a, Table 2, page 8).
b. Before 1995, Yucca Mountain Project power was not metered separately.
c. Projected.



Source: Adapted from TRW (1998e, Figure 3).

Figure 3-22. Existing Nevada Test Site electric power supply.

repository construction began in 2005. Historically, from 1995 through 1997 Exploratory Studies Facility use has accounted for about 15 percent to 20 percent of the electric power used by all of the Nevada Test Site (TRW 1998a, Table 2, page 8).

Fossil Fuel. The fossil fuels that DOE has used at the Exploratory Studies Facility are heating oil, propane, diesel, gasoline, and kerosene. Natural gas, coal, and jet fuel have not been used. In 1996, site activities consumed about 1.02 million liters (270,000 gallons) of heating oil and diesel fuel and about 65,000 liters (17,000 gallons) of propane; in 1997, they consumed slightly less than 1 million liters (264,000 gallons) of heating oil and diesel fuels. The amounts of gasoline and kerosene used at the Exploratory Studies Facility were very small in those years. Fossil-fuel supplies are delivered to the Nevada Test Site and the Exploratory Studies Facility by truck from readily available supplies in southern Nevada.

3.1.11.3 Site Services

DOE has established an existing support infrastructure to provide emergency services to the Exploratory Studies Facility. The Yucca Mountain Project *Emergency Management Plan* (DOE 1998k, all) describes emergency planning, preparedness, and response. The project cooperates with the Nevada Test Site in such areas as training and emergency drills and exercises to provide full emergency preparedness capability to the site. In addition, the project trains and maintains an underground rescue team. The Nevada Test Site security program is responsible for project security, with enforcement provided by a contractor following direction from DOE. The Nye County Sheriff’s Department provides law enforcement and officers for Yucca Mountain site patrol. Nevada Test Site personnel and equipment support fire protection and medical services. Medical services are provided through the Nevada Test Site by two paramedics and an ambulance stationed in Area 25 with backup from other Test Site locations. The Yucca Mountain staff uses a medical clinic with outpatient capability at Mercury. Urgent medical transport is provided by the “Flight for Life” and “Air Life” programs from Las Vegas. Nellis Air Force Base and Nye County also provide emergency support.

3.1.12 WASTE AND HAZARDOUS MATERIALS

The Yucca Mountain Site Characterization Project developed its waste management systems to handle the waste and recyclable material generated by its activities. This material includes nonhazardous solid waste; construction debris; hazardous waste; recyclables such as lead-acid batteries, used oil, metals, paper, and cardboard (Harris 1997, Page 6); sanitary sewage; and wastewater. It does not include low-level radioactive or mixed wastes. DOE uses landfills to dispose of solid waste and construction debris; accumulates and consolidates hazardous waste, then transports it off the site for treatment and disposal; treats and reuses wastewater; and treats and disposes of sanitary waste. In most categories of waste, especially solid waste, some types of material can be recycled or reused. DOE has processes in place to ensure that it collects the material and recycles it as appropriate.

3.1.12.1 Solid Waste

DOE disposes of Yucca Mountain Site Characterization Project solid waste and construction debris in landfills in Areas 23 and 9, respectively, on the Nevada Test Site. The Area 23 landfill has a capacity of 450,000 cubic meters (16 million cubic feet) (DOE 1996f, page 4-37) and a 100-year estimated life (DOE 1995f, page 9). The Area 9 landfill, which is in Crater U-10C, is an open circular pit with steep, almost vertical sides formed as a result of an underground nuclear test. The Area 9 landfill has a disposal capacity of 990,000 cubic meters (35 million cubic feet) (DOE 1996f, page 4-37) and an estimated 70-year operational life (DOE 1995f, page 8). The environmental impact statement for the Nevada Test Site describes these landfills (DOE 1996f, page 4-37). DOE disposes of Yucca Mountain Site

Characterization Project oil-contaminated debris from maintenance activities at the industrial landfill at Apex, Nevada, using an environmental company for transport and disposal. The Apex facility is a multilined landfill with on- and offsite monitoring in compliance with State of Nevada requirements (Harris 1997, page 4).

DOE recycles as many materials as feasible from its site characterization activities. The *Waste Minimization and Pollution Prevention Awareness Plan, Approved* (DOE 1997h, all) governs recycling and other waste minimization activities. At present, a Nevada Test Site contractor collects paper, cardboard, and scrap metal and recycles it. For such recyclables as oils, solvents, coolants, lead-acid batteries, and oil-contaminated soils, the Yucca Mountain Site Characterization Project contracts directly with recycling services (Harris 1997, pages 1 to 3).

3.1.12.2 Hazardous Waste

The Yucca Mountain Site Characterization Project is a small-quantity [less than 1,000 kilograms (2,200 pounds) a month] generator of hazardous waste. DOE accumulates hazardous wastes near their generation sources, consolidates them at a central location at the Yucca Mountain site (Harris 1997, page 5), and ships them off the site for treatment and disposal. The hazardous waste accumulation areas are managed in accordance with Federal and State regulations. The waste is treated and disposed of off the site at a permitted treatment, storage, and disposal facility under contract to the Nevada Test Site (Harris 1997, page 5).

3.1.12.3 Wastewater

DOE uses a septic system to treat and dispose of sanitary sewage at the Yucca Mountain site (TRW 1998f, page 15). The system design can handle a daily flow of about 76,000 liters (20,000 gallons) (TRW 1998g, page 64).

At present, wastewater from tunneling operations and water from secondary containment (following rains) is processed through an oil-water separator, and the treated water is used for dust suppression in accordance with a State of Nevada permit (Harris 1997, page 2). The oil is recycled with the other used oil generated by the project.

3.1.12.4 Existing Low-Level Radioactive Waste Disposal Capacity

The Nevada Test Site accepts low-level radioactive waste for disposal from approved generator sites. It has an estimated disposal capacity of 3.1 million cubic meters (110 million cubic feet). DOE estimates that a total of approximately 670,000 cubic meters (23.7 million cubic feet) of low-level radioactive waste will be disposed of at the Test Site through 2070 (DOE 1998l, page 2-23), not including repository-generated waste.

Commercial spent nuclear fuel generators and contractor-operated transportation facilities such as an intermodal transfer station would dispose of low-level radioactive waste in commercial facilities. Commercial disposal capacity for a broad range of low-level radioactive wastes is available at two licensed facilities, and three more disposal facilities are under license review (NRC 1997a, U.S. Low-Level Radioactive Waste Disposal Section).

3.1.12.5 Materials Management

DOE has programs and procedures in place to procure and manage hazardous and nonhazardous chemicals and materials (DOE 1996h, all). By using these programs, the Department is able to minimize the number and quantities of hazardous chemicals and materials stored at the Yucca Mountain site and maintain appropriate storage facilities.

The chemical and material inventory report (Dixon 1999, pages 4, 4a, and 5) for the Nevada State Fire Marshal's office lists 33 hazardous chemicals and materials. The Yucca Mountain Project holds many of these in small quantities, and it stores sulfuric acid in larger quantities [above the threshold planning quantity of about 450 kilograms (1,000 pounds) that requires emergency planning]. Most of the sulfuric acid is in lead-acid batteries (Dixon 1999, all). In addition, the Yucca Mountain Site Characterization Project stores the following hazardous chemicals in large amounts [exceeding 4,500 kilograms (10,000 pounds)]: propane, gasoline, cement, and lubricating and hydraulic oils. The project does not store highly toxic substances in quantities higher than the State of Nevada reporting thresholds (Dixon 1999, page 1).

3.1.13 ENVIRONMENTAL JUSTICE

ENVIRONMENTAL JUSTICE TERMS

Minority: Hispanic, Black, Asian/Pacific Islander, American Indian/Eskimo, Aleut, and other non-white person.

Low income: Below the poverty level as defined by the Bureau of the Census.

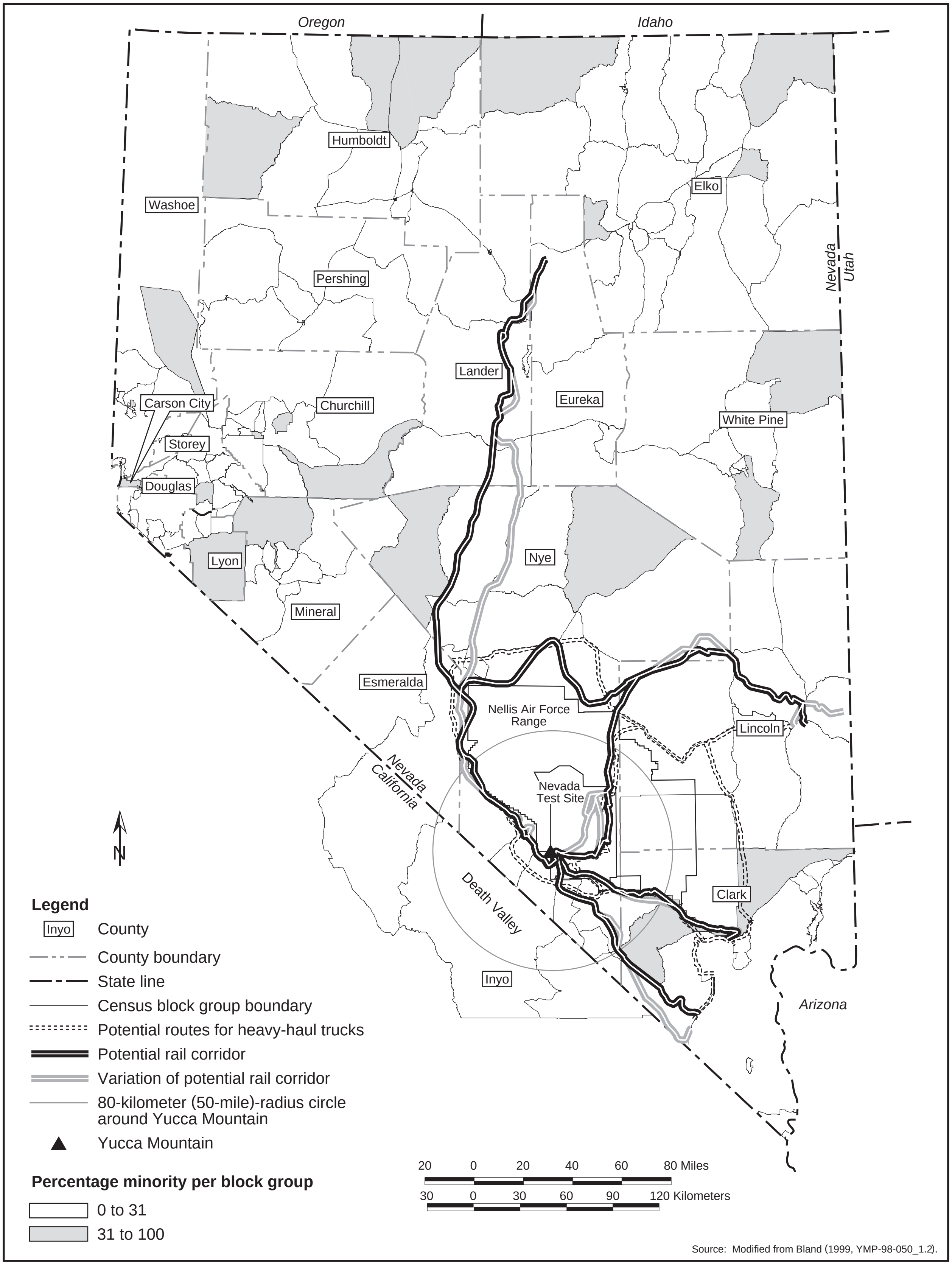
Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*, directs each Federal agency "to make achieving environmental justice a part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations." In a memorandum that accompanies the Executive Order, President Clinton directs that "...environmental effects, including human health, economic and social effects, of Federal actions, including effects on minority communities and low-income communities, [be analyzed] when such analysis is required by the National Environmental Policy Act."

DOE has identified the minority and low-income communities in the Yucca Mountain region of influence, which consists of Clark, Lincoln, and Nye Counties in southern Nevada. Unless otherwise noted, the *Environmental Baseline File for Environmental Justice* (TRW 1999q, all) is the basis for information in this section.

To identify minority and low-income communities in the region of influence, DOE analyzed Bureau of the Census population designations called *block groups*. DOE pinpointed block groups where the percentage of minority or low-income residents is meaningfully greater than average. For environmental justice purposes, the pinpointed block groups are minority or low-income communities. This EIS considers whether activities at Yucca Mountain could cause disproportionately high and adverse human health or environmental effects to those communities.

3.1.13.1 State of Nevada

Minority persons comprised 21 percent of the population in Nevada in the 1990 census (Bureau of the Census 1992a, Tables P8 and P12). As defined by the Nuclear Regulatory Commission (NRC 1995, all), a minority population is present in a community when the percentage of minority persons in the area exceeds the percentage of minority persons in the state or region affected by a project by 10 percent or more (that is, 31 percent or more minority persons in a community). This analysis identifies communities at the Bureau of the Census block group level. The following discussion uses data from the 1990 census. Figure 3-23 shows block groups in which 31 percent or more of the population consists of minority persons.



Source: Modified from Bland (1999, YMP-98-050_1.2).

Figure 3-23. Minority communities in Nevada.

The 1990 census characterized about 10 percent of the people in Nevada as living in poverty (Bureau of the Census 1992a, Table P117). The Bureau of the Census characterizes persons in poverty as those whose income is less than a statistical poverty threshold, which is based on family size and the ages of its members. In the 1990 census the threshold for a family of four was a 1989 income of $12,674 (Bureau of the Census 1995, Section 14). In this environmental impact statement, low-income communities are those in which the percentage of persons in poverty equals or exceeds 20 percent as reported by the Bureau of the Census. Figure 3-24 shows low-income communities.

3.1.13.2 Clark County

In 1990, the minority population of Clark County was about 180,000 persons, or 25 percent of the total population (Bureau of the Census 1992b, Tables P8 and P12). A total of 6,800 residents, or 11 percent of the Clark County population, was characterized as living in poverty (Bureau of the Census 1992b, Table P117) Forty-three of Clark County's 325 block groups had both minority populations greater than the 31-percent threshold necessary for identification as minority communities and populations that exceeded the 20-percent low-income community threshold. Thirty-five more block groups had minority populations greater than the 31-percent threshold. An additional 12 block groups had low-income populations greater than the 20-percent threshold. In all, the process identified 90 block groups in Clark County for environmental justice study.

3.1.13.3 Lincoln County

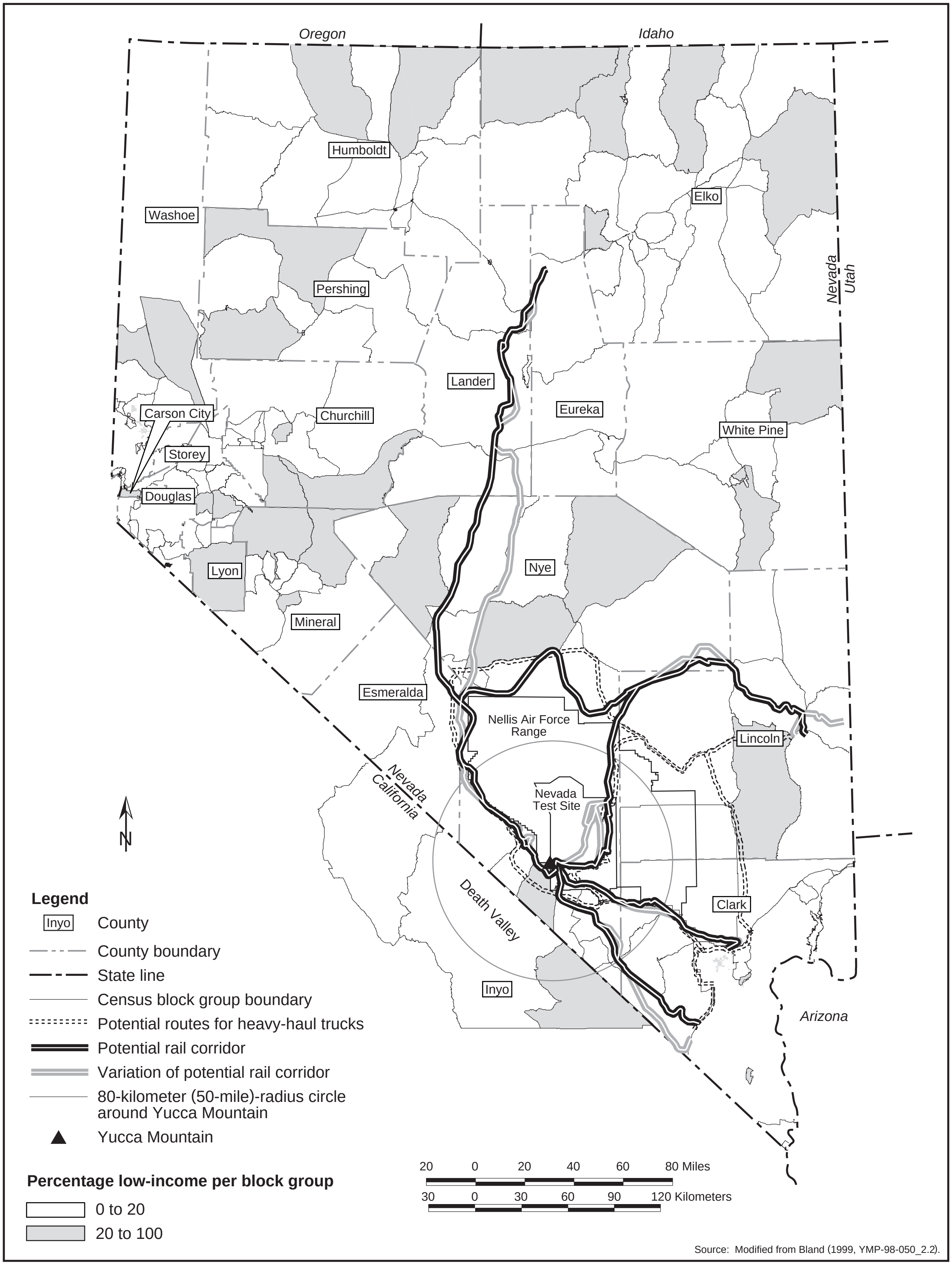
In 1990, the Lincoln County minority population consisted of about 370 persons, or 10 percent of the population (Bureau of the Census 1992c, Tables P8 and P12). Five hundred persons, or 14 percent of the population, were characterized as living in poverty (Bureau of the Census 1992c, Table P117). No block groups exceeded the 31-percent threshold for identification as a minority community. One of the block groups in Lincoln County exceeded the threshold for identification as a low-income community.

3.1.13.4 Nye County

In 1990, the Nye County minority population was about 2,200 persons, or 12 percent of the population (Bureau of the Census 1992d, Tables P8 and P12). There were 2,000 persons, or 11 percent of the population, characterized as living in poverty (Bureau of the Census 1992d, Table P117). Two block groups had populations that exceeded the thresholds for both minority and low-income populations. Three more of the 25 block groups in Nye County exceeded the threshold for identification as low-income communities.

3.1.13.5 Inyo County, California

One block group with a low-income population located in the area of the Stewart Valley in Inyo County, California, lies partly within the 80-kilometer (50-mile) air quality region of influence for the repository (Figure 3-21). DOE performed additional review and concluded that low-income persons living in the block group would be likely to live outside the 80-kilometer region of influence for the repository.



Source: Modified from Bland (1999, YMP-98-050_2.2).

Figure 3-24. Low-income communities in Nevada.

3.2 Affected Environment Related to Transportation

This section describes the existing (or baseline) environmental conditions along the potential transportation corridors to the Yucca Mountain site. Section 3.2.1 discusses the existing national transportation infrastructure that DOE would use to ship spent nuclear fuel and high-level radioactive waste to Nevada.

Section 3.2.2 describes the existing environmental conditions along the proposed transportation corridors and routes in Nevada.

3.2.1 NATIONAL TRANSPORTATION

The loading and shipping of spent nuclear fuel and high-level radioactive waste would occur at 72 commercial and 5 DOE sites in 37 states. The Department's efforts to transport these materials to the Yucca Mountain site could use trains, legal-weight trucks, heavy-haul trucks, and barges; the trains and trucks would travel on the Nation's railroads and highways. Barges and heavy-haul trucks would be used for short-distance transport of spent nuclear fuel from storage sites to nearby railheads. (Heavy-haul trucks could also be used for Nevada transportation, as discussed in Section 3.2.2.2.)

The national transportation of spent nuclear fuel and high-level radioactive waste would use existing highways and railroads and would represent a small fraction of the existing national highway and railroad traffic [0.006 percent of truck miles per year or 0.007 percent of railcar miles per year (BTS 1998, page 5)]. Because no new land acquisition and construction would be required to accommodate these shipments, this EIS focuses on potential impacts to human health and safety and the potential for accidents along the shipment routes.

The region of influence for public health and safety along existing transportation routes is 800 meters (0.5 mile) from the centerline of the transportation rights-of-way and from the boundary of railyards for incident-free (nonaccident) conditions. The region of influence extends to 80 kilometers (50 miles) to address potential human health and safety impacts from accident scenarios.

3.2.1.1 Highway Transportation

Highway (legal-weight truck) transportation of spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site would use local highways near the commercial and DOE sites and near Yucca Mountain, Interstate Highways, Interstate bypasses around metropolitan areas, and preferred routes designated by state routing agencies where applicable. DOE used the HIGHWAY computer program (Johnson et al. 1993a, all) to derive highway routes for shipping spent nuclear fuel and high-level radioactive waste. This model considered population densities along the routes, and selected existing highway routes between the commercial and DOE sites and the proposed repository in accordance with U.S. Department of Transportation routing constraints. Population density distributions were calculated along the routes to support human health risk consequences.

Appendix J describes the routes used for analysis in this EIS. Final transportation mode and routing decisions will be made on a site-specific basis during the transportation planning process, following a decision to build a repository at Yucca Mountain.

3.2.1.2 Rail Transportation

In most cases, rail transportation of spent nuclear fuel and high-level radioactive waste would originate on track operated by shortline rail carriers that provide service to the commercial and DOE sites. At railyards near the sites, shipments in general freight service would switch from trains and tracks operated by the shortline rail carriers to trains and tracks operated by national mainline railroads. Figure 2-29 in Chapter 2 is a map of mainline track for the major U.S. railroads that DOE could use for shipments to Nevada. This interlocking network has about 290,000 kilometers (180,000 miles) of track that link the major population centers and industrial, agricultural, and energy and mineral resources of the Nation (AAR 1996, all). With the exception of shortline regional railroads that serve the commercial and DOE sites, DOE anticipates that cross-country shipments would move on mainline railroads.

Rail transportation routing of spent nuclear fuel and high-level radioactive waste shipments is not regulated by the U.S. Department of Transportation. The routes used in this EIS were derived from the INTERLINE computer program (Johnson et al. 1993b, all). The selection of these routes was based on current routing activities using existing routes. Appendix J describes the rail routes used in this EIS analysis.

3.2.1.3 Barge and Heavy-Haul Truck Transportation

Commercial sites that do not have direct rail service could ship spent nuclear fuel on heavy-haul trucks or barges to nearby railheads. Heavy-haul trucks would use local highways to carry the spent nuclear fuel to a nearby railhead for transfer to railcars for transport to Nevada. Barge shipments would use navigable waterways accessible from the nuclear plant site. These shipments would travel on the waterways to nearby railheads for transfer to railcars for transport to Nevada. Appendix J describes the heavy-haul truck and barge routes used in this EIS analysis.

3.2.2 NEVADA TRANSPORTATION

Shipments of spent nuclear fuel and high-level radioactive waste arriving in Nevada would be transported to the Yucca Mountain site by legal-weight truck, rail, or heavy-haul truck. The discussion of national transportation modes and routes in Section 3.2.1 addresses the affected environment for legal-weight truck transport from commercial and DOE facilities to the Yucca Mountain site, including travel in Nevada. This section addresses the affected environment in Nevada for candidate rail corridors, heavy-haul truck routes, and potential locations for an intermodal transfer station that DOE could use for transporting spent nuclear fuel and high-level radioactive waste and that would require new construction.

Legal-weight truck shipments in Nevada would use existing highways and would be a very small fraction of the total traffic [less than 0.5 percent of commercial vehicle traffic on U.S. Highway 95 in southern Nevada (NDOT 1997, page 9; Cerocke 1998, page 1). Because no new land acquisition and construction would be required to accommodate legal-weight trucks, this EIS focuses on potential impacts to human health and safety and the potential for accidents along the shipment routes from legal-weight truck shipments. Appendix J contains baseline environmental information related to human health and safety and the impacts from accident scenarios.

To allow large-capacity rail cask shipments to the repository, DOE is considering the construction of a new branch rail line or the establishment of heavy-haul truck shipment capability. Sections 3.2.2.1 and 3.2.2.2 describe the existing (or baseline) environment for each of the candidate rail corridors and heavy-haul truck routes and for potential locations for an intermodal transfer station.

3.2.2.1 Environmental Baseline for Potential Nevada Rail Corridors

This section discusses the environmental characteristics of land areas that could be affected by the construction and operation of a rail line to transport spent nuclear fuel and high-level radioactive waste to the proposed repository. It describes the environmental conditions in five alternative rail corridors—Caliente, Carlin, Caliente-Chalk Mountain, Jean, and Valley Modified. Chapter 2, Section 2.1.3.2, describes these corridors in more detail. Figures 6-10 through 6-15 in Chapter 6 show detailed maps for these corridors.

To define the existing (or baseline) environment along the five proposed rail corridors; DOE has compiled environmental information for each of the following subject areas:

- *Land use and ownership:* The condition of the land, current land-use practices, and land ownership information (Section 3.2.2.1.1)
- *Air quality and climate:* The quality of the air and the climate (Section 3.2.2.1.2)
- *Hydrology:* The characteristics of surface water and groundwater (Section 3.2.2.1.3)
- *Biological resources:* Important biological resources (Section 3.2.2.1.4)
- *Cultural resources:* Important cultural resources (Section 3.2.2.1.5)
- *Socioeconomic environments:* The existing socioeconomic environments (Section 3.2.2.1.6)
- *Noise:* The existing noise environments (Section 3.2.2.1.7)
- *Aesthetics:* The existing visual environments (Section 3.2.2.1.8)
- *Utilities, energy, and materials:* Existing supplies of utilities, energy, and materials (Section 3.2.2.1.9)
- *Environmental justice:* The locations of low-income and minority populations (Section 3.2.2.1.10)

The INTERLINE computer program (Johnson et al. 1993b, all) provided population distributions for differing population zones (urban, rural, suburban) along the alternative rail corridors. This approach is consistent with the national transportation analysis (see Chapter 6 for more detail).

DOE expects waste quantities generated by rail line construction and operation to be minor in comparison to those from repository construction and operation. As such, no discussion of existing waste disposal infrastructure along the routes is provided.

DOE evaluated the potential impacts of the implementing alternatives in regions of influence for each of the subject areas listed above. Table 3-32 defines these regions, which are specific to the subject areas, in which DOE could reasonably expect to predict potentially large impacts related to rail line construction and operation. The following sections describe the various environmental baselines for the rail implementing alternatives.

3.2.2.1.1 *Land Use and Ownership*

Table 3-33 summarizes the estimated land commitment and current ownership or control of the land in each rail corridor. Public lands in and near the corridors are used for a variety of activities including grazing, mining, and recreation. All public land in the Caliente, Carlin, Jean, and Valley Modified corridors is open to mining and mineral leasing laws and offroad vehicle use, with restrictions in some areas (BLM 1979, all; BLM 1994b, all; BLM 1999a, all).

Caliente. Most of the lands associated with the Caliente corridor (88 percent) are public lands managed by the Ely, Battle Mountain, and Las Vegas offices of the Bureau of Land Management. Detailed

Table 3-32. Regions of influence for rail implementing alternatives.

Subject area	Region of influence
Land use and ownership	Land areas that would be disturbed or whose ownership or use would change as a result of construction and use of branch rail line
Air quality and climate	The Las Vegas Valley for implementing alternatives where constructing and operating a branch rail line could contribute to the level of carbon monoxide and PM_{10} already in nonattainment of standards, and the atmosphere in the vicinity of sources of criteria pollutants that would be emitted during branch rail line construction and operations
Hydrology	*Surface water:* areas near where construction would take place that would be susceptible to erosion, areas affected by permanent changes in flow, and areas downstream of construction that could be affected by eroded soil or potential spills of construction contaminants *Groundwater:* aquifers that would underlie areas of construction and operations and aquifers that might be used to obtain water for construction
Biological resources	Habitat, including jurisdictional wetlands and riparian areas inside the 400-meter-wide[a] corridors; habitat, including jurisdictional wetlands outside the corridor that could be disturbed by rail line construction and operations; habitat, including jurisdictional wetlands, and riparian areas that could be affected by permanent changes in surface-water flows; migratory ranges of big game animals that could be affected by the presence of a branch rail line
Cultural resources	Lands inside the 400-meter-wide rail corridors
Socioeconomic environments	Clark, Lincoln, Nye and other counties that a potential branch rail line would traverse
Public health and safety	800 meters[b] on each side of the rail line for incident-free transportation, 80-kilometer[c] radius for potential impacts from accident scenarios
Noise	Inhabited commercial and residential areas where noise from rail line construction and operations could be a concern
Aesthetics	The landscapes along the potential rail corridors with aesthetic qualities that could be affected by construction and operations
Utilities, energy, and materials	Local, regional, and national supply infrastructure that would be required to support rail line construction and operations
Environmental justice	Varies with the individual resource area

a. 400 meters = 0.25 mile.
b. 800 meters = 0.5 mile.
c. To convert kilometers to miles, multiply by 0.62137.

Table 3-33. Land ownership for the candidate rail corridors.[a]

	Land in corridor					
	Totals	Ownership or control (percent)[d]				
Corridor	(km^2)[b,c]	BLM	USAF	DOE	Private	Other
Caliente	200	88	9	2	< 1	0
Carlin	210	85	9	2	3	0
Caliente-Chalk Mountain	140	57	16	27	< 1	0
Jean	72	83	0	12	5	0
Valley Modified	64	50	14	33	0	3

a. Source: (TRW 1999d, all).
b. To convert square kilometers (km^2) to acres, multiply by 247.1.
c. Totals might differ from sums due to rounding.
d. Bureau of Land Management (BLM) property is public land administered by the Bureau; U.S. Air Force property is the Nellis Air Force Range; DOE property is the Nevada Test Site; and the single Other designation is the Desert National Wildlife Refuge managed by the Fish and Wildlife Service.

information on land use is available in the *Proposed Tonopah Resource Management Plan and Final Environmental Impact Statement* (BLM 1994b, all), the *Department of the Interior Final Environmental Impact Statement Proposed Domestic Livestock Grazing Management Program for the Caliente Area* (BLM 1979, all), the *Draft Caliente Management Framework Plan Amendment and Environmental Impact Statement for the Management of Desert Tortoise Habitat* (BLM 1999a, all), and the *Proposed Las Vegas Resource Management Plan and Final Environmental Impact Statement* (BLM 1998, all).

The U.S. Air Force uses about 9 percent of the lands associated with the Caliente corridor. The corridor crosses the western boundary of the Nellis Air Force Range near Scotty's Junction. Detailed information on current and future uses of the Nellis Air Force Range is available in the *Renewal of the Nellis Air Force Range Land Withdrawal Department of the Air Force Legislative Environmental Impact Statement* (USAF 1999, all).

DOE uses about 2 percent of the lands associated with the Caliente corridor. The corridor enters the Nevada Test Site south of Beatty. Detailed information on current and future uses of the Nevada Test Site is available in the *Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada* (DOE 1996f, all).

Less than 1 percent of the land associated with the Caliente corridor is private. The corridor crosses private land near Caliente.

Carlin. Most of the lands associated with the Carlin corridor (about 85 percent) are public lands managed by the Battle Mountain and Las Vegas offices of the Bureau of Land Management. Detailed information on land use is available in the *Draft Management Plan and Environmental Impact Statement for the Shoshone-Eureka Resource Area, Nevada* (BLM 1983, all), the *Proposed Tonopah Resource Management Plan and Final Environmental Impact Statement* (BLM 1994b, all), and the *Proposed Las Vegas Resource Management Plan and Final Environmental Impact Statement* (BLM 1998, all).

The U.S. Air Force uses about 9 percent of the lands associated with the Carlin corridor. The combined Carlin/Caliente corridor crosses into the western portion of the Nellis Air Force Range near Scotty's Junction. Detailed information on current and future uses of the Nellis Air Force Range is available in USAF (1999, all).

DOE uses about 2 percent of the lands associated with the Carlin corridor. The combined Carlin/Caliente corridor enters the Nevada Test Site south of Beatty. Detailed information on current and future uses of the Nevada Test Site is available in DOE (1996f, all).

About 3 percent of the land associated with the Carlin corridor is private. The corridor crosses private roads in the northern part of the route, from Beowawe through Crescent Valley.

Caliente-Chalk Mountain. Most of the lands associated with the Caliente-Chalk Mountain corridor (about 57 percent) are public lands managed by the Ely office of the Bureau of Land Management. Detailed information on land use is available in BLM (1979, all) and BLM (1999a, all).

The U.S. Air Force uses about 16 percent of the lands associated with the Caliente-Chalk Mountain corridor. The corridor enters the Nellis Air Force Range west of Rachel, Nevada, and travels south through the range. Detailed information on current and future uses of the Nellis Air Force Range is available in USAF (1999, all).

DOE uses about 27 percent of the lands associated with the Caliente-Chalk Mountain corridor. The corridor crosses the northern border of the Nevada Test Site and travels to the Yucca Mountain site. Detailed information on current and future uses of the Nevada Test Site is available in DOE (1996f, all).

Less than 1 percent of the lands associated with the Caliente-Chalk Mountain corridor is private. The combined Caliente and Caliente-Chalk Mountain corridor crosses private lands near Caliente.

Jean. Most of the lands associated with the Jean corridor (about 83 percent) are public lands managed by the Las Vegas office of the Bureau of Land Management. Detailed information on land use is available in BLM (1998, all).

DOE uses about 12 percent of the lands associated with the Jean corridor. The corridor enters the Nevada Test Site near the Amargosa Valley traveling north to the Yucca Mountain site. Detailed information on current and future uses of the Nevada Test Site is available in DOE (1996f, all).

About 5 percent of the land associated with the Jean corridor is private. The corridor crosses private lands in the Pahrump Valley.

Valley Modified. Half of the lands associated with the Valley Modified corridor are public lands managed by the Las Vegas office of the Bureau of Land Management. Detailed information on land use is available in BLM (1998, all).

The U.S. Air Force uses about 14 percent of the lands associated with the Valley Modified corridor. The corridor crosses Nellis Air Force Base northeast of Las Vegas and the Nellis Air Force Range near Indian Springs. Detailed information on current and future uses of the Nellis Air Force Range is available in USAF (1999, all).

DOE uses about 33 percent of the lands associated with the Valley Modified corridor. The corridor enters the Nevada Test Site near Mercury, traveling northwest to the Yucca Mountain site. Detailed information on current and future uses of the Nevada Test Site is available in DOE (1996f, all).

The Fish and Wildlife Service manages about 3 percent of the lands associated with the Valley Modified corridor as part of the Desert National Wildlife Refuge, which was established in 1936 for the protection and preservation of desert bighorn sheep. Portions of this refuge overlap the Nellis Air Force Range and are controlled jointly by the Air Force and the Fish and Wildlife Service. Use and public access to the joint-use area of the Desert National Wildlife Refuge and Nellis Air Force Range are restricted by a memorandum of understanding (USAF 1999, Appendix C).

3.2.2.1.2 *Air Quality and Climate*

This section contains information on the existing air quality in areas through which the candidate rail corridors pass. It also provides background on the general climate in those areas.

Air Quality. The Caliente, Carlin, Caliente-Chalk Mountain, and Jean corridors pass through rural parts of Nevada that are either unclassifiable or in attainment for criteria pollutants (EPA 1999c, all). There are no State air-quality monitoring stations in these corridors (NDCNR 1999, pages A1-1 through A1-9).

The Valley-Modified rail corridor crosses central Clark County at the north end of the Las Vegas Valley and continues in a northwest direction toward the Nevada Test Site. The air quality in the part of the corridor that passes through the Las Vegas Valley and extends part of the way to Indian Springs is in nonattainment for particulate matter with a diameter of less than 10 micrometers (PM_{10}). Clark County adopted a plan for demonstrating PM_{10} attainment (Clark County 1997b, all) that includes a request to the Environmental Protection Agency to extend the year for attainment demonstration from 2001 to 2006. The plan includes proposals to reduce emissions of particulate matter from a variety of sources. The Las Vegas Valley is also a nonattainment area for carbon monoxide.

Climate. There are two general climate descriptions for the five rail corridors: one for the three corridors that approach the Yucca Mountain site from the north and one for the two corridors that approach the site from the south or southeast. The Caliente, Carlin, and Caliente-Chalk Mountain corridors approach from the north and cross a number of mountain ranges and valleys with elevations well above 1,500 meters (4,900 feet). Although much of Nevada is arid, in central Nye County the annual precipitation exceeds 20 centimeters (8 inches), and the annual snowfall exceeds 25 centimeters (10 inches); annual precipitation exceeds 40 centimeters (16 inches) in some mountainous areas, and snowfall exceeds 100 centimeters (40 inches) (Houghton, Sakamoto, and Gifford 1975, pages 45, 49, and 52). Occasional brief periods of intense rainfall at rates exceeding 5 centimeters (2 inches) an hour can occur in the summer.

The Jean and Valley Modified corridors approach the Yucca Mountain site from the south where precipitation is generally between 10 and 20 centimeters (4 and 8 inches) per year and snowfall is rare. Occasional brief periods of intense rainfall at rates exceeding 5 centimeters (2 inches) an hour can occur in the summer (Houghton, Sakamoto, and Gifford 1975, pages 45, 49, and 52).

3.2.2.1.3 *Hydrology*

This EIS discusses hydrologic conditions in terms of surface water and groundwater.

3.2.2.1.3.1 Surface Water. Researchers studied the alternative rail corridors for their proximity to sensitive environmental resources, including surface waters and riparian lands (TRW 1999k, Appendixes E, F, G, H, and I). The goal in planning the corridors was to avoid springs and riparian lands by 400 meters (1,300 feet) if possible. Table 3-34 summarizes potential surface-water-related resources along the candidate corridors. It lists resources within the 400-meter corridor or within a 1-kilometer (0.6-mile) region of influence along the corridor.

Potential hydrologic hazards along the rail corridors include flash floods and debris flow. All corridors have potential flash flooding concerns. DOE would design and build a rail line that would be able to withstand a 100-year flood event safely.

3.2.2.1.3.2 Groundwater. Groundwater basins that the candidate rail corridors cross represent part of the potentially affected environment. As described for groundwater in the immediate region of Yucca Mountain (Section 3.1.4.2.1), the State of Nevada has been divided into groundwater basins and sub-basins. The sub-basins are called hydrographic areas. A map of these areas (Bauer et al. 1996, page 543) was overlain with a drawing of the proposed rail corridors to produce a reasonable approximation of the areas that would be crossed by each corridor. Table 3-35 lists results of this effort. The table also lists estimates of the perennial yield for each hydrographic area crossed and if the area is a State Designated Groundwater Basin [a hydrographic area in which the permitted water rights approach or exceed the estimated perennial yield and the water resources are depleted or require additional administration, including a State declaration of preferred uses (municipal and industrial, domestic supply, agriculture, etc.)] (NDWP 1999b, Region 14). These are the areas where additional water demand would be most likely to produce an adverse effect on local groundwater resources. The table indicates that none of the corridors would completely avoid Designated Groundwater Basins. However, the Caliente-Chalk Mountain corridor would cross only two Designated Basins, one at Panaca Valley near the start of the corridor and one at Penoyer Valley where the Caliente and Caliente-Chalk Mountain corridors split.

Table 3-34. Surface-water-related resources along candidate rail corridors.[a]

Rail corridor	Distance from corridor (kilometers)[b]	Feature
Caliente		
Caliente to Meadow Valley	0.5	Springs – two unnamed springs, in Meadow Valley north of Caliente
	Within	Riparian area/stream – corridor crosses and is adjacent to stream and riparian area in Meadow Valley Wash
Meadow Valley to Sand Spring Valley	1.0	Spring – Bennett Spring, 3.2 kilometers southeast of Bennett Pass
	0.05 - 2.6	Springs – group of five springs (Deadman, Coal, Black Rock, Hamilton, and one unnamed) east of White River
	Within	Riparian/river – corridor parallels (and crosses) the White River for about 25 kilometers. August 1997 survey found river to be mostly underground with ephemeral washes above ground.
	0.8	Spring – McCutchen Spring, north of Worthington Mountains
Sand Spring Valley to Mud Lake	0.02	Spring – Black Spring, south of Warm Springs
Mud Lake to Yucca Mountain	Within - 2.5	Springs – numerous springs and seeps along Amargosa River in Oasis Valley
	Within	Riparian area – designated area east of Oasis Valley, flowing into Amargosa Valley
	0.3 - 1.3	Springs – group of 13 unnamed springs in Oasis Valley north of Beatty
	Within - 0.3	Riparian area/stream – Amargosa River, with persistent water and extensive wet meadows near springs and seeps
Carlin		
Beowawe to Austin	0.5	Spring – Tub Spring, northeast of Red Mountain
	0.8	Spring – Red Mountain Spring, east of Red Mountain
	0.9	Spring – Summit Spring, west of corridor and south of Red Mountain
	0.4	Spring – Dry Canyon Spring, west of Hot Springs Point
	0.8	Spring – unnamed spring on eastern slope of Toiyabe Range, southwest of Hot Springs Point
	1.0	Riparian area – intermittent riparian area associated with Rosebush Creek, in western Grass Valley, north of Mount Callaghan
	Within	Riparian/creek – corridor crosses Skull Creek, portions of which have been designated riparian areas
	Within	Riparian/creek – corridor crosses intermittent Ox Corral Creek; portions designated as riparian habitat. An August 1997 survey found creek dry with no riparian vegetation present
	0.1	Spring – Rye Patch Spring, at north entrance of Rye Patch Canyon, west of Bates Mountain
	Within	Riparian area – corridor crosses and parallels riparian area in Rye Patch Canyon
	0.7	Spring – Bullrush Spring, east of Rye Patch Canyon
Austin to Mud Lake	0.8	Springs – group of 35 unnamed springs, about 25 kilometers north of Round Mountain on east side of Big Smokey Valley
	0.6	Riparian area – marsh area formed from group of 35 springs
	0.6	Spring – Mustang Spring, south of Seyler Reservoir
	0.3	Riparian/reservoir – Seyler Reservoir, west of Manhattan
Mud Lake to Yucca Mountain		See Caliente corridor
Caliente-Chalk Mountain		
Caliente to Meadow Valley		See Caliente corridor
Meadow Valley to Sand Spring Valley		See Caliente corridor
Sand Spring Valley to Yucca Mountain	1.0	Spring – Reitman's Seep, in eastern Yucca Flat, east of BJ Wye
	0.8	Spring – Cane Spring, on north side of Skull Mountain on Nevada Test Site
Jean		None identified
Valley Modified		None identified

a. Source: TRW (1999k, Appendixes E, F, G, H, and I).

b. To convert kilometers to miles, multiply by 0.62137.

Table 3-35. Hydrographic areas (groundwater basins) crossed by candidate rail corridors.

Rail corridor	Hydrographic area[a] No.	Hydrographic area[a] Name	Perennial yield (acre-feet)[b,c,d]	Designated Groundwater Basin[e,f]
Caliente				
Caliente to Sand Spring Valley	204	Clover Valley	1,000	No
	203	Panaca Valley	9,000	Yes
	181	Dry Lake Valley	2,500	No
	208	Pahroc Valley	21,000	No
	171	Coal Valley	6,000	No
	172	Garden Valley	6,000	No
Sand Spring Valley to Mud Lake	170	Penoyer Valley (Sand Spring Valley)	4,000	Yes
	173A	Railroad Valley, southern part	2,800	No
	156	Hot Creek	5,500	No
	149	Stone Cabin Valley	2,000	Yes
	141	Ralston Valley	6,000	Yes
Mud Lake to Yucca Mountain	142	Alkali Spring Valley	3,000	No
	145	Stonewall Flat	100	No
	144	Lida Valley	350	No
	146	Sarcobatus Flat	3,000	Yes
	228	Oasis Valley	1,000	Yes
	229	Crater Flat	220	No
	227A	Fortymile Canyon and Jackass Flats	880[g]	No
Carlin				
Beowawe to Austin	54	Crescent Valley	16,000	Yes
	138	Grass Valley	13,000	No
Austin to Mud Lake – Via Big Valley	137B	Big Smokey Valley, northern part	65,000	Yes
	137A	Big Smokey Valley and Tonopah Flat	6,000	Yes
Mud Lake to Yucca Mountain	142 to 227A	See Caliente corridor		
Caliente-Chalk Mountain				
Caliente to Sand Spring Valley	204 to 170	See Caliente corridor		
Sand Spring Valley to Yucca Mountain	158A	Emigrant Valley and Groom Lake Valley	2,800	No
	159	Yucca Flat	350	No
	160	Frenchman Flat	16,000	No
	227A	Fortymile Canyon and Jackass Flats	880[g]	No
Jean				
Jean to Yucca Mountain	165	Jean Lake Valley	50	Yes
	164A	Ivanpah Valley, northern part	700	Yes
	163	Mesquite Valley (Sandy Valley)	2,200	Yes
	162	Pahrump Valley	12,000	Yes
	230	Amargosa Desert	24,000	Yes
	227A	Fortymile Canyon and Jackass Flats	880[g]	No
Valley Modified				
Dike Siding (north of Las Vegas) to Yucca Mountain	212	Las Vegas Valley	25,000	Yes
	211	Three Lakes Valley, southern part	5,000	Yes
	161	Indian Springs Valley	500	Yes
	225	Mercury Valley	250	Yes
	226	Rock Valley	30	No
	227A	Fortymile Canyon and Jackass Flats	880[g]	No

a. Source: Bauer et al. (1996, pages 542 and 543 with corridor map overlay).

b. Source: NDWP (1998, Regions 4, 10, 13, and 14), except hydrographic areas 225 through 230 for which the source is Thiel (1997, pages 6 to 12). The Nevada Division of Water Planning identifies a perennial yield of only 24,000 acre-feet (30 million cubic meters) for the combined area of hydrographic areas 225 through 230 (NDWP 1998, 1999b, hydrographic area 225; NDWP (1999b, hydrographic area 230).

c. Perennial yield is the estimated quantity of groundwater that can be withdrawn annually from a basin without depleting the reservoir.

d. To convert acre-feet to cubic meters, multiply by 1,233.49.

e. Source: NDWP (1999b, Regions 4, 10, 13, and 14).

f. "Yes" indicates the State of Nevada considers the area a Designated Groundwater Basin where permitted water rights approach or exceed the estimated perennial yield and the water resources are being depleted or require additional administration, including a State declaration of preferred uses (municipal and industrial, domestic supply, agriculture, etc.). Designated Groundwater Basins are also referred to as Administered Groundwater Basins.

g. The perennial yield value shown for Area 227A is the lowest estimated value presented in Thiel (1997, page 8) and is further broken down into 370,000 cubic meters (300 acre-feet) for the eastern third of the area and 715,000 cubic meters (580 acre-feet) for the western two-thirds.

There are a number of published estimates of perennial yield for many of the hydrographic areas in Nevada, and they often differ from one another by large amounts. This is the reason for listing a range of perennial yield values in Table 3-10 for the hydrographic areas in the Yucca Mountain region. For simplicity, the perennial yield values listed in Table 3-35 generally come from a single source (NDWP 1998, Regions 4, 10, 13, and 14) and, therefore, do not show a range of values for each area. The hydrographic areas in the Yucca Mountain region (that is, areas 225 through 230) are the exception to perennial yield values from the single source. The perennial yield values for these areas are from Thiel (1997, pages 6 to 12), which compiles estimates from several sources. The table lists the lowest values in that document.

The perennial yield value shown for Area 227A is the lowest estimated value presented in Thiel (1997, page 8) and is further divided into 300 acre-feet (370,000 cubic meters) for the eastern third of the area and 580 acre-feet (715,000 cubic meters) for the western two-thirds.

3.2.2.1.4 *Biological Resources*

The following sections describe biological resources along each of the candidate rail corridors. These environments include habitat types and springs and riparian areas located in a 400-meter (1,300-foot)-wide corridor along each route. Springs and riparian areas are important because they provide habitat for large numbers of plants, animals, and insects. Unless otherwise noted, this information is from the *Environmental Baseline File for Biological Resources* (TRW 1999k, all).

Caliente. From the beginning of the corridor at Caliente to Mud Lake, the Caliente rail corridor crosses Meadow, Dry Lake, Coal, Garden, Sand Spring, Railroad, Reveille, Stone Cabin, and Ralston Valleys. From Mud Lake, the corridor crosses Stonewall and Sarcobatus flats, the upper portion of the Amargosa River, the lower portion of Beatty Wash, and Crater and Jackass Flats. The valleys and flats along the corridor range in elevation from 900 to 1,900 meters (3,000 to 6,200 feet). The corridor also crosses several mountain ranges including the Highland, Seaman, Golden Gate, Worthington, and Kawich mountain ranges at elevations ranging from 1,400 to 1,900 meters (4,600 to 6,200 feet). The Caliente rail corridor is in the southern Great Basin from its beginning at Caliente to near Beatty Wash. The land cover types along this portion of the corridor include salt desert scrub (60 percent) and sagebrush (33 percent). South of Beatty Wash, the corridor crosses into the Mojave Desert. Predominant land cover types from Beatty Wash to Yucca Mountain include creosote-bursage (59 percent), Mojave mixed scrub (22 percent), and salt desert scrub (19 percent) (TRW 1999k, page 3-22).

The only resident threatened or endangered species in the Caliente rail corridor is the desert tortoise, which occurs only along the southern end of the corridor from about Beatty Wash to Yucca Mountain (Bury and Germano 1994, pages 57 to 72). This area is not critical habitat for desert tortoises (50 CFR 17.95) and their abundance in this area is low in relation to other areas in the range of the species in Nevada (Karl 1981, pages 76 to 92; Rautenstrauch and O’Farrell 1998, pages 407 to 411). The only other threatened or endangered species near the corridor is the Federally threatened (State of Nevada protected, Nevada Administrative Code 503.067) Railroad Valley springfish (*Crenichthys nevadae*), which occurs in Warm Springs about 3 kilometers (1.9 miles) north of the corridor in Hot Creek Valley (FWS 1996, all).

Four other species classified as sensitive by the Bureau of Land Management occur in the corridor (NNHP 1997, all). Unnamed subspecies of the Meadow Valley Wash speckled dace (*Rhinichthys osculus* ssp.) and Meadow Valley Wash desert sucker (*Catostomus clarki* ssp. 2) have been found in Meadow Valley Wash north of Caliente. In the Beatty area, the Nevada sanddune beardtongue (*Penstemon arenarius*) has been found on sandy soils 10 kilometers (6 miles) north of Springdale. A number of bats classified as sensitive by the BLM also may occur along the corridor and the southern end of the corridor is in the range of the chuckwalla (*Sauromalus obesis*).

The Caliente rail corridor crosses several areas designated as game habitat (BLM 1979, pages 2-27 through 2-36; BLM 1994b, Maps 9 through 13). A bighorn sheep (*Ovis canadensis*) winter forage area is in the Cedar Range, approximately 13 kilometers (8 miles) west of Crestline, and the corridor also crosses bighorn sheep habitat west of Goldfield near Stonewall Mountain. Mule deer also use the winter forage area in the Cedar Range, and the corridor crosses mule deer use areas in or near the Chief Mountains, Delamar Mountains, Reveille Range, Kawich Range/Quinn Canyon, Stonewall Mountain, and west of the Worthington Mountains. The corridor crosses pronghorn antelope (*Antilocapra americana*) habitat in the Sand Spring, Railroad, Reveille, and Stone Cabin Valleys, and from Mud Lake to Stonewall Mountain. Meadow Valley Wash north of Caliente is classified as habitat for waterfowl.

At least six springs or groups of springs and three streams or riparian areas are within 0.4 kilometer (0.25 mile) of the corridor (TRW 1999k, page 3-23). These might be wetlands or other waters of the United States, as defined in the Clean Water Act, although no formal wetlands delineation has been conducted along the corridor. Black Spring is near the corridor at the north end of the Kawich Range and an unnamed spring is near the corridor at the north end of the North Pahroc Range. An unnamed spring is 0.3 kilometer (0.2 mile) east of the corridor between Mud Lake and Yucca Mountain west of Willow Spring. A series of springs is in the corridor near the Amargosa River in Oasis Valley. The corridor crosses the Meadow Valley Wash south of Panaca. The corridor also crosses the White River between U.S. 93 and Sand Spring Valley and parallels the river for approximately 25 kilometers (16 miles). An August 1997 survey of that portion of the river found it was mostly dry with some standing water in stock waterholes. The corridor crosses the Amargosa River in the north end of the Oasis Valley, in an area designated as a riparian area by the Bureau of Land Management (BLM 1994b, Maps 14 and 15). The corridor also crosses a number of ephemeral streams that might be classified as waters of the United States under Section 404 of the Clean Water Act.

The Caliente rail corridor also crosses eight Bureau of Land Management-designated wild horse or wild horse and burro herd management areas (BLM 1979, pages 2-26 through 2-35; BLM 1994b, Maps 18 and 19). From U.S. Highway 93 to Sand Spring Valley, the corridor passes through a herd management area in the Chief Range. From Sand Spring Valley to Mud Lake, the corridor crosses the Saulsbury, Reveille, and Stone Cabin herd management areas, and from Mud Lake to Yucca Mountain the route crosses the Goldfield, Stonewall, and Bullfrog herd management areas.

Carlin. The Carlin rail corridor crosses Crescent and Grass Valleys, then passes through Big Smokey Valley to Mud Lake. From Mud Lake, the corridor crosses Stonewall and Sarcobatus Flats, the upper portion of the Amargosa River, the lower portion of Beatty Wash, and Crater and Jackass Flats. Elevations along the route range from 900 to 2,200 meters (3,000 to 7,200 feet).

The Carlin rail corridor is in the Great Basin from its start in Beowawe to near Beatty Wash. Land cover types along this portion of the corridor are dominated by salt desert scrub (57 percent), sagebrush (28 percent), and greasewood (7 percent). At Beatty Wash, the corridor crosses into the Mojave Desert. Predominant land cover types from Beatty Wash to Yucca Mountain include creosote-bursage (59 percent), Mojave mixed scrub (22 percent), and salt desert scrub (19 percent) (TRW 1999k, page 3-24).

The only resident threatened or endangered species in the Carlin rail corridor is the desert tortoise, which occurs only along the southern end of the corridor from about Beatty Wash to Yucca Mountain (Bury and Germano 1994, pages 57 to 72). This area is not critical habitat for desert tortoises (50 CFR 17.95) and their abundance in the region is low (Karl 1981, pages 76 to 92; Rautenstrauch and O’Farrell 1998, pages 407 to 411).

Three other species classified as sensitive by the Bureau of Land Management or as protected by Nevada occur along the Carlin rail corridor. A ferruginous hawk (*Buteo regalis*) (also classified as protected by Nevada) nesting area is east of Mount Callaghan. The San Antonio pocket gopher (*Thomomys umbrinus curtatus*) has been found in Big Smokey Valley northwest of the San Antonio Mountains. The Nevada sand dune beardtongue has been found in sandy soils 10 kilometers (6 miles) north of Springdale (NNHP 1997, all). A number of bats classified as sensitive by the Bureau of Land Management might occur along the corridor, and the southern end of the corridor is in the range of the chuckwalla.

The Carlin rail corridor crosses several areas designated as game habitat by the Bureau of Land Management (BLM 1983, Map 3-1; BLM 1994b, Maps 9 to 13; TRW 1999k, page 3-25). The corridor crosses an area designated as sage grouse (*Centrocercus urophasianus*) habitat in western Grass Valley and another at the southeast end of Rye Patch Canyon. The corridor enters pronghorn antelope habitat north of U.S. Highway 50 near Rye Patch Canyon, north of Toquima Range near Hickison summit, along most of Big Smokey Valley, and from Mud Lake to Stonewall Mountain. The corridor crosses mule deer habitat on the west side of Grass Valley, in the Simpson Park Range, and at Stonewall Mountain. The corridor crosses bighorn sheep habitat east of Goldfield and at Stonewall Mountain.

Three springs, seven riparian areas, and one reservoir are within 0.4 kilometer (0.25 mile) of the Carlin corridor (TRW 1999k, page 3-25). These areas might be wetlands or other waters of the United States, as defined by the Clean Water Act, although no formal wetlands delineation has been conducted along the corridor. Rye Patch Spring is on the edge of the corridor at the south end of the Simpson Park Mountains. An unnamed spring is 0.3 kilometer (0.2 mile) east of the corridor between Mud Lake and Yucca Mountain, west of Willow Spring. A series of springs is in the corridor near the Amargosa River in Oasis Valley. Seyler Reservoir is 0.2 kilometer (0.1 mile) from the corridor in the south end of Big Smokey Valley. Five of the riparian areas (Skull, Steiner, and Ox Corral creeks, and Water and Rye Patch canyons) are along the section of the route between Beowawe and Austin at the south end of Grass Valley. Two of these (Steiner and Ox Corral creeks, both at the south end of Grass Valley) are ephemeral and have little or no riparian vegetation where the route crosses them. The corridor crosses the Amargosa River in the north end of the Oasis Valley, in an area designated as a riparian area by the Bureau of Land Management. This corridor also crosses a number of ephemeral streams that might be classified as waters of the United States under Section 404 of the Clean Water Act.

The corridor crosses two wild horse or wild horse and burro herd management areas between Beowawe and Austin (Mount Callaghan and Bald Mountain), one in Big Smokey Valley (Hickison) and three between Mud Lake and Yucca Mountain (Goldfield, Stonewall, and Bullfrog) (BLM 1983, Map 2-4; BLM 1994b, Maps 18 and 19).

Caliente-Chalk Mountain. The Caliente-Chalk Mountain rail corridor begins near Caliente and is identical to the Caliente rail corridor from Caliente to Sand Spring Valley, crossing Meadow, Dry Lake, Coal, and Garden Valleys at elevations ranging from 1,400 to 1,600 meters (4,600 to 5,200 feet). This portion of the corridor also crosses the Highland, Seaman, Golden Gate, and Worthington mountain ranges at elevations of 1,500 to 1,800 meters (4,900 to 5,900 feet). After splitting from the Caliente rail corridor, the Caliente-Chalk Mountain rail corridor proceeds south through Sand Spring and Emigrant Valleys, over Groom Pass, and through Yucca and Jackass Flats to Yucca Mountain. The elevation along this portion of the route ranges from approximately 1,100 to 1,700 meters (3,600 to 5,600 feet).

Predominant land cover types between Caliente and Sand Spring Valley include sagebrush (50 percent) and salt desert scrub (47 percent). The vegetation along the route from Sand Spring Valley to Yucca Flat is typical of the southern portion of the Great Basin. From Yucca Flat to Yucca Mountain, the corridor passes through a zone of transition between the Mojave and Great Basin deserts. The predominant land cover types from Sand Spring Valley to the Yucca Mountain site are blackbrush (50 percent), salt desert scrub (31 percent), and sagebrush (9 percent).

The only resident threatened or endangered species in the Caliente-Chalk Mountain rail corridor is the desert tortoise, which occurs on the Nevada Test Site south of Yucca Flat. This area is not critical habitat for desert tortoises (50 CFR 17.95) and their abundance is low (Rautenstrauch and O'Farrell 1998, pages 407 to 411).

Seven species classified as sensitive by the Bureau of Land Management have been found in the corridor (NNHP 1997, all). Unnamed subspecies of the Meadow Valley Wash speckled dace and Meadow Valley Wash desert sucker have been found in Meadow Valley Wash. Ripley's springparsley (*Cymopterus ripleyi* var. *saniculoides*) has been reported between Sand Spring Valley and Yucca Mountain in Yucca Flat. The largeflower suncup (*Camissonia megalantha*) has been found in the corridor at three locations in Yucca Flat. Beatley's scorpionweed (*Phacelia beatleyae*) also has been reported at two locations in Yucca Flat. The long-legged myotis (*Myotis volans*, a bat) has been found in Jackass Flats and other bats classified as sensitive by the Bureau of Land Management also may occur near the corridor. Chuckwalla may occur in suitable habitat on the Nevada Test Site.

The Caliente-Chalk Mountain rail corridor crosses several areas designated as game habitat by the Bureau of Land Management (BLM 1979, pages 2-26 through 2-35; BLM 1994b, Maps 9, 10, 11). A bighorn sheep winter forage area is in the Cedar Range, approximately 13 kilometers (8 miles) west of Crestline. Mule deer also use the winter forage area in the Cedar Range, and the corridor crosses mule deer use areas in or near the Chief, Delamar, Worthington, and Quinn Canyon mountains. The corridor crosses pronghorn habitat in Sand Spring and Emigrant Valleys. Areas within 0.4 kilometer (0.25 mile) of springs, seeps, and livestock watering developments in Meadow Valley are classified as crucial areas for quail and portions of the area are classified as habitat for waterfowl.

Three springs and two streams occur within 0.4 kilometer (0.25 mile) of the corridor. These areas might be classified as wetlands or other waters of the United States (TRW 1999k, page 3-27), as defined in the Clean Water Act, although no formal wetlands delineation has been conducted. An unnamed spring is near the corridor at the north end of the North Pahroc Range. The corridor crosses Meadow Valley Wash south of Panaca. The corridor crosses the White River between U.S. 93 and Sand Spring Valley and parallels the river for approximately 25 kilometers (16 miles). An August 1997 survey of that portion of the river found it was mostly dry with some standing water in stock waterholes. This corridor also crosses a number of ephemeral streams or washes that might be classified as waters of the United States.

The Caliente-Chalk Mountain rail corridor passes through two wild horse or wild horse and burro herd management areas (BLM 1979, pages 2-42 and 2-43; BLM 1994b, Maps 18 and 19) in the Cedar Mountains south of Panaca and in the Chief Range west of Panaca.

Jean. The Jean rail corridor starts in Ivanpah Valley north of Jean and proceeds west of Wilson Pass to the Pahrump Valley. The corridor continues to the Yucca Mountain site through Pahrump Valley and across the Amargosa Desert and Jackass Flats. This corridor is in the Mojave Desert, with elevations ranging from about 850 to 1,500 meters (2,800 to 4,900 feet).

The predominant land cover types in the corridor are creosote-bursage (59 percent), Mojave mixed scrub (21 percent), and blackbrush (18 percent) (TRW 1999k, page 3-28).

The only resident threatened or endangered species in the Jean rail corridor is the desert tortoise. The entire corridor is in the range of this species (Bury and Germano 1994, pages 57 to 72). Along most of the corridor, especially the western portions from Pahrump to Yucca Mountain, the abundance of desert tortoises is low (Karl 1980, pages 75 to 87; Rautenstrauch and O'Farrell 1998, pages 407 to 411). However, some areas crossed by the corridor in Ivanpah, Goodsprings, Mesquite, and Pahrump Valleys have a higher abundance of tortoises (BLM 1992, Map 3-13). The corridor does not cross areas classified as critical habitat for desert tortoises (50 CFR 17.95).

One location of each of two subspecies of the pinto beardtongue (*Penstemon bicolor bicolor* and *P.b. roseus),* which is classified as sensitive by the Bureau of Land Management, is in the first 5 kilometers (3 miles) of the corridor near Jean (NNHP 1997, all). No other Bureau of Land Management sensitive species have been documented in the corridor, although chuckwalla, gila monsters (*Heloderma suspectus cinctum*), and a number of bat species classified as sensitive probably occur there in suitable habitat.

The Jean rail corridor crosses several areas the Bureau of Land Management designates as game habitat (BLM 1998, Maps 3-7, 3-8, and 3-9). The corridor crosses four areas designated as quail/chukar or quail habitat: at the intersection of State Highway 161, northeast of Goodsprings, south of Potosi Spring, and east of Pahrump. An additional quail habitat area is on the route from the town of Johnnie to Yucca Mountain. Designated mule deer habitat occurs in three places along the corridor: on the southern half of Potosi Mountain, northwest of Goodsprings, and south of the intersection with State Highway 161. Bighorn sheep winter areas occur south of the intersection of the corridor with State Highway 161. Bighorn sheep habitat is in the Wilson Pass area and to the north on Potosi Mountain. The corridor also crosses a potential bighorn sheep migration corridor from winter range in the Devils Hole Hills to historic but currently unoccupied habitat at the west end of the Spring Mountains.

There are no springs, perennial streams, or riparian areas within 0.4 kilometer (0.25 mile) of this corridor. The corridor crosses a number of ephemeral washes that might be classified as waters of the United States under Section 404 of the Clean Water Act.

There are three wild horse and burro herd management areas in the corridor (BLM 1998, Map 2-1). The Red Rock herd management area is southeast of the Spring Mountains and the Wheeler Pass and Johnnie herd management areas are west of the Spring Mountains.

Valley Modified. The Valley Modified rail corridor begins in the northeastern corner of the Las Vegas Valley, crosses the northern edge of the valley south of the Las Vegas Range, and continues northwest toward Indian Springs. The route continues across the southern portion of Three Lakes and Indian Springs Valleys to the Nevada Test Site and passes through Mercury Valley, Rock Valley, and Jackass Flats to the Yucca Mountain site. The corridor ranges in elevation from approximately 700 to 1,100 meters (2,300 to 3,600 feet).

This route is in the Mojave Desert and the predominant land cover types are creosote-bursage (79 percent) and Mojave mixed scrub (16 percent; TRW 1999k, page 3-29).

The only resident threatened or endangered species in the Valley Modified rail corridor is the desert tortoise. The entire corridor is in the range of this species (Bury and Germano 1994, pages 57 to 72). In general, the abundance of tortoises along this corridor through Las Vegas Valley, Indian Springs Valley, and the Nevada Test Site is low (BLM 1992, Map 3-13; Rautenstrauch and O'Farrell 1998, pages 407 to 411). This corridor does not cross areas classified as critical habitat for desert tortoises (50 CFR 17.95). The razorback sucker (*Xyrauchen texanus*), classified as threatened under the Endangered Species Act and as protected under Nevada Administrative Code, has been introduced into ponds at Floyd Lamb State Park, 4.2 kilometers (2.6 miles) south of the corridor (TRW 1999k, page 3-29). Refuge populations of the Pahrump poolfish (*Empetrichthys latos latos*), classified as endangered under the Endangered Species Act and Nevada Administrative Code, has been introduced into ponds in Floyd Lamb State Park and into the outflow of Corn Creek Springs, 4.5 kilometers (2.8 miles) northeast of the corridor (NNHP 1997, all; TRW 1999k, page 3-29).

Two other species classified as sensitive by the Bureau of Land Management occur in the corridor. Three populations of Parish's scorpionweed (*Phacelia parishii*) and a population of Ripley's springparsley have been reported on the Nevada Test Site in Rock Valley. No other Bureau of Land Management sensitive species have been documented in the corridor, although chuckwalla, gila monsters, and a number of bat species probably occur there in suitable habitat.

There are no herd management areas, Areas of Critical Environmental Concern, or designated game habitat in the Valley Modified rail corridor (TRW 1999k, page 3-29; BLM 1998, Maps 3-7, 3-8, and 3-9). No springs or riparian areas occur within 0.4 kilometer (0.25 mile) of this rail corridor. This corridor crosses a number of ephemeral streams or washes that might be classified as waters of the United States under Section 404 of the Clean Water Act.

3.2.2.1.5 *Cultural Resources*

The baseline environmental conditions presented in this section focus on the archaeological and historic resources associated with the candidate rail corridors. This section also discusses Native American interests in relation to two of the corridors. Unless otherwise noted, this information is from the *Environmental Baseline File for Archaeological Resources* (TRW 1999m, all). In addition, information from the *American Indian Perspectives on the Yucca Mountain Site Characterization Project and the Repository Environmental Impact Statement* (AIWS 1998, all) was used.

Archaeological and Historic Resources. Archaeological data from the five rail corridors, including a 0.2-kilometer (0.1-mile)-wide buffer zone on either side of each corridor, are very limited. Based on a records search at the Desert Research Institute in Las Vegas and Reno, and at the Harry Reid Center at the University of Nevada, Las Vegas, archaeological surveys have been conducted in less than 1 percent of the total areas for the Caliente, Jean, and Valley Modified corridors, less than 3 percent of the total area for the Carlin corridor, and less than 5 percent of the total area for the Caliente-Chalk Mountain corridor. Although it is possible to identify areas in a corridor that are most likely to contain cultural resources based on such factors as general land forms and proximity to water, these predictions are highly uncertain and, therefore, are not included in this EIS.

Records indicate that a number of archaeological sites have been identified along the corridors and that some of these sites are recorded as potentially eligible for nomination to the *National Register of Historic Places*. Table 3-36 summarizes this information. The table also lists potentially eligible sites by type. For conservatism, this group includes sites not yet evaluated for eligibility. The sites recorded but not included in the potentially eligible group represent sites that had no recommendations about eligibility to the National Register.

DOE is implementing the stipulations and forms of a Programmatic Agreement (DOE 1988b, all) with the Advisory Council on Historic Preservation to address DOE's responsibilities under Sections 106 and 110 of the National Historical Preservation Act and the Council's implementing regulations. Although not a formal signatory to the Agreement, the Nevada State Historic Preservation Officer has the right at any time, upon request, to participate in monitoring DOE compliance with the Programmatic Agreement. In addition, DOE provides annual reports to the Advisory Council on Historic Preservation and the Nevada State Historic Preservation Officer describing the activities conducted by DOE each year to implement the stipulations of the Programmatic Agreement. This report includes a description of DOE coordinations and consultations with Federal and State agencies and Native American tribes concerning historic and culturally significant properties at Yucca Mountain.

Table 3-36. Number of archaeological sites along candidate rail corridors.

Category[a]	Caliente	Carlin	Caliente-Chalk Mountain	Jean	Valley Modified
Potentially eligible for nomination					
Temporary camps	--[b]	--	3	--	--
Extractive localities	--	--	3	--	--
Processing localities	--	--	--	--	--
Localities	--	1	16	--	--
Caches	--	--	--	--	--
Stations	--	--	--	--	--
Historic sites	--	--	3	--	--
Unknown type	7	20	3	--	7
Total potentially eligible	***7***	***21***	***28***	***0***	***7***
Not evaluated	29	26	6	2	4
Recorded sites (approximate total)	***97***	***110***	***100***	***6***	***19***

a. Section 3.1.6 contains the definitions of site types for potentially eligible for nomination sites (temporary camps, extractive localities, etc.).

b. -- = none identified.

DOE will continue to seek input from the Nevada State Historic Preservation Officer and the Advisory Council on Historic Preservation, and will interact appropriately to meet the reporting and other stipulations of the Programmatic Agreement.

There is some additional information available for the Carlin corridor. The northern part of this corridor is not well known archaeologically. The central part has been the subject of important archaeological and ethnographic investigations. Elston (1986, all) summarizes the region’s prehistory. Archaeological research in Monitor Valley at the Gatecliff Shelter established important chronological data for this part of the Great Basin. In addition, there have been studies of settlement patterns in the Upper Reese River Valley west of the Carlin rail corridor.

Thomas, Pendleton, and Cappannari (1986, all) summarizes ethnographic studies in this region. The Big Smokey Valley, which the Carlin corridor crosses, was part of several ethnographic studies of the Western Shoshone. A part of the Pony Express route crosses the northern end of the Carlin rail corridor.

Native American Interests. Through the American Indian Writers Subgroup of the Consolidated Group of Tribes and Organizations, Native Americans have noted that, while transportation issues are of extreme interest to them, at present they cannot provide specific comments on any of the Nevada transportation project alternatives (AIWS 1998, pages 4-4 to 4-6) due to the absence of systematic ethnographic studies for any of the proposed project areas.

General concerns for potential transportation-related impacts raised by Native Americans include the following:

- Radioactive and hazardous waste transportation could have an adverse impact along rail or highway routes near existing or planned Native American communities, people, businesses, and resources.

- All of the proposed routes being considered pass through the traditional holy lands of the Southern Paiute, Western Shoshone, and Owens Valley Paiute and Shoshone peoples.

- Many of these routes correspond or are adjacent to ancient pathways and complex trail systems known to and used by Native American peoples.

- The Consolidated Group of Tribes and Organizations is aware of important culturally sensitive areas, traditional use areas, sacred sites, and other important resources that fall in the proposed transportation project areas, and will present this information when appropriate in the development of the Nevada transportation system.

These general concerns apply to the proposed rail corridors discussed in this section, and the proposed heavy-haul route alternatives and intermodal transfer station locations discussed in Section 3.2.2.2.5.

Native Americans live in the vicinity of two of the candidate rail corridors:

- *Jean.* The Pahrump Paiute Tribe is a non-Federally recognized tribe without a land base. The tribe consists of about 100 Southern Paiute people living in the Pahrump area (see Section 3.1.6.2). Individual members of the tribe live as close as 5 kilometers (3 miles) from the Jean corridor.
- *Valley Modified.* The Las Vegas Paiute Colony is a Federally recognized tribe consisting of about 100 people living on two separate tribal parcels in southern Nevada. One parcel near downtown Las Vegas consists of about 73,000 square meters (18 acres) of land with 21 homes and various businesses. This parcel is about 11 kilometers (7 miles) from the route of the Valley Modified rail corridor. The other parcel is in the northwest part of the Las Vegas Valley along U.S. 95. It consists of 16 million square meters (4,000 acres) with 12 homes and various business enterprises. This parcel is about 1.6 kilometers (1 mile) from the Valley Modified rail corridor.

3.2.2.1.6 *Socioeconomics*

Section 3.1.7 describes the socioeconomic backgrounds of the three counties (Clark, Lincoln, and Nye) most involved in the corridors. The Carlin corridor includes other counties— Esmeralda, Eureka, and Lander—in addition to Nye County. This section contains baseline socioeconomic information for Eureka, Esmeralda, and Lander Counties.

Socioeconomic effects from the construction of a rail line would be small and, for the most part, short-term. Therefore, the socioeconomic information for Esmeralda, Eureka, and Lander Counties is less detailed than the information for the counties in the repository site region of influence in Section 3.1.7.

Employment. Section 3.1.7.2 contains employment and economic information on Clark, Nye, and Lincoln Counties. Portions of the potential Carlin rail route pass through Esmeralda, Eureka, and Lander Counties. In 1994, Esmeralda, Eureka, and Lander Counties had average labor forces of about 670, 840, and 3,000, respectively, and average unemployment rates of 7.7, 9.5, and 10 percent (Bureau of the Census 1998, all). During the same year, the per capita income of Esmeralda, Eureka, and Lander Counties was about $33,000, $27,000, and $20,000, respectively (NDETR 1999, all). All three of these counties are small in economic terms and have chronically high unemployment.

Population. Section 3.1.7.1 contains population data on Clark, Lincoln, and Nye Counties. This section provides population background for the other counties potentially affected by the Carlin rail corridor (Esmeralda, Eureka, and Lander).

The population of Esmeralda County is 100 percent rural. The 1990 Census population for the county was about 1,300 persons. The two block groups that comprise the county had densities of 0.3 and 0.4 person per square mile. The Esmeralda County population projection for 2000 is about 1,400 (NSDO 1998, Esmeralda).

The population of Eureka County is 100 percent rural. The 1990 Census population of the county was about 1,500. Density at the block group level ranged from 0 to 5.3 persons per square mile. The projected population of Eureka County for 2000 is about 2,100 (NSDO 1998, Eureka).

The population of Lander County is 56 percent urban and 44 percent rural, with the urban population concentrated entirely in Battle Mountain. The 1990 Census population of the county was about 6,300 persons. The projected population of Lander County for 2000 is about 7,700 (NSDO 1998, Lander).

Housing. Section 3.1.7.4 contains housing data on Clark, Lincoln, and Nye Counties. Esmeralda, Eureka, and Lander Counties are rural areas. The housing stock of Esmeralda County in 1990 was about 1,000 units, of which about 590 were occupied (Bureau of the Census 1998, Esmeralda). The housing stock of Eureka County in 1990 was about 820 units, of which about 620 were occupied (Bureau of the Census 1998, Eureka). The housing stock of Lander County in 1990 was about 2,600 housing units, of which about 2,200 were occupied (Bureau of the Census 1998, Lander).

Economy. Section 3.1.7.2 contains employment and economic information on Clark, Lincoln, and Nye Counties. For the Esmeralda, Eureka, and Lander portions of the Carlin corridor. Esmeralda, Eureka, Lander, and Nye are very small counties in economic terms. Esmeralda County is particularly small, smaller even than Lincoln County in earnings and employment. Like Lincoln County, Esmeralda and Lander have lower per capita incomes than other Nevada counties and chronically high unemployment.

Public Services. Section 3.1.7.5 contains information on public services in Clark, Lincoln, and Nye Counties. Esmeralda, Eureka, and Lander Counties are rural areas. Public services (for example, hospitals, libraries, community centers) are available in small communities in the counties (for example, Battle Mountain, Ely, Eureka). Community water and sewer services are available in small communities; wells and septic tanks serve outlying areas.

3.2.2.1.7 *Noise*

Most of the proposed rail corridors pass through unpopulated desert with average day-night background sound levels of 22 to 38 A-weighted decibels (dBA). (A-weighted decibels are explained in Section 3.1.9.1.) However, each candidate corridor passes near small rural communities (see Figures 6-10 through 6-15). Noise levels in rural communities usually range from 40 to 55 dBA. DOE used computerized mapping programs to examine proposed transportation corridors for the presence and proximity to routes that could be designated for the transfer of nuclear material to the Yucca Mountain site. The process involved the examination of computerized maps at very high detail to determine the extent of road grids in communities and major road intersections. The analysis estimated the distance from the proposed rail corridor and the community to determine if the community was in the region of influence for rail transportation.

Caliente. Most of the Caliente corridor passes through undeveloped Bureau of Land Management land where background noise levels range from 22 to 38 dBA (Table 3-30), influenced primarily by wind. Noise levels of 40 to 55 dBA are present in the rural communities along the corridor including Goldfield, Panaca, and Caliente (Table 3-30).

Carlin. The Carlin rail corridor, from its origin at Beowawe to its terminus at Yucca Mountain, including the Monitor Valley option and other options south of Tonopah, traverses mostly unpopulated desert. The only town within 1.6 kilometers (1 mile) of the corridor is Hadley at the southern end of Big Smokey Valley (Monitor Valley option). Noise levels of 40 to 55 dBA are present in rural communities near the corridor, including Goldfield, Tonopah, Austin, and smaller communities between Tonopah and Battle

Mountain (Table 3-30). Occasional noise from military aircraft overflights occurs near the Nellis Air Force Range.

Caliente-Chalk Mountain. Almost half of the 345-kilometer (214-mile) Caliente-Chalk Mountain corridor is on Nellis Air Force Range or Nevada Test Site land; the remainder is on Bureau of Land Management land. Noise levels of 40 to 55 dBA are present in rural communities along the corridor including Panaca and Caliente (Table 3-30). Occasional noise from military aircraft overflights occurs near and in the Nellis Air Force Range.

Jean. The Jean rail corridor, with the Stateline option, passes through Bureau of Land Management land and a small section of private land. A large portion of this proposed corridor passes through unpopulated desert. Noise levels of 40 to 55 dBA are present in small communities along the corridor including Amargosa Valley, Goodsprings, Pahrump, and Jean (Table 3-30). Occasional noise from military aircraft overflights occurs near and in the Nellis Air Force Range.

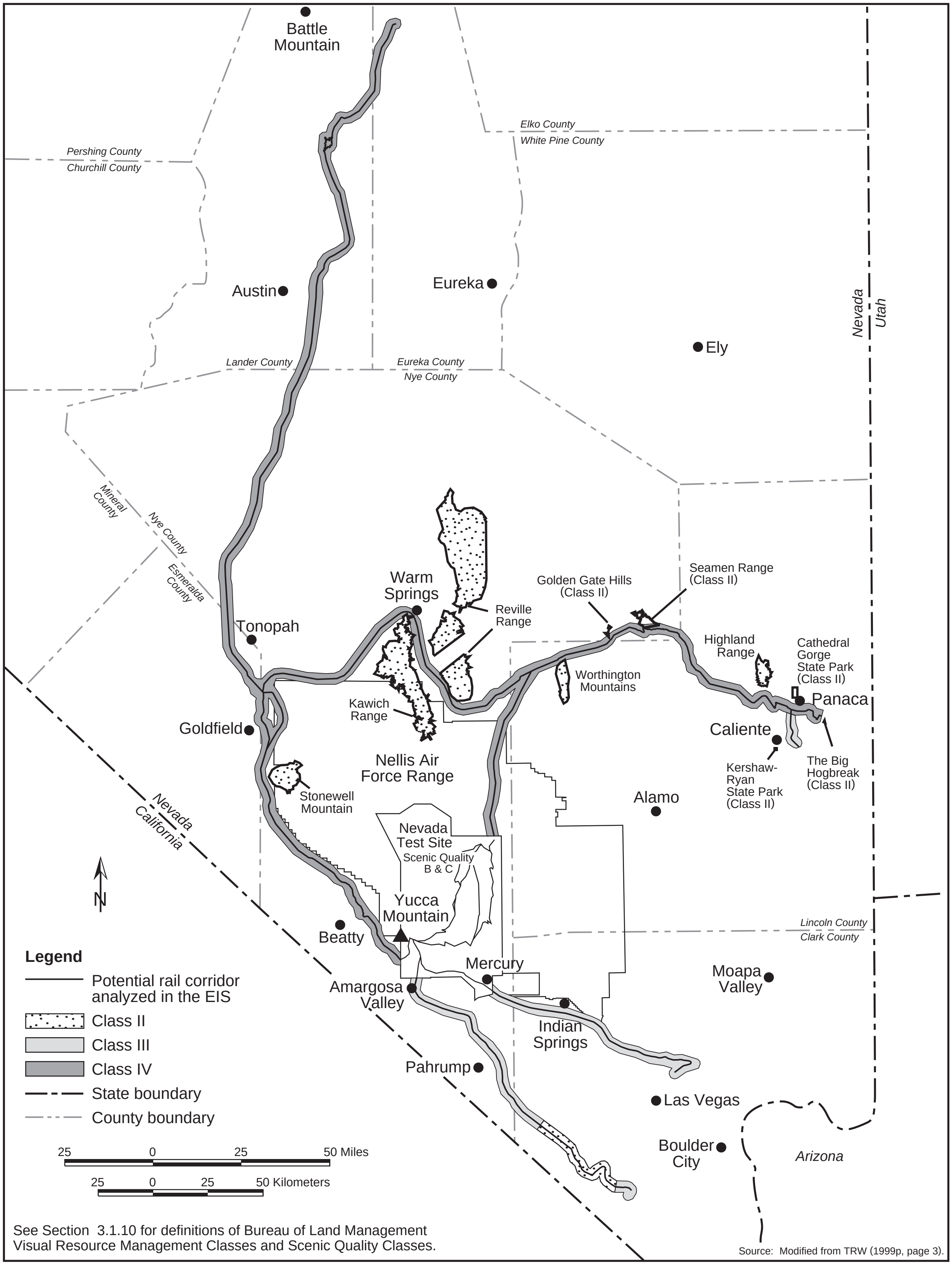
Valley Modified. The Valley Modified rail corridor, and its various options, begins in the northeast end of the Las Vegas Valley, travels west across Nellis Air Force Base and the southern end of the Desert National Wildlife Range, and then closely parallels U.S. 95 to the vicinity of Mercury. Noise levels along stretches of unpopulated desert should range from 22 to 38 dBA, which are typical for a desert environment during calm and windy days (Brown-Buntin 1997, page 7). The corridor would pass 3 kilometers (2 miles) north of Floyd R. Lamb State Park and less than 5 kilometers (3 miles) south of Corn Creek Station, which is part of the Desert National Wildlife Range managed by the Fish and Wildlife Service. Noise levels at the state park and at Corn Creek would probably be only slightly higher than those in an unpopulated desert environment. Noise levels in the northern Las Vegas Valley can be as high as 60 dBA (Table 3-30). Noise levels in Indian Springs and Mercury probably range from 45 to 55 dBA (Table 3-30). Occasional noise from military aircraft overflights occurs near and in the Nellis Air Force Range.

3.2.2.1.8 *Aesthetics*

To assist in the management of public lands under its control, the Bureau of Land Management established land management guidelines based on the visual resources of an area. Visual resources include the natural and manmade physical features that give a particular landscape its character and value as an environmental factor. There are four visual resource classes. Classes I and II are the more highly valued. Class III is moderately valued, and Class IV is of least value. The majority of land in the potential rail corridors is under the jurisdiction of the Bureau of Land Management. The following paragraphs contain aesthetic baseline information for each of the rail corridors. Section 3.1.10 contains more information on the Bureau of Land Management visual resource classes and scenic quality classes. Unless otherwise noted, this information is from the *Environmental Baseline File: Aesthetics* (TRW 1999p, all).

Caliente. Section 3.2.2.1.4 describes the environmental setting along the Caliente corridor. The corridor passes through the Caliente, Schell, Tonopah, and Las Vegas Bureau of Land Management resource areas. The corridor crosses mostly Class IV lands, crosses Class III land near Caliente, and crosses or skirts the edges of Class II lands near Caliente and in the Seaman, Reveille and Kawich ranges, the Golden Gate Hills, and the Worthington Mountains. Lands crossed on the Nevada Test Site have scenic quality ratings of Class B or C (Figure 3-25).

Carlin. Section 3.2.2.1.4 describes the environmental setting of the Carlin corridor. The corridor passes through four Bureau of Land Management resource areas (Elko, Shoshone-Eureka, Tonopah, and Las



See Section 3.1.10 for definitions of Bureau of Land Management Visual Resource Management Classes and Scenic Quality Classes.

Source: Modified from TRW (1999p, page 3).

Figure 3-25. Visual Resource Management classes along the potential rail corridors.

Vegas). The route is on Class IV land from its beginning to the Nevada Test Site border. Lands crossed on the Nevada Test Site have scenic quality ratings of Class B or C (Figure 3-25).

Caliente-Chalk Mountain. Section 3.2.2.1.4 describes the environmental setting of the Caliente-Chalk mountain corridor. The corridor passes through the Caliente and Schell Bureau of Land Management resource areas. The route begins on Class III land east of Caliente, and crosses mostly Class IV land to the border of the Nevada Test Site (Figure 3-25). On the Nevada Test Site the corridor passes through lands with scenic quality Class B or C.

Jean. Section 3.2.2.1.4 describes the environmental setting of the Jean corridor. The corridor crosses the Las Vegas and the Northern and Eastern Mojave Bureau of Land Management resource areas. The Wilson Pass alternate passes through Class II land in Goodsprings Valley, but the rest of the route and west of the Stateline Pass secondary corridor cross Class III land. Approximately 10 kilometers (6 miles) of the route crosses lands in California; that area does not have Visual Resource Management class ratings. Lands crossed on the Nevada Test Site have scenic quality ratings of Class B or C (Figure 3-25).

Valley Modified. Section 3.2.2.1.4 describes the environmental setting of the Valley Modified corridor. The corridor crosses the Las Vegas Bureau of Land Management resource area. The entire route to the boundary of the Nevada Test Site crosses Class III land. Lands on the Nevada Test Site have scenic quality ratings of Class B or C (Figure 3-25).

3.2.2.1.9 *Utilities, Energy, and Materials*

All five primary rail corridors pass through typically remote Nevada countryside but are within the southern Nevada supply chain for the commodities required during construction and operation. Electric power, which would be available to a limited extent at nearby communities or other locations near power lines, probably would not be needed.

3.2.2.1.10 *Environmental Justice*

The five candidate rail corridors would not appreciably affect counties other than those through which they pass. Section 3.1.13 contains information on the minority and low-income communities in the three counties most involved in the corridors (Clark, Lincoln, and Nye). The Carlin corridor is the only route that passes through other counties (Esmeralda, Eureka, and Lander, in addition to Nye). This section contains baseline information on minority and low-income communities in Esmeralda, Eureka, and Lander Counties. Unless otherwise noted, the *Environmental Baseline File for Environmental Justice* (TRW 1999q, all) is the basis for the information in this section.

In 1990, the minority population (White Hispanic, Black, Asian/Pacific Islander, American Indian/ Eskimo/Aleut, and Other) of Esmeralda County was about 210, or 15 percent of the population. No block group in the county exceeded the threshold for identification as a minority community (Bureau of the Census 1992e, Tables P8 and P12). In 1990, there were about 210 persons living in poverty, or 15 percent of the population. No block group in Esmeralda County exceeded the threshold for identification as a low-income community (Bureau of the Census 1992e, Table P117). (Section 3.1.13 defines minority and low-income communities.)

In 1990, the minority population of Eureka County was about 170 persons, or 11 percent. No block group in the county exceeded the threshold for identification as a minority community (Bureau of the Census 1992f, Tables P8 and P12). In 1990, there were about 160 persons living in poverty, or 10 percent of the population. No block group in Eureka County exceeded the threshold for identification as a low-income community (Bureau of the Census 1992f, Table P117).

In 1990, the minority population of Lander County was about 1,100 persons, or 17 percent. No block group in the county exceeded the threshold for identification as a minority community (Bureau of the Census 1992g, Tables P8 and P12). In 1990, there were about 670 persons living in poverty, or 11 percent of the population. No block group in Lander County exceeded the threshold for identification as a low-income community (Bureau of the Census 1992g, Table P117).

Tables 3-37 and 3-38 list by county the number of census block groups with high minority and low-income populations, respectively, that the rail corridors pass through or near. Table 3-39 lists the number of census block groups with high minority populations, high low-income populations, or both that each rail corridor could affect. More than 300 block groups in the City of Las Vegas have either low-income or minority populations. However, the rail corridors do not intersect any of these block groups.

Ninety block groups in the City of Las Vegas have low-income or minority populations or both. However, the rail corridors do not intersect any of these block groups.

Table 3-37. High minority population census block groups near or crossed by rail corridors.

County	Crosses	Near
Eureka	0	0
Lander	0	0
Nye	0	1[a]
Esmeralda	0	0
Clark[b]	2	2
Lincoln	0	0

a. This block group is also a high low-income population block group included in Table 3-39.
b. Outside Las Vegas.

Table 3-38. High low-income population census block groups near or crossed by rail corridors.

County	Crosses	Near
Eureka	0	0
Lander	0	0
Nye	2	3[a]
Esmeralda	0	0
Clark[b]	0	0
Lincoln	0	0

a. One block group is also a high minority population block group included in Table 3-39.
b. Outside Las Vegas.

Table 3-39. High minority and high low-income population census block groups near or crossed by rail corridors.

Corridor	Minority	Low-income	Minority and low-income
Caliente	0	2 near, 3 crossed[a]	0
Carlin	0	2 crossed[a]	1 near[a]
Caliente-Chalk Mountain	0	0	0
Jean	0	1 near[a]	0
Valley Modified	2 crossed[b]	0	0

a. In Nye County.
b. In Clark County outside Las Vegas.

3.2.2.2 Heavy-Haul Truck Route and Intermodal Transfer Station Environmental Baseline

This section discusses the environmental characteristics of counties and land areas that could be affected by the construction and operation of an intermodal transfer station and the operation of heavy-haul trucks carrying spent nuclear fuel and high-level radioactive waste to the Yucca Mountain Repository on Nevada highways. The discussion describes existing environmental conditions in the candidate areas where an intermodal transfer station could be located along Nevada highway routes that could be used for the heavy-haul truck transportation of casks containing spent nuclear fuel and high-level radioactive waste. The candidate locations for an intermodal transfer station are near the communities of Caliente, Sloan, and Jean, and northeast of Las Vegas near Dry Lake on the Union Pacific Railroad Valley siding. These locations can be grouped into three general sites near existing rail lines and highways: near Caliente

(Caliente), southeast of Las Vegas (Sloan/Jean), and northeast of Las Vegas (Apex/Dry Lake). DOE is considering more than one site for the station in each general area.

The heavy-haul trucks would use existing highways that would be upgraded as necessary to accommodate such vehicles. There are five potential heavy-haul routes. Three of these routes (Caliente, Caliente-Chalk Mountain, and Caliente-Las Vegas) are associated with the Caliente intermodal transfer station site. The Sloan/Jean and Apex/Dry Lake intermodal transfer station sites are associated with one candidate route each.

To define the existing (or baseline) environment associated with the three candidate intermodal transfer station locations and along the five candidate heavy-haul truck routes, DOE has compiled environmental information for each of the following subject areas.

- *Land use and ownership:* The condition of the land, current land-use practices, and land ownership information (Section 3.2.2.2.1)
- *Air quality and climate:* The quality of the air and climate (Section 3.2.2.2.2)
- *Hydrology:* The characteristics of surface water and groundwater (Section 3.2.2.2.3)
- *Biological resources:* Important biological resources (Section 3.2.2.2.4)
- *Cultural resources:* Important cultural resources (Section 3.2.2.2.5)
- *Socioeconomic environments:* The existing socioeconomic environments (Section 3.2.2.2.6)
- *Noise:* The existing noise environments (Section 3.2.2.2.7)
- *Aesthetics:* The existing visual environments (Section 3.2.2.2.8)
- *Utilities, energy, and materials:* Existing supplies of utilities, energy, and materials (Section 3.2.2.2.9)
- *Environmental justice:* The locations of low-income and minority populations (Section 3.2.2.2.10)
- *Existing traffic on potential routes for heavy-haul trucks:* Existing traffic in terms of level of service (on the five alternative heavy-haul routes for trucks) (Section 3.2.2.2.11)

The HIGHWAY computer program (Johnson et al. 1993a, all) provided population distributions for the different population zones (urban, rural, and suburban) along the alternative highway routes for heavy-haul trucks. This approach, which Chapter 6 and Appendix J describe in detail, is consistent with the national transportation analysis. DOE expects the waste quantities generated by intermodal transfer station construction to be small in comparison to those from repository construction and operation. Therefore, this discussion does not include existing waste disposal infrastructure along the routes.

DOE evaluated potential impacts of the implementing alternatives in the region of influence for each of the following subject areas. Table 3-40 defines these regions, which are specific to the subject areas in which DOE could reasonably expect to predict potentially large impacts related to heavy-haul infrastructure construction and operations.

Table 3-40. Regions of influence for heavy-haul implementing alternatives.

Subject area	Region of influence
Land use and ownership	Land areas that would be disturbed or for which ownership or use would change as a result of construction and use of an intermodal transfer station and associated highway route
Air quality and climate	The Las Vegas Valley for implementing alternatives in which the construction and operation of an intermodal transfer station and associated heavy-haul route could contribute to the level of carbon monoxide and PM_{10} already in nonattainment of standards, and the atmosphere in the vicinity of sources of criteria pollutants that would be emitted during construction and operations
Hydrology	*Surface water:* areas where construction would take place that would be susceptible to erosion, areas affected by permanent changes in flow, and areas downstream of construction that would be affected by eroded soil or potential spills of construction contaminants
	Groundwater: aquifers that would underlie areas of construction and operations and that could be used to obtain water for construction
Biological resources	Habitat, including jurisdictional wetlands, that could be disturbed by construction and operation of an intermodal transfer station and associated heavy-haul route; habitat, including jurisdictional wetlands, and riparian areas that could be affected by permanent changes in surface-water flow
Cultural resources	Land areas that would be disturbed by the construction and operation of an intermodal transfer station and associated heavy-haul route
Socioeconomic environments	Clark, Lincoln, Nye, and other counties that a route for heavy-haul vehicles could traverse
Occupational and public health and safety	800 meters[a] on each side of the route for heavy-haul vehicles for incident-free transportation, 80-kilometer[b] radius for potential impacts from accidents
Noise	Inhabited commercial and residential areas where noise from the construction and operation of an intermodal transfer station and associated routes for heavy-haul vehicles could be a concern
Aesthetics	The landscapes along potential routes for heavy-haul vehicles and at potential locations for intermodal transfer station where aesthetic quality could be affected by construction and operation
Utilities energy, and materials	Local, regional, and national supply infrastructure that would be required to support construction and operation of an intermodal transfer station and associated route for heavy-haul vehicles
Environmental justice	Varies with the individual resource area

a. 800 meters = 0.5 mile.
b. 80 kilometers = 50 miles.

Caliente. DOE has identified two locations for an intermodal transfer station southwest of the City of Caliente. Table 3-41 lists the ownership of the land involved. Both sites would use a local road to provide access to U.S. 93, the starting point for all three of the heavy-haul routes associated with this intermodal transfer station. Both parcels being considered are in the Rainbow Canyon section of Meadow Valley Wash. This canyon is used for a variety of recreational purposes and is the route of the Union Pacific railroad. Kershaw-Ryan State Park is across Meadow Valley Wash about 0.4 kilometer (0.25 mile) east of the station sites (DOE 1998j, all). The northern parcel includes a wastewater treatment plant.

3.2.2.2.1 *Land Use and Ownership*

This section describes existing land use and ownership for the candidate intermodal transfer station locations and for the candidate heavy-haul routes. Table 3-41 summarizes the estimated land commitment for each site at the three candidate locations. The following paragraphs describe the candidate intermodal transfer station sites.

Sloan/Jean. DOE has identified three possible parcels in the area of Sloan and Jean for potential use as the location of an intermodal transfer station. Each provides adequate land area adjacent to the Union Pacific mainline and has access to existing roadways. Figure 2-29 in Chapter 2 shows these sites. The Bureau of Land Management controls all lands associated with these parcels through its Las Vegas Field Office. Detailed information on land use is available in the *Proposed Las Vegas Resource Management Plan and Environmental Impact Statement* (BLM 1998, all).

Apex/Dry Lake. DOE has identified two land parcels near the intersection of U.S. 93 and Interstate 15 at the Apex and Dry Lake areas northeast of Las Vegas for the possible location of an intermodal transfer station. Both provide adequate land area close to the Union Pacific mainline and have access to existing roadways. The Bureau of Land Management controls all lands associated with these parcels through its Las Vegas Field Office. Detailed information on land use is available in BLM (1998, all). The Moapa Indian Reservation is about 5 kilometers (3 miles) north of the proposed station site. The Dry Lake solar enterprise zone is almost 5 kilometers west of the site (DOE 1996f, page 4-227). The Apex industrial complex is about 16 kilometers (10 miles) to the southwest. Tenants at the complex include Kerr-McGee Chemical Corporation, Chemstar Inc., and Georgia Pacific Corporation. Silver State Disposal operates a waste landfill and waste-processing facilities east of I-15 about 5 kilometers south of the southernmost site.

Table 3-41. Estimated land commitment areas for candidate intermodal transfer station sites (square kilometers).[a,b]

	Commitment		
		Percentage current ownership or control[c]	
Potential location	Total area	BLM	City of Caliente[d]
Caliente			
North Site	0.5		100
South Site	0.25		100
Sloan/Jean			
North Site	3.3	100	
Middle Site	3.1	100	
South Site	1	100	
Apex/Dry Lake			
North Site	3.5	100	
South Site	1	100	

a. Source: TRW (1999d, all).
b. To convert square kilometers to acres, multiply by 247.1.
c. Bureau of Land Management property is public land administered by the Bureau.
d. "City of Caliente" designates patented land owned by the city. A small undesignated portion of both Caliente sites is Bureau of Land Management land.

Routes for Heavy-Haul Trucks. The five possible routes that heavy-haul trucks could use in Nevada—Caliente, Caliente-Las Vegas, Caliente-Chalk Mountain, Sloan/Jean, and Apex/Dry Lake—have existing highways in established rights-of-way. The routes use combinations of highways that, after improvement, heavy-haul trucks could use to travel from an intermodal transfer station at a mainline railroad to the repository.

3.2.2.2.2 *Air Quality and Climate*

This section summarizes existing air quality and climate conditions for each of the candidate intermodal transfer station sites and the five candidate heavy-haul routes.

Air Quality. Both the Caliente and Apex/Dry Lake sites are in areas that are either unclassified or in attainment for criteria pollutants (Fosmire 1999, all). The northern portion of the Sloan/Jean site is in the Las Vegas nonattainment area (Fosmire 1999 all; EPA 1999c, all). There are no State of Nevada air quality monitoring stations at or near either the Caliente or Apex/Dry Lake site (NDCNR 1999, pages A1-1 through A1-9). Clark County operates a particulate matter (PM_{10}) monitoring station at Jean.

The Caliente and Caliente-Chalk Mountain heavy-haul routes both pass through rural parts of Nevada. These areas are either unclassifiable or in attainment for criteria pollutants. The air quality in these areas is good. There are no State of Nevada air quality monitoring stations along these routes (NDCNR 1999, pages A1-1 through A1-9). These statements are also true for the Caliente-Las Vegas, Sloan/Jean, and Apex/Dry Lake routes before they enter and after they leave the Las Vegas Valley.

The air quality in the segments of the Caliente-Las Vegas, Sloan/Jean, and Apex/Dry Lake routes that pass through the Las Vegas Valley and extend part of the way to Indian Springs is in serious nonattainment for particulate matter (PM_{10}) (EPA 1999c, Region 9 PM_{10} Nonattainment Areas). Clark County adopted a plan for demonstrating PM_{10} attainment (Clark County 1997b, all) that includes a request to the Environmental Protection Agency to extend the year for attainment demonstration from 2001 to 2006. The plan includes proposals to reduce emissions of particulate matter from a variety of sources. In addition, the Las Vegas Valley is in serious nonattainment for carbon monoxide. Efforts are being made to bring the area into attainment status.

Climate. This section describes the climate affecting the candidate intermodal transfer station sites and heavy-haul routes.

The community of Caliente and the site of the proposed intermodal transfer station are in Meadow Valley Wash, a relatively narrow canyon that trends to the northeast. Small canyons enter Meadow Valley Wash from the east and west. The diurnal cycle of up-canyon winds during the daytime and down-canyon winds at night minimizes periods of calm conditions. The community of Caliente is about 1,300 meters (4,300 feet) above sea level. Average annual precipitation is about 22 centimeters (9.0 inches); average snowfall is about 35 centimeters (14 inches) (TRW 1997a, page A-14). The maximum single-day precipitation record is 5.4 centimeters (2.1 inches). Occasional brief periods of intense rainfall at rates exceeding 5 centimeters (2 inches) an hour can occur in the summertime. The mean maximum July temperature is 35ºC (95ºF), and the mean minimum January temperature is –8.2ºC (18ºF) (TRW 1997a, page A-14).

The climate at the Sloan/Jean and Apex/Dry Lake station sites is similar to Las Vegas (TRW 1997a, Section 4.1; Houghton, Sakamoto, and Gifford 1975, pages 45, 49, and 52). Precipitation in Las Vegas averages between 10 and 20 centimeters (4 and 8 inches) a year and snowfall is rare. Occasional brief periods of intense rainfall, at rates exceeding 5 centimeters (2 inches) an hour, can occur in the summertime. The maximum recorded daily precipitation is 6.6 centimeters (2.6 inches). The mean maximum July temperature is 40ºC (104ºF), and the mean minimum January temperature is 0.9ºC (33ºF).

The Caliente and Caliente-Chalk Mountain heavy-haul routes, and to a lesser extent the Caliente-Las Vegas route, cross mountain ranges and valleys with elevations well above 1,500 meters (4,900 feet). Although much of Nevada is arid, in central Nevada the annual precipitation exceeds 20 centimeters (8 inches), and the annual snowfall exceeds 25 centimeters (10 inches) in central White Pine and Nye Counties; annual precipitation exceeds 40 centimeters (16 inches) in some mountainous areas, and snowfall exceeds 100 centimeters (40 inches) (Houghton, Sakamoto, and Gifford 1975, pages 45, 49, and 52). The southern portion of the Caliente-Las Vegas route, through Clark County, is at low elevations where precipitation averages between 10 and 20 centimeters (4 and 8 inches) a year and snowfall is rare (Houghton, Sakamoto, and Gifford 1975, pages 45, 49, and 52). Along all three of these routes, occasional brief periods of intense rainfall at rates exceeding 5 centimeters (2 inches) an hour can occur in the summertime.

The Sloan/Jean and Apex/Dry Lake heavy-haul routes are at low elevations where precipitation averages between 10 and 20 centimeters (4 and 8 inches) a year and snowfall is rare (Houghton, Sakamoto, and Gifford 1975, pages 45, 49, and 52). However, occasional brief periods of intense rainfall, at rates exceeding 5 centimeters (2 inches) an hour, can occur in the summertime.

3.2.2.2.3 *Hydrology*

This section describes hydrologic conditions in terms of surface water and groundwater near the candidate intermodal transfer stations and along the candidate heavy-haul shipment routes.

3.2.2.2.3.1 Surface Water. DOE studied each of the candidate intermodal transfer station sites and associated highway routes for their proximity to sensitive environmental resources (TRW 1999k, Appendixes J, K, L, M, N, and O), including surface waters and riparian lands. Table 3-42 summarizes potential surface-water-related resources within a 1-kilometer (0.6-mile) region of influence from the station sites and highway routes that heavy-haul trucks would use. The table lists surface-water-related resources associated with the Caliente intermodal transfer station site and with each of the potential routes starting at that site. No surface-water-related resources were identified in the region of influence for either the Sloan/Jean or Apex/Dry Lake station site, and none were identified along the associated routes.

Intermodal Transfer Station Locations

Caliente. Flood Insurance Rate Maps published by the Federal Emergency Management Agency address the area in Meadow Valley Wash south of Caliente where the two proposed sites for the Caliente intermodal transfer stations are located. The maps (FEMA 1988a, all; FEMA 1988b, all) show two areas on the west side of the Union Pacific rail tracks that match up with the proposed sites. Both areas are outside the inundation boundary of the 100-year flood, but within the boundary of the 500-year flood.

Sloan/Jean. Based on Flood Insurance Rate Maps, the southernmost site proposed for the Jean intermodal transfer station (on the west site of the Union Pacific rail tracks) would be in the same general area as a 100-year flood inundation zone. The flood map (FEMA 1995a, all) shows three separate washes or drainage areas that originate in the area northwest of the intersection of State Route 161 (or State Route 53 on the map) and I-15. From their origins, the washes drain to the southeast, beneath I-15, and join a southwest drainage that parallels the rail tracks until it reaches the Roach Lake area to the south. The southern Jean intermodal transfer station site is in the area where the first southeast-draining channel curves around into a southwest-draining channel. The 100-year flood inundation areas appear to be about 150 meters (500 feet) wide for these drainage channels.

The northern site proposed for the Jean intermodal transfer station is on the east side of the tracks in an area where the map shows no inundation lines (FEMA 1995a, all). In fact, the map identifies this area with a Zone X designation, indicating it is outside the 500-year floodplain.

According to the Federal Emergency Management Agency Map Index for Clark County, Nevada, and Incorporated Areas (FEMA 1995b, all), the northernmost site for this area, the Sloan intermodal transfer station site, is in an area (Panel 32003C2925 D) with no printed map. The Map Index further describes these unprinted areas as Zone X, indicating they are outside the 500-year floodplain.

Apex/Dry Lake. Based on the Flood Insurance Rate Map for the area of the Apex/Dry Lake intermodal transfer station sites (FEMA 1995c, all), both proposed locations are outside any 100-year flood zone. The nearest flood zone identified on the map is for the Dry Lake area west of the sites. At its closest, the inundation area approaches to within about 300 meters (1,000 feet) of I-15, but the intermodal transfer station site would be on the other side (east side) of I-15. The northern site would appear to be at least

Table 3-42. Surface-water-related resources at potential intermodal transfer station sites and along candidate routes for heavy-haul trucks.[a]

Station or route	Distance from station or route (kilometers)[b]	Feature
Caliente station	0.5	Spring – unnamed spring, southwest of Caliente and northwest of station site
	0.2	Riparian/stream – perennial stream and riparian habitat along Meadow Valley Wash
Caliente route		
Caliente to Crystal Springs	0.3	Spring – unnamed, west of Caliente
	0.5	Spring – unnamed, in Newman Canyon
	0.8	Spring – unnamed, in Newman Canyon
Crystal Springs to Rachel	0.01 - 0.07	Spring – Crystal Springs, group of thermal springs near Town of Crystal Springs, flows along road
Rachel to Yucca Mountain (via Tonopah)	0.2	Springs – Twin Springs, 15 kilometers east of Warm Springs
	Within - 0.2	Springs – Warm Springs, group of thermal springs near town of Warm Springs, outflow crosses the route
	0.4	Spring – Fivemile Spring in Stone Cabin Valley
	1.0	Spring – Rabbit Spring, west of Goldfield
	0.1	Spring – unnamed, in upper Oasis Valley, northwest of Beatty
	0.3	Spring – unnamed, in upper Oasis Valley
	0.4	Spring – unnamed, in upper Oasis Valley, northwest of Beatty
	0.4	Spring – unnamed, east of U.S. 95 in upper Oasis Valley
	0.4	Spring – Fleur-de-lis Spring at Springdale
	0.1	Spring – unnamed, east of U.S. 95 in upper Oasis Valley
	0.1	Spring – unnamed, east of U.S. 95 north of Beatty
	0.9	Spring – unnamed, east of U.S. 95, north of Beatty
	0.9	Spring – Gross Spring, east of U.S. 95, north of Beatty
	Within	River – Amargosa River, parallels U.S. 95 for about 23 kilometers near Beatty
	0.2 - 0.3	Springs – group of thermal springs on east border of U.S. 95, north of Beatty
	0.3	Spring – Well Spring, west of U.S. 95, north of Beatty
	0.4	Spring – Ute Spring, north of Beatty
	0.6	Spring – unnamed, west of U.S. 95, north of Beatty
	0.3	Spring – Revert Spring in Beatty
	0.3	Spring – unnamed, east of U.S. 95, south of Beatty
Caliente-Chalk Mountain route		
Caliente to Crystal Springs	0.3	Spring – unnamed, west of Caliente
	0.4	Spring – unnamed, in Newman Canyon
	0.8	Spring – unnamed, in Newman Canyon
Crystal Springs to Rachel	0.01 - 0.07	Spring – Crystal Springs, group of thermal springs near Town of Crystal Springs, flows along road
Rachel to Yucca Mountain (via Nellis Air Force Range and Nevada Test Site)	0.9	Spring – Cane Spring, north of Skull Mountain on Nevada Test Site
Caliente-Las Vegas route		
Caliente to Crystal Springs	0.3	Spring – unnamed, west of Caliente
	0.4	Spring – unnamed, in Newman Canyon
	0.8	Spring – unnamed, in Newman Canyon
Crystal Springs to I-15 (via U.S. 93)	0.7	Spring – Pedretti Seeps, 3.5 kilometers southeast of Crystal Springs
	0.7	Spring – unnamed, west of route, just south of Pedretti Seeps
	0.8	Spring – Deacon Spring, 5 kilometers southeast of State Highway 375
	1.0	Spring – Brownie Spring, 5 kilometers southeast of State Highway 375
	0.1	Spring – Ash Springs, 7 kilometers southeast of State Highway 375, flows under road
	0.7	Spring – Grove Spring, 1.5 kilometers north of Upper Pahranagat Valley
	0.1	Lakes – route parallels Upper and Lower Pahranagat lakes and associated inundated areas (marshes) for about 15 kilometers
	0.1	Spring – unnamed, 0.2 kilometers west of U.S. 93 and Maynard Lake
	0.1	Lake – Maynard Lake, route borders for about 1 kilometer
	0.8	Spring – Coyote Springs, 21.5 kilometers north of junction with State Route 168
U.S. 93/I-15 junction to U.S. 95 (via the proposed northern beltway)		None
U.S. 95 to Yucca Mountain		None
Sloan/Jean station		None identified
Sloan/Jean route		None identified
Apex/Dry Lake station		None identified
Apex/Dry Lake route		None identified

a. Source: TRW (1999k, Appendixes J, K, L, M, N, and O).

b. To convert kilometers to miles, multiply by 0.62137.

300 meters from the inundation zone. Both areas are in Zone X (determined to be outside the 500-year floodplain).

Highway Routes for Heavy-Haul Trucks

Potential hydrologic hazards along a heavy-haul route include flash flooding and debris flow. All routes have potential flash flooding concerns. However, because of the required road upgrades, the robustness of the vehicle and shipping cask, and the en route safeguards (for example, escorts), flash flooding or standing water is not expected to be a serious threat to heavy-haul shipments.

3.2.2.2.3.2 Groundwater. As discussed in relation to the potential rail corridors, all of Nevada has been divided into groundwater basins and sub-basins, with these latter, smaller divisions termed hydrographic areas. The water resource planning and management information generated by the State of Nevada for these hydrographic areas provides the basis for groundwater information presented for both intermodal transfer station locations and the candidate highway routes that would be used by heavy-haul trucks. The following paragraphs provide an overview of the groundwater conditions at these sites and along the associated routes. Water demand at an intermodal transfer station would be small for both construction and operations. Water needs during operations would consist primarily of the needs of the personnel that staff the station. Water needs for construction and operations would be met by trucking water to the site, installing a well, or possibly by connection to a local water distribution system. This demand would be unlikely to cause noticeable change in water consumption rates for the area. Consequently, no baseline water-use information is provided.

Intermodal Transfer Station Locations

Caliente. The two sites southwest of Caliente being considered for the intermodal transfer station are close to one another and are located in Nevada’s Colorado River Basin (designated Hydrographic Region 13). This hydrographic region covers about 32,000 square kilometers (12,000 square miles) and parts of four counties (NDWP 1999b, Region 13). The Colorado River Basin is further divided into 27 hydrographic areas including Lower Meadow Valley Wash (Area 205), where the Caliente sites are located. This area has been assigned a “Designated Groundwater Basin” status, which means that its permitted water rights approach or exceed the estimated perennial yield and its water resources are being depleted or require additional administration. The additional administration normally includes a State declaration of preferred uses (municipal and industrial, domestic supply, agriculture, etc.) for the groundwater from this area.

Sloan/Jean. The Jean sites being considered for the intermodal transfer station are in Nevada’s Central Hydrographic Region (also designated Region No. 10). This is the largest hydrographic region in Nevada, encompassing about 120,000 square kilometers (46,000 square miles) and parts of 13 counties (NDWP 1999b, Region 10). The Central Region has 90 hydrographic areas and sub-areas, including Ivanpah Valley/Northern Part (Area 164A), where the Jean sites are located. This area has also been assigned a Designated Groundwater Basin status. The depth to groundwater in the vicinity of the candidate Jean sites is approximately 150 meters (490 feet) (Thomas, Welch, and Dettinger 1996, Plate 1).

The site near Sloan being considered for the intermodal transfer station is in Nevada’s Colorado River Basin (Hydrographic Region 13), as described for the Caliente sites. The Sloan site is in the hydrographic area designated Las Vegas Valley (Area 212). This area has also been assigned a Designated Groundwater Basin status. The depth to groundwater at Sloan is approximately 240 meters (790 feet) (Thomas, Welch, and Dettinger 1996, Plate 1).

Apex/Dry Lake. The two sites near Apex/Dry Lake being considered for the intermodal transfer station are close to one another and are in Nevada’s Colorado River Basin, as described for the Caliente sites.

The Apex/Dry Lake sites are in the hydrographic area designated Garnet Valley (Area 216). The estimated perennial yield for the groundwater in this area is only 490,000 cubic meters (400 acre-feet), but it is not a Designated Groundwater Basin. The depth to groundwater at Apex/Dry Lake is about 60 meters (200 feet) (Thomas, Welch, and Dettinger 1996, Plate 1).

Highway Routes for Heavy-Haul Trucks

The highway routes in Nevada that heavy-haul trucks could use cross through several hydrographic regions and a greater number of hydrographic areas. To identify groundwater that could potentially be affected, a map of these hydrographic areas (Bauer et al. 1996, page 543) was overlain with a drawing of the proposed highway routes to get a reasonable approximation of the areas that would be crossed. The results of this effort are listed in Table 3-43. This table also lists estimates of the perennial yield for each of the hydrographic areas crossed and if the area is a Designated Groundwater Basin. Basins with this designation are the areas where additional water demand would be most likely to adversely affect local groundwater resources. None of the candidate routes would totally avoid Designated Groundwater Basins. However, the Caliente-Chalk Mountain route would cross only two designated basins: one in the Lower Meadow Valley Wash at the beginning of the route and one at Penoyer Valley where the Caliente and Caliente-Chalk Mountain routes split.

There are a number of published estimates of perennial yield for many of the hydrographic areas in Nevada, and they often differ from one another by large amounts. This is the reason for listing a range of perennial yield values in Table 3-11. For simplicity, the perennial yield values listed in Table 3-43 generally come from a single source (NDWP 1998, Regions 10, 13, and 14) and, therefore, are not ranges of values. The hydrographic areas in the vicinity of Yucca Mountain (that is, Areas 225 through 230) are the exception to perennial yield values coming from the single source. The perennial yield values for these areas come from Thiel (1997, pages 6 to 12), which compiles estimates from several sources. The table lists the lowest values presented in that document.

3.2.2.2.4 *Biological Resources*

The existing biological environments described in this section includes the areas inside the boundaries of the intermodal transfer station sites and within 100 meters (about 330 feet) of the centerline of the heavy-haul routes. It also includes springs within 400 meters (0.25 mile) of the intermodal transfer sites and the routes. The section discusses environmental settings and important biological resources for each candidate station and associated heavy-haul routes. Unless otherwise noted, this information is from the *Environmental Baseline File for Biological Resources* (TRW 1999k, all).

Caliente Intermodal Transfer Station

The 0.7-square kilometer (170-acre) area DOE is considering for the Caliente intermodal transfer station is about 1 kilometer (0.6 mile) southwest of Caliente and less than 500 meters (1,600 feet) west of Meadow Valley Wash. This area is at an elevation of about 1,200 meters (3,900 feet). The land cover types at this site are primarily agricultural—pasture, 88 percent, and salt desert scrub, 12 percent.

No species classified as Federally threatened or endangered, as State protected, or as sensitive by the Bureau of Land Management occur in the proposed location of the Caliente intermodal transfer station. However, two species classified as sensitive by Bureau of Land Management, the Meadow Valley Wash speckled dace and the Meadow Valley Wash desert sucker (*Catostomus clarki* ssp.), occur in the adjacent Meadow Valley Wash (NNHP 1997, all). Nevada also classifies the Meadow Valley Wash desert sucker as sensitive.

Table 3-43. Hydrographic areas (groundwater basins) crossed by candidate routes for heavy-haul trucks.[a]

	Hydrographic area			
Route	Number	Name	Perennial yield[b,c] (acre-feet)[d]	Designated groundwater basin[e,f]
Caliente				
Caliente to Crystal Springs (near Hiko)	203	Panaca Valley	9,000	Yes
	181	Dry Lake Valley	2,500	No
	182	Delamar Valley	3,000	No
Crystal Springs to Rachel	209	Pahranagat Valley	25,000	No
	169A	Tikaboo Valley, Northern Part	1,300	No
Rachel to Yucca Mountain (via Tonopah)	170	Penoyer Valley (Sand Spring Valley)	4,000	Yes
	173A	Railroad Valley, Southern Part	2,800	No
	173B	Railroad Valley, Northern Part	75,000	No
	156	Hot Creek	5,500	No
	149	Stone Cabin Valley	2,000	Yes
	141	Ralston Valley	6,000	Yes
	137A	Tonopah Flat	6,000	Yes
	142	Alkali Spring Valley	3,000	No
	144	Lida Valley	350	No
	146	Sarcobatus Flat	3,000	Yes
	228	Oasis Valley	1,000	Yes
	230	Amargosa Valley	24,000	Yes
	229	Crater Flat	220	No
	227A	Fortymile Canyon and Jackass Flats	880[g]	No
Caliente-Chalk Mountain				
Caliente to Crystal Springs (near Hiko)	203 to 209	See Caliente Route		
Crystal Springs to Rachel	209 to 170	See Caliente Route		
Rachel to Yucca Mountain (via Nellis Air Force Range and Nevada Test Site)	170			
	158A	Emigrant Valley and Groom Lake Valley	2,800	No
	159	Yucca Flat	350	No
	160	Frenchman Flat	16,000	No
	227A	Fortymile Canyon and Jackass Flats	880[g]	No
Caliente-Las Vegas				
Caliente to Crystal Springs (near Hiko)	203 to 209	See Caliente Route		
Crystal Springs (near Hiko) to U.S. 93/I-15 junction at Dry Lake	209			
	210	Coyote Springs Valley	18,000	Yes
	217	Hidden Valley	200	No
U.S. 93/I-15 junction at Dry Lake to U.S. 95 junction	216	Garnet Valley	400	No
U.S. 95 junction to Yucca Mountain	212	Las Vegas Valley	25,000	Yes
	211	Three Lakes Valley, Southern Part	5,000	Yes
	161	Indian Springs Valley	500	Yes
	225	Mercury Valley	250	No
	226	Rock Valley	30	No
	227A	Fortymile Canyon and Jackass Flats	880[g]	No
Sloan/Jean[h]				
Jean to U.S. 95 junction	164A	Ivanpah Valley, Northern Part	700	Yes
	165	Jean Lake Valley	50	Yes
U.S. 95 junction to Yucca Mountain	212 to 227A	See Caliente-Las Vegas route		
Apex/Dry Lake				
U.S. 93/I-15 junction at Dry Lake to U.S. 95 junction	216 to 212	See Caliente-Las Vegas route		
U.S. 95 junction to Yucca Mountain	212 to 227A	See Caliente-Las Vegas route		

a. Source: Bauer et al. (1996, pages 542 and 543 with route map overlay).

b. Perennial yield is the estimated quantity of groundwater that can be withdrawn annually from a basin without depleting the reservoir.

c. Source: NDWP (1998, Regions 10, 13, and 14); for Hydrographic Areas 225 through 230 the source is Thiel (1997, pages 6 to 12). The Nevada Division of Water Planning identifies a perennial yield of only 24,000 acre-feet for the combined area of hydrographic areas 225 through 230 (NDWP 1998, all; NDWP 1999a, page 9).

d. To convert acre-feet to cubic meters, multiply by 1,233.49.

e. "Yes" indicates that the State of Nevada considers the area a Designated Groundwater Basin where permitted water rights approach or exceed the estimated perennial yield, and the water resources are being depleted or require additional administration, including a State declaration of preferred uses (municipal and industrial, domestic supply, agriculture, etc.). Designated Groundwater Basins are also referred to as Administered Groundwater Basins.

f. Source: NDWP (1999b, Regions 10, 13, and 14).

g. The perennial yield value shown for Area 227A is the lowest estimated value in Thiel (1997, page 8), and is accompanied by the additional qualification: 370,000 cubic meters (300 acre-feet) for the eastern third of the area and 720,000 cubic meters (580 acre-feet) for the western two-thirds.

h. The hydrographic areas listed for the Sloan/Jean Route are based on the intermodal transfer station located at Jean. For the Sloan location, the route would begin with Hydrographic Area 212, then proceed as shown.

There is no designated game habitat in this area, but the adjacent Meadow Valley Wash is classified as important habitat for Gambel's quail (BLM 1979, pages 2-34 and 2-35).

There are no springs at the proposed station location, but moist areas in the proposed station location might be wetlands (TRW 1999k, pages 3-35 and 3-36). The adjacent perennial stream and riparian habitat along Meadow Valley Wash also might be classified as a wetlands or other waters of the United States, although there has been no formal wetlands delineation.

Caliente Route. This route passes through the southern Great Basin Desert from the beginning of the route in Caliente to near Beatty. From south of Beatty to Yucca Mountain, the route passes through the Mojave Desert. The predominant land cover types along the entire route are salt desert scrub (49 percent), sagebrush (14 percent), and creosote-bursage (13 percent).

Three threatened or endangered species occur within 100 meters (about 330 feet) of the Caliente heavy-haul route. The Hiko White River springfish (*Crenicthys baileyi grandis*, Federally endangered) occurs in Crystal Springs (FWS 1998, page 16), which is about 75 meters (250 feet) south of State Route 375 near the intersection with U.S. 93. The springs and outflow, which come within about 10 meters (33 feet) of State Route 375, are critical habitat for the Hiko White River springfish (50 CFR 17.95). A population of the Railroad Valley springfish (*Crenicthys nevadae*, Federal threatened) has been introduced into Warm Springs, the outflow of which crosses U.S. Highway 6 (FWS 1996, page 20). The southern part of the route, along U.S. 95 from Beatty to Yucca Mountain, is within the range of the desert tortoise (Bury and Germano 1994, pages 57 to 72). This area is not classified as critical habitat for desert tortoises (50 CFR 17.95), and the relative number of tortoises in this area is low (Karl 1981, pages 76 to 92; Rautenstrauch and O'Farrell 1998, pages 407 to 411).

Six species classified as sensitive by the Bureau of Land Management have been documented within 100 meters (about 330 feet) of the route (NNHP 1997, all). The Pahranagat speckled dace (*Rhinichthys osculus velfier*) occurs in Crystal Springs. The Railroad Valley tui chub (*Gila bicolor* ssp 7) (also classified as sensitive by Nevada) occurs in Twin Spring Slough along State Route 375. The Amargosa toad (*Bufo nelsoni*) and the Oasis Valley speckled dace (*Rhinichthys osculus* ssp 1) (both also classified as protected by Nevada) occur in the Amargosa River and elsewhere in the Oasis Valley. Two bats, the Townsend's big-eared bat (*Corynorhinus townsendii*) and fringed myotis (*Myotis thysanodes*), have been documented near the southern end of the route, and other bats classified as sensitive by the Bureau of Land Management might occur near the route. The chuckwalla lizard (*Sauromalus obesus*) also might occur in suitable habitat along the southern end of the route.

This route crosses eight areas designated as game habitat (BLM 1979, pages 2-27 to 2-36; BLM 1994b, Maps 9, 10, 12, and 13). Portions of Meadow Valley Wash are designated important habitat for Gambel's quail (*Callipepla gambelii*) and waterfowl. The route crosses mule deer habitat in Newman Canyon, in the Pahroc Range, in the Pahranagat Range, and northwest of the Groom Range. It also crosses bighorn sheep habitat in the Pahranagat Range, and pronghorn habitat northwest of the Groom Range and from west of Sand Spring Valley through Railroad, Stone Cabin, and Ralston Valleys.

Nineteen springs or riparian areas within 0.4 kilometer (0.25 mile) of the route might be considered wetlands or other waters of the United States under Section 404 of the Clean Water Act, although no formal wetlands delineation has been conducted. The route is adjacent to Meadow Valley Wash at the proposed location of the intermodal transfer station. There is an unnamed spring near U.S. 93 west of Caliente. Crystal Spring and its outflow are about 10 meters (33 feet) from State Route 375, which also passes within 250 meters (820 feet) of Twin and Warm Springs and crosses their outflows. Fivemile Spring is about 0.4 kilometer from U.S. 6 in Stone Cabin Valley. U.S. 95 passes within 0.4 kilometer of 12 springs or groups of springs in the Oasis Valley and along the Amargosa River, and crosses the

Amargosa River at Beatty. This route also crosses a number of ephemeral streams that might be classified as waters of the United States under Section 404 of the Clean Water Act.

The route also borders the Bureau of Land Management Oasis Valley Area of Critical Environmental Concern, which is designed to protect riparian areas and sensitive species in Oasis Valley south of Springdale (TRW 1999k, page 3-32).

Caliente-Chalk Mountain Route. From Caliente to Crystal Springs, this heavy-haul route crosses the Burnt Spring Range, Dry Lake Valley, Sixmile Flat, and the north end of the South Pahroc Range at elevations from 1,200 to 1,900 meters (3,900 to 6,200 feet). From Crystal Springs to Rachel the route crosses Hancock Summit and Tikaboo Valley at elevations ranging from about 1,300 to 1,700 meters (4,300 to 5,600 feet). From Rachel to Yucca Mountain the route passes through Sand Spring and Emigrant Valleys, and Yucca Flat, Frenchman Flat, and Jackass Flats, at elevations from 1,700 to 1,900 meters (5,600 to 6,200 feet). Along the entire route, the predominant land cover types are salt desert scrub (37 percent), blackbrush (16 percent), sagebrush (11 percent), and creosote-bursage (10 percent).

Two resident threatened or endangered species occur within 100 meters (about 330 feet) of the Caliente-Chalk Mountain heavy-haul route. The Hiko White River springfish (*Crenichthys baileyi grandis*, Federally endangered) occurs in Crystal Springs (FWS 1998, page 16). The springs and outflow, which come within about 10 meters (33 feet) of State Route 375, are critical habitat for the Hiko White River springfish (50 CFR 17.95). The part of the route from the northern end of Frenchman Flat to Yucca Mountain is within the range of the desert tortoise (Rautenstrauch, Brown, and Goodwin 1994, all). This area is not classified as critical habitat for desert tortoises (50 CFR 17.95), and the relative abundance of tortoises in this area is low (Rautenstrauch and O’Farrell 1998, pages 407 to 411).

Three species classified as sensitive by the Bureau of Land Management occur within 100 meters (about 330 feet) of this route (NNHP 1997, all). The Pahranagat speckled dace occurs in Crystal Springs, Ripley’s springparsley (*Cymopterus ripleyi* var. *saniculoides*) occurs in a number of locations in Yucca Flat on the Nevada Test Site, and the fringed myotis has been observed in Fortymile Wash on the Nevada Test Site. A number of bats classified as sensitive by the Bureau of Land Management might occur along the route and the southern end of the route is within the range of the chuckwalla.

This route crosses six areas designated as game habitat (BLM 1979, pages 2-27 to 2-36; BLM 1994b, Maps 9, 10, 12, and 13). Meadow Valley Wash is designated important habitat for Gambel’s quail and waterfowl. The route crosses mule deer habitat in four areas: west of Caliente, near Pahroc Summit Pass, in the Pahranagat Range, and in the Groom Range. It also crosses bighorn sheep habitat in the Pahranagat Range.

Three springs or riparian areas within 0.4 kilometer (0.25 mile) of the route might be wetlands or other waters of the United States under Section 404 of the Clean Water Act, including Meadow Valley Wash, an unnamed spring near U.S. 93 west of Caliente, and Crystal Springs and its outflow. No formal wetlands delineation has been conducted along this route. This route also crosses a number of ephemeral streams or washes that might be classified as waters of the United States under Section 404 of the Clean Water Act.

Caliente-Las Vegas Route. From Caliente to Crystal Springs, this candidate route crosses the Burnt Spring Range, Dry Lake Valley, Sixmile Flat, and the north end of the South Pahroc Range at elevations from 1,200 to 1,900 meters (3,900 to 6,200 feet). From Crystal Springs to Las Vegas, the route parallels the White River through Pahranagat Valley, and then through Coyote Springs, Hidden, Dry Lake, Las Vegas, Mercury, and Rock Valleys, and crosses Jackass Flats to Yucca Mountain. Elevations along the section from Crystal Springs to Yucca Mountain range from 610 to 1,200 meters (2,000 to 3,900 feet). Along the route the predominant land cover types are creosote-bursage (62 percent) and Mojave mixed scrub (16 percent).

Three resident threatened or endangered species occur within 100 meters (about 330 feet) of the Caliente-Las Vegas heavy-haul route. The section of the route from about Alamo to Yucca Mountain is within the range of the threatened desert tortoise (Bury and Germano 1994, pages 57 to 72). An approximately 100-kilometer (60-mile) section of U.S. 93 from Maynard Lake south to a point approximately 6 kilometers (4 miles) north of I-15 is critical habitat for the desert tortoise (50 CFR 17.95). The relative abundance of desert tortoises along the remainder of the route through Las Vegas Valley, Indian Springs Valley, and the Nevada Test Site is low (BLM 1992, Map 3-13; Rautenstrauch and O'Farrell 1998, pages 407 to 411). The White River springfish (*Crenichthys baileyi baileyi*, Federally endangered and Nevada protected) has been found in Ash Springs, less than 100 meters from U.S. 93 in northern Pahranagat Valley (FWS 1998, pages 12 to 14). The route crosses the outflow of Ash Springs, which is designated critical habitat for the White River springfish (50 CFR 17.95). The Pahranagat roundtail chub (*Gila robusta jordani*, Federally endangered and Nevada protected) occurs in Ash Springs, the outflow, and throughout Pahranagat Creek, but now is restricted to an approximately 3.5-kilometer (2.2-mile) length of Pahranagat Creek and approximately 2.5 kilometers (1.6 mile) of irrigation ditch in the area (FWS 1998, pages 11 to 12).

Nine other species classified as sensitive by the Bureau of Land Management have been documented within 100 meters (about 330 feet) of the route (NNHP 1997, all). The Pahranagat speckled dace occurs in Ash Springs. The Pahranagat pebblesnail (*Fluminicola merriami*), Pahranagat naucorid (*Pelocoris shoshone shoshone*), and the grated tryonia (*Tryonia clathrata*) occur in Ash Springs, and the Pahranagat Valley montane vole (*Microtus montanus fucosus*) has been observed near the route in Pahranagat National Wildlife Refuge. In addition, pinto beardtongue (*Penstemon bicolor bicolor* and *P. b. roseus*) occurs along U.S. 93 north of I-15, Ripley's springparsley and Parish's scorpionweed (*Phacelia parishii*) occur adjacent to Jackass Flats Road in eastern Rock Valley, and the fringed myotis has been observed in Fortymile Wash on the Nevada Test Site. A number of other bats classified as sensitive by the Bureau of Land Management occur along the route and most of the route south from Pahranagat Valley is within the range of the chuckwalla and gila monster (*Heloderma suspectus*).

Seven springs, streams, or lakes less than 0.4 kilometer (0.25 mile) from the route might be classified as wetlands under Section 404 of the Clean Water Act, including Meadow Valley Wash, Ash Springs and its outflow, unnamed springs on U.S. 93 west of Caliente and near Maynard Lake, Upper and Lower Pahranagat lakes and their associated marshes, and Maynard Lake. This route also crosses a number of ephemeral streams that might be classified as waters of the United States under Section 404 of the Clean Water Act.

The route crosses eight areas designated as game habitat (BLM 1979, pages 2-26 to 2-35; BLM 1998, Maps 3-7 to 3-9). Meadow Valley Wash and much of Pahranagat Valley are designated as habitat for Gambel's quail and waterfowl, and areas along U.S. 93 north of I-15 are designated as quail habitat. U.S. 93 crosses mule deer habitat west of Caliente and around Maynard Lake, two bighorn sheep migration routes, and crucial bighorn sheep habitat north of the U.S. 93 and I-15 junction.

Sloan/Jean Station and Route

The area that DOE is considering for the Sloan/Jean intermodal transfer station is in Ivanpah Valley. DOE is considering three sites in this valley: southwest of Sloan [3.2 square kilometers (800 acres)], northeast of Jean [3 square kilometers (750 acres)], and east of Jean [1 square kilometer (250 acres)]. These sites are at an elevation of about 910 meters (3,000 feet) and have vegetation typical of the Mojave Desert. The predominant land cover type is creosote-bursage (97 percent). Elevations along the associated Sloan/Jean heavy-haul route range from about 700 to 1,100 meters (2,300 to 3,600 feet). Predominant land cover types along the route include creosote-bursage (78 percent), Mojave mixed scrub (12 percent), and urban development (9 percent).

The three sites that DOE is considering for the Sloan/Jean intermodal transfer station are in the range of the threatened desert tortoise. The abundance of tortoises generally is moderate to high in Ivanpah Valley in relation to other areas in Nevada (Karl 1980, pages 75 to 87; BLM 1992, Map 3-13). This area is not critical habitat for desert tortoises (50 CFR 17.95).

One species classified by the Bureau of Land Management as sensitive, and by the State of Nevada as protected, occurs in the candidate Sloan/Jean station sites (NNHP 1997, all). The pinto beardtongue (*Penstemon bicolor* ssp. *roseus)* has been observed on the site southwest of Sloan and on the site east of Jean. There are no important game habitats (BLM 1998, Maps 2-1, 3-7, 3-8, and 3-9) and no springs, riparian areas, or other potential wetlands within 0.4 kilometer (0.25 mile) of these sites (TRW 1999k, page 3-36).

The only resident threatened or endangered species along the Sloan/Jean heavy-haul route is the desert tortoise. The entire route is within the range of the desert tortoise (Bury and Germano 1994, pages 57 to 72). The abundance of tortoises along the first part of the route in Ivanpah Valley is moderate to high in relation to other areas in Nevada (BLM 1992, Map 3-13). The abundance of tortoises along the remainder of the route through Las Vegas Valley, Indian Springs Valley, and the Nevada Test Site generally is low to very low (BLM 1992, Map 3-13; Rautenstrauch and O'Farrell 1998, pages 407 to 411). This route does not cross areas classified as critical habitat for desert tortoises (50 CFR 17.95).

Four species classified as sensitive by the Bureau of Land Management have been documented within 100 meters (about 330 feet) of this route (NNHP 1997, all). The pinto beardtongue (*Penstemon bicolor bicolor* and *P. b. roseus*) occurs in the Las Vegas Valley. Ripley's springparsley and Parish's scorpionweed occur adjacent to Jackass Flats Road in eastern Rock Valley on the Nevada Test Site, and the fringed myotis has been observed near the Yucca Mountain in Fortymile Wash. A number of other bats classified as sensitive by the Bureau of Land Management might occur along the route, and the route is within the range of the chuckwalla and gila monster.

The route crosses ephemeral streams that might be classified as waters of the United States under Section 404 of the Clean Water Act. The route does not cross designated game habitats (BLM 1998, Maps 3-7 to 3-9) and there are no springs, riparian areas, or other potential wetlands within 0.4 kilometer (0.25 mile).

Apex/Dry Lake Station and Route

The area that DOE is considering for the Apex/Dry Lake intermodal transfer station is northeast of Las Vegas in Dry Lake Valley. The Department is considering three sites in this area, two to the west of I-15 [0.18 and 3.6 square kilometers (45 and 890 acres)] and one east of the Interstate [0.95 square kilometer (240 acres)]. The elevation of these sites is about 610 meters (2,000 feet). This area is in the Mojave Desert and the predominant land cover type is creosote-bursage (100 percent). The associated route starts at the station area and crosses Las Vegas, Mercury, and Rock Valleys and Jackass Flats to Yucca Mountain at elevations ranging from 700 to 1,100 meters (2,300 to 3,600 feet). Predominant land cover types along this route are creosote-bursage (77 percent) and Mojave mixed scrub (16 percent).

The only resident threatened or endangered species along the Apex/Dry lake heavy-haul route is the desert tortoise. The entire route passes through desert tortoise habitat (Bury and Germano 1994, pages 57 to 72), and the relative abundance of tortoises along this route through the Las Vegas Valley, Indian Springs Valley, and the Nevada Test Site generally is low (BLM 1992, Map 3-13; Rautenstrauch and

O'Farrell 1998, pages 407 to 411). This route does not cross areas classified as critical habitat for desert tortoises (50 CFR 17.95).

Three species classified as sensitive by the Bureau of Land Management have been documented within 100 meters (about 330 feet) of this route (NNHP 1997, all). Ripley's springparsley and Parish's scorpionweed occur adjacent to Jackass Flats Road on the Nevada Test Site in eastern Rock Valley, and the fringed myotis has been observed near Yucca Mountain in Fortymile Wash. A number of other bats classified as sensitive by the Bureau of Land Management might occur along the route, and the route is within the range of the chuckwalla and gila monster.

The route crosses ephemeral streams that might be classified as waters of the United States under Section 404 of the Clean Water Act. The route does not cross designated game habitat (BLM 1998, Maps 3-7 to 3-9). There are no springs, riparian areas, or other potential wetlands within 0.4 kilometer (0.25 mile) of the intermodal transfer station area or the route.

3.2.2.2.5 *Cultural Resources*

The description of environmental conditions in this section focuses on archaeological and historic resources associated with the candidate intermodal transfer station areas and the associated heavy-haul routes. In addition, this section discusses Native American interests in relation to several of the heavy-haul truck routes. Unless otherwise noted, the *Environmental Baseline File for Archaeological Resources* (TRW 1999m, all) is the basis for the information in this section.

Archaeological and Historic Resources. Archaeological data from the candidate intermodal transfer station sites are very limited. Based on a records search at the Desert Research Institute in Las Vegas and Reno and at the Harry Reid Center at the University of Nevada, Las Vegas, four, seven, and two archaeological sites have been recorded at the Caliente, Sloan/Jean, and Apex/Dry Lake sites, respectively. These sites have not been evaluated with regard to their potential eligibility for listing in the *National Register of Historic Places.*

There is some relevant information about the candidate Caliente intermodal transfer location. Various cultural groups have occupied the Caliente/Meadow Valley Wash area for at least the past 11,000 years (Fowler et al. 1973, all; Fowler and Madsen 1986, all). Previously recorded prehistoric archaeological resources in the region include scattered lithic artifacts, rock shelters, temporary camps, and rock art (Kautz and Oothoudt 1992, all). Historic archaeological resources in the region typically consist of remains of late nineteenth- and early twentieth-century activities such as mining and ranching. The Caliente Railroad Depot is listed in the *National Register of Historic Places.*

In general, there are little or no current data for the presence of cultural resource sites in the existing road rights-of-way; with the exception of one route, field inventories have not been conducted. A few archaeological surveys have been conducted along or near the Caliente-Chalk Mountain heavy-haul route. An archival search of a 0.2-kilometer (0.1-mile)-wide corridor along this route identified five archaeological sites. Two of these sites are not considered eligible for inclusion on the National Register; the other three have not been evaluated.

Native American Interests. Section 3.2.2.1.5 discusses general Native American concerns about transportation routes.

The Moapa Paiute Indian Tribe is a Federally recognized tribe of about 290 Southern Paiute people. The tribe's reservation near the town of Moapa on I-15 and the Union Pacific Railroad's mainline contains homes and business enterprises. The reservation is about 6 kilometers (4 miles) east of the Caliente-Las

Vegas heavy-haul route and about 5 kilometers (3 miles) north of the Apex/Dry Lake station site (AIWS 1998, Chapter 4).

The Las Vegas Paiute Colony is a Federally recognized tribe of about 100 people living on two separate tribal parcels in southern Nevada (AIWS 1998, Chapter 4). One parcel near downtown Las Vegas consists of 73,000 square meters (18 acres) of land with 21 homes and various business enterprises. This parcel is about 11 kilometers (7 miles) from an overlapping portion of the Caliente-Las Vegas, Sloan/Jean, and Apex/Dry Lake heavy-haul routes (northern Las Vegas beltway for the Las Vegas and Apex/Dry Lake routes, and western Las Vegas beltway for the Sloan/Jean route). The other parcel is in the northwest part of the Las Vegas Valley along U.S. 95. It consists of 16.2 square kilometers (4,000 acres) with 12 homes and various business enterprises. An overlapping portion of the Caliente-Las Vegas, Sloan/Jean, and Apex/Dry Lake heavy-haul routes goes through a 1.6-kilometer (1-mile) corner of this parcel.

3.2.2.2.6 *Socioeconomics*

The candidate heavy-haul intermodal transfer station sites and routes would not appreciably affect counties other than those in which the facilities were located. Section 3.1.7 contains socioeconomic background information on the three counties (Clark, Lincoln, and Nye) most involved in the heavy-haul routes. The Caliente heavy-haul route is the only route involving a county outside the region of influence; it passes through Esmeralda County in addition to Lincoln and Nye Counties. Section 3.2.2.1.6 contains socioeconomic information for Esmeralda County.

3.2.2.2.7 *Noise*

Most of the proposed routes pass through unpopulated desert with background noise levels of 22 to 38 dBA. All routes pass through small rural communities (see Figures 6-10 through 6-15). Noise levels in rural communities usually range from 40 to 55 dBA (Table 3-30). Traffic noise along highways generally ranges from 5 to 15 dBA above natural background levels (EPA 1974, page D.5). Roadside noise levels are highly dependent on the volume of traffic, the road surface, composition of the traffic (trucks, automobiles, motorcycles, etc.), and vehicle speed. Measurements taken 90 meters (300 feet) from the centerline of U.S. 95 just outside the Nevada Test Site ranged from 45 to 55 dBA (Brown-Buntin 1997, pages 8 and 9). Less traveled rural highways would have lower 1-hour noise levels, possibly as low as 33 dBA at 90 meters (300 feet) from the centerline. Communities potentially affected by the candidate intermodal transfer stations and associated heavy-haul routes were identified by examining the proposed route of each corridor and estimating if construction or heavy-haul vehicle noise could affect area communities. Occasional noise from passing military aircraft occurs near and in the Nellis Air Force Range.

Caliente Station

DOE is considering two parcels of land in Meadow Valley Wash several miles south of Caliente for the intermodal transfer station. A water treatment plant adjacent to the larger parcel could contribute to background noise levels. The other parcel of land has no buildings. Estimated noise levels range from 22 to 45 dBA depending on traffic volume (based on Table 3-30).

Caliente Route. The Caliente heavy-haul route goes from Caliente to the Yucca Mountain site, passing through or near the towns of Caliente, Tonopah, Goldfield, Beatty, Hiko, Rachel, Warm Springs, and Amargosa Valley. Estimated noise levels in these communities range from 40 to 55 dBA (based on Table 3-30). This longest route travels on existing highways through predominantly Bureau of Land Management land.

Caliente-Chalk Mountain Route. The Caliente-Chalk Mountain heavy-haul route would use existing paved roads to a point in western Lincoln County where it would turn south through the Nellis Air Force Range and the Nevada Test Site. Caliente and Rachel are the only towns through which the heavy-haul route would pass. Estimated noise levels in these communities would range from 45 to 55 dBA (based on Table 3-30).

Caliente-Las Vegas Route. The Caliente-Las Vegas heavy-haul route follows U.S. 93 from Caliente to I-15, then into Las Vegas primarily on Bureau of Land Management land. The section of the route on the planned Northern Beltway to U.S. 95 would have the highest noise levels, biased toward the 55-dBA level. Traffic noise levels along U.S. 95 would range from 45 to 55 dBA (Brown-Buntin 1997, pages 8 and 9). Estimated noise levels in Caliente, Alamo, Indian Springs, and Mercury range from 40 to 55 dBA (based on Table 3-30).

Sloan/Jean Station

DOE is considering three parcels of land in the Sloan/Jean area. Some residences, a quarry, and a concrete plant are next to the northernmost site. The eastern parcel is along I-15 adjacent to several commercial enterprises. The third parcel is in the community of Jean and is close to two large casinos. Estimated noise levels in these areas, which are greater than levels encountered in unpopulated desert areas, range from 40 to 55 dBA (based on Table 3-30).

Sloan/Jean Route. The Sloan/Jean heavy-haul route would use existing paved roads from the intermodal transfer station to the Yucca Mountain site, and would pass through a number of small towns and the western and northern portions of the Las Vegas Valley. Existing noise levels in the Las Vegas Valley probably range from 52 to 74 dBA; estimated noise levels in Indian Springs and Mercury range from 40 to 55 dBA (based on Table 3-30).

Apex/Dry Lake Station

The candidate location for the Apex/Dry Lake intermodal transfer station is in an unpopulated part of Dry Lake Valley. Existing noise levels are probably somewhat higher than typical levels for a desert environment because of vehicles that travel along I-15 in this area. Depending on local meteorological conditions, noise from the Apex industrial site and passing trains would add to the existing acoustic environment at this site. The northern boundary of one possible location for an intermodal transfer station in the Apex/Dry Lake area is about 3 kilometers (2 miles) south of the Moapa Indian Reservation.

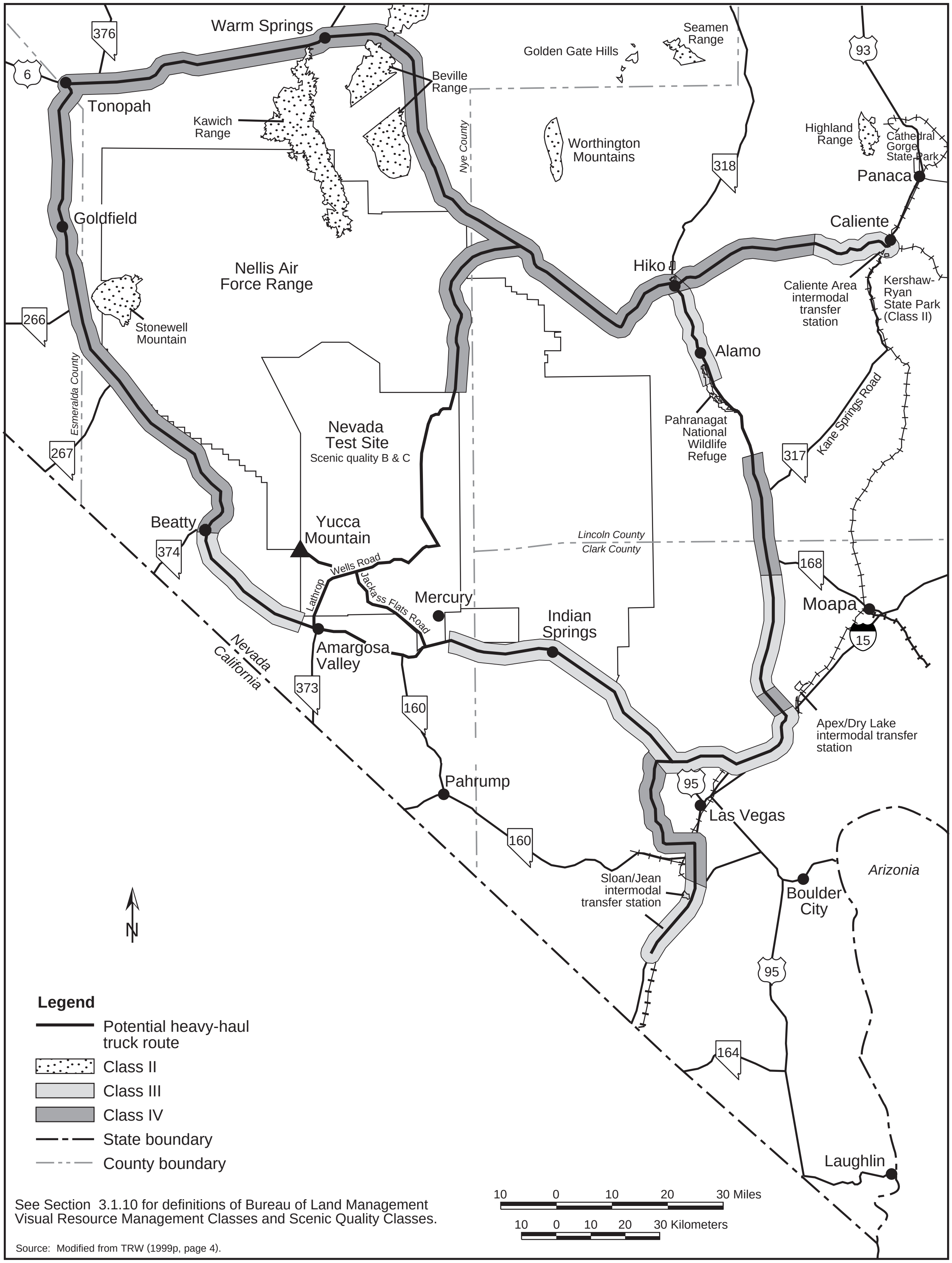
Apex/Dry Lake Route. The Apex/Dry Lake heavy-haul route would use existing paved roads from the intermodal transfer station to the Yucca Mountain site. It would pass through a number of small communities and the north end of the Las Vegas Valley. Existing noise levels in Indian Springs and Mercury probably range from 40 to 55 dBA (Table 3-30). Estimated noise levels in the Las Vegas Valley range from 52 to 74 dBA (based on Table 3-30).

3.2.2.2.8 *Aesthetics*

This section describes the existing aesthetic qualities associated with each of the intermodal transfer station sites and associated heavy-haul routes. Section 3.1.10 provides additional description of Bureau of Land Management visual resource classes and scenic quality classes. Unless otherwise noted, this information is from the *Environmental Baseline File: Aesthetics* (TRW 1999p, all).

Caliente Station

The proposed location for the Caliente facility is southeast of Caliente, on the western edge of Meadow Valley Wash. This area is in the Caliente Bureau of Land Management resource area and is classified Class III (Figure 3-26).



See Section 3.1.10 for definitions of Bureau of Land Management Visual Resource Management Classes and Scenic Quality Classes.

Source: Modified from TRW (1999p, page 4).

Figure 3-26. Visual Resource Management classes along the potential routes for heavy-haul trucks.

Caliente Route. Section 3.2.2.2.4 describes the environmental setting along the Caliente route. The route passes through the Caliente, Schell, Tonopah, and Las Vegas Bureau of Land Management resource areas. From Caliente to the south end of the Burnt Springs Range the route passes through Class III land, and then through Class IV land to Rachel. From Rachel to Tonopah the route crosses Class III land except portions of the Reveille and Kawich Ranges near Warm Springs, which are Class II areas. From Tonopah to Beatty, the route crosses Class IV land, then Class III land from Beatty to the Nevada Test Site boundary. Lands crossed on the Nevada Test Site have scenic quality ratings of Class B or Class C (Figure 3-26).

Caliente-Chalk Mountain Route. Section 3.2.2.2.4 describes the environmental setting along the route. The route passes through the Caliente and Schell Bureau of Land Management resource areas. From Caliente to the south end of Burnt Springs Range, the route passes through Class III land. From the Burnt Springs Range west through Crystal Springs to Rachel, the route passes through Class IV land. The route from Rachel south crosses Class III and VI land to the Nevada Test Site boundary. Lands crossed on the Nevada Test Site are rated Class B or Class C (Figure 3-26).

Caliente-Las Vegas Route. Section 3.2.2.2.4 describes the environmental setting along the Caliente-Las Vegas route. The route passes through the Caliente, Schell, and Las Vegas Bureau of Land Management resource areas. From Caliente to Crystal Springs the route crosses Class III and Class IV land. From Crystal Springs south to the Pahranagat National Wildlife Refuge, the route crosses Class III land. The refuge is rated Class II. The route from the south end of the refuge to I-15 crosses Class III and IV land. The remainder of the route along I-15, the Northern Beltway, and U.S. 95 passes through Class III land. Lands crossed on the Nevada Test Site are rated Class B or Class C (Figure 3-26).

Sloan/Jean Station and Route

Section 3.2.2.2.4 describes the environmental setting for the Sloan/Jean intermodal transfer station and associated route. The potential location for the Sloan/Jean intermodal transfer station has three parcels located some distance apart, two near Jean and one near Sloan. All portions of these parcels are in the Las Vegas Bureau of Land Management resource area and are designated as Class III lands. From Jean to Sloan the route travels through Class III lands. From Sloan along the Las Vegas Beltway to U.S. 95 is designated as Class IV lands. The portion of the route to the Nevada Test Site is through Class III lands. The remainder of the route on the Nevada Test Site is classified as scenic quality Class B and C (Figure 3-26).

Apex/Dry Lake Station and Route

Section 3.2.2.2.4 describes the environmental setting for the Apex/Dry Lake intermodal transfer station and route. Most of the land in the potential intermodal transfer areas is classified as Class IV lands. A small portion of the southern section of land is designated as Class III lands. The entire route passes through Class III lands from the Apex/Dry Lake siding (and the location of the intermodal transfer station) to the Nevada Test Site boundary. On the Nevada Test Site the route to the repository passes through lands with a scenic quality designated as Class B and C (Figure 3-26).

3.2.2.2.9 *Utilities, Energy, and Materials*

The implementation of the heavy-haul approach for transporting spent nuclear fuel and high-level waste to the repository would involve the construction and operation of an intermodal transfer station and upgrades of existing highways. The scope of the utilities, energy, and materials analysis includes consumption of electric power, fossil fuel, and construction materials such as concrete and steel to support these activities. The sites studied for the intermodal transfer station (Caliente, Sloan/Jean, and Apex/Dry Lake) are in areas with at least some light industrial activity or other activity that requires electric power. The sites would, therefore, have access to light industrial levels of electric power. The sites under consideration would also have access to the regional supply capability to provide fossil fuel and construction materials. Heavy-haul route upgrades would also use the southern Nevada regional supply system to provide materials for highway upgrades.

3.2.2.2.10 *Environmental Justice*

The candidate location for the Caliente intermodal transfer station is in Lincoln County and the associated heavy-haul routes go through Lincoln, Nye, and Esmeralda Counties for the Caliente route; Lincoln and Nye Counties for the Caliente-Chalk Mountain route; and Lincoln, Clark, and Nye Counties for the Caliente-Las Vegas route. Section 3.1.13 discusses minority and low-income populations in Clark, Lincoln, and Nye Counties; Section 3.2.2.1.10 discusses minority and low-income populations in Esmeralda County. Unless otherwise noted, the *Environmental Baseline File for Environmental Justice* (TRW 1999q, all) is the basis for the information in this section.

The candidate locations for both the Sloan/Jean and Apex/Dry Lake intermodal transfer stations are in Clark County; the associated heavy-haul routes both go through Clark and Nye Counties. Section 3.1.13 discusses minority and low-income populations in Clark and Nye Counties.

None of the proposed intermodal transfer station sites is in a census block group with high minority or low-income populations, though a facility in the Caliente area would be near a block group with a low-income population and a facility in the Apex/Dry Lake area would be near the Moapa Indian Reservation, a block group with a high minority population.

Ninety block groups in the City of Las Vegas have low-income or minority populations or both. However, the block groups are not near any of the possible sites for an intermodal transfer station. Tables 3-44 and 3-45 list by county the number of census block groups with high minority or low-income populations, respectively, near or through which the heavy-haul routes would pass. Table 3-46 lists the number of census block groups with high minority populations, high low-income populations, or both that each heavy-haul route could encounter.

Table 3-44. High minority population census block groups near or crossed by candidate routes for heavy-haul trucks.

County	Crosses	Near
Eureka	No route	No route
Lander	No route	No route
Nye	0	0
Esmeralda	0	0
Clark[a]	2	0
Lincoln	0	0

a. Outside Las Vegas.

Table 3-45. High low-income population census block groups near or crossed by candidate routes for heavy-haul trucks.

County	Crosses	Near
Eureka	No route	No route
Lander	No route	No route
Nye	2	1
Esmeralda	0	0
Clark[a]	0	0
Lincoln	1	0

a. Outside Las Vegas.

Table 3-46. High minority and high low-income population census block groups near or crossed by candidate routes for heavy-haul trucks.

Route	Minority	Low-income	Minority and low-income
Caliente	0	1[a]	0
Caliente-Chalk Mountain	0	0	0
Caliente-Las Vegas	2[b]	0	0
Apex/Dry Lake	2[b]	0	0
Sloan/Jean	1	0	0

a. Route passes near a low-income block groups in Nye County.
b. Route crosses two minority block groups in Clark County.

The transportation routes would not intersect any of the 90 block groups in the City of Las Vegas with low-income or minority populations or both.

3.2.2.2.11 *Existing Traffic on Candidate Routes for Heavy-Haul Trucks*

The description of the affected transportation environment characterizes routes in terms of traffic volume and roadway capability (DOE 1998m, pages 3-1 to 3-14). The potential for congestion and other problems on a roadway is expressed in terms of levels of service. The level of service scale ranges from A to F, as follows:

A	Indicates free-flow conditions.
B	Indicates free-flow, but the presence of other vehicles begins to be noticeable. Average travel speeds are somewhat lower than level of service A.
C	Indicates a range in which the influence of traffic density on flow becomes marked. The ability to maneuver in the traffic stream and to select an operating speed is clearly affected by the presence of other vehicles.
D	Indicates conditions in which speed and the ability to maneuver are severely restricted due to traffic congestion.
E	Indicates full capacity; a disruption, no matter how minor, causes backups to form.
F	Indicates breakdown of flow or stop-and-go traffic.

Each level is defined by a range of volume-to-capacity ratios. Level of service A, B, or C is considered good operating conditions in which minor or tolerable delays of service are experienced by motorists. Level of service D represents below average conditions. Level of service E corresponds to the maximum capacity of the roadway. Level of service F indicates a heavily congested or overburdened capacity. Roads outside the Las Vegas metropolitan area are generally level of service A or B; roads inside the Las Vegas metropolitan area are generally level of service E or F. Table 3-47 lists current levels of service on potential heavy-haul routes (excluding the planned Las Vegas Beltway).

Table 3-47. Existing levels of service along candidate routes for heavy-haul trucks.[a]

Route segment	Level of service
Caliente	
U.S. 93 to U.S. 6/U.S. 95 interchange	A
U.S. 95/U.S. 6 to Tonopah city limit	C
U.S. 95 (to Mercury, Nevada)	B
Caliente-Chalk Mountain	
Caliente to Rachel	A
Cost of route on U.S. Government facility	N/A
Caliente-Las Vegas	
U.S. 93 (between I-15 and Caliente)	A
I-15 (to Craig interchange)	A
I-15 (in Las Vegas)	E or F[b]
U.S. 95 (in Las Vegas)	E or F[b]
U.S. 95 (Las Vegas to Mercury)	B
Sloan/Jean	
I-15 (to and in Las Vegas)	C, F[b]
U.S. 95 (in Las Vegas)	C, F[b]
U.S. 95 (Las Vegas to Mercury)	B
Apex/Dry Lake	
I-15 (to Craig interchange	A
I-15 (in Las Vegas)	E and F[b]
U.S. 95 (in Las Vegas)	E and F[b]
U.S. 95 (Las Vegas to Mercury)	B

a. Source: DOE (1998m, pages 3-1 to 3-14).

b. Does not consider the Las Vegas Beltway.

3.3 Affected Environment at Commercial and DOE Sites

The No-Action Alternative analyzes the impacts of not constructing and operating a monitored geologic repository at Yucca Mountain. It assumes that the spent nuclear fuel and high- level radioactive waste would remain at commercial and DOE sites throughout the United States. For this alternative, this section describes the affected environment that reflect the average or mean conditions of the sites. The affected environment includes spent nuclear fuel and high-level radioactive waste inventories, climatic parameters, groundwater flowrates, downstream surface-water users, and downstream surface-water flowrates. In all cases, DOE used data from actual sites to develop the hypothetical sites.

To develop the hypothetical sites (see Appendix K for more information), DOE divided the 77 sites among five regions (Figure 3-27). Climate varies considerably across the United States. The radionuclide release rates would depend primarily on the interaction of climate and materials. DOE analyzed these release rates for a hypothetical site in each region that was a mathematical representation of the actual sites in that region. The development process for the hypothetical site used weighted values for material inventories, climate, and groundwater flow information from each actual site to ensure that the results of the analyses of the hypothetical site were comparable to the results for each actual site, if analyzed independently. Similarly, the process constructed downstream populations of water users and river flow for the hypothetical sites from population and river flow data for actual sites, so they reflect the populations downstream of actual storage facilities and the actual amount of water those populations use.

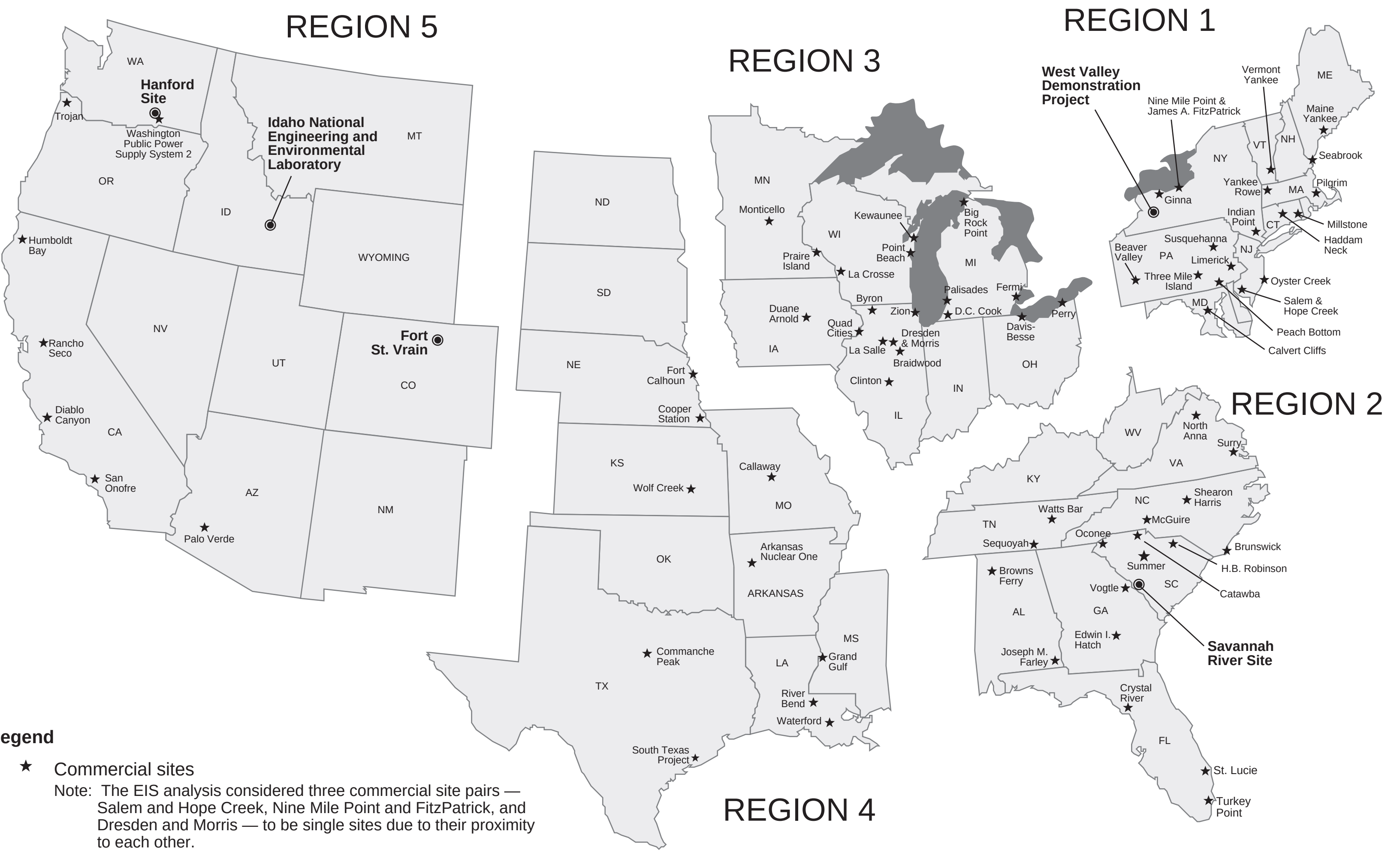
3.3.1 CLIMATIC FACTORS AND MATERIAL

DOE assumed that a single hypothetical site in each region would store all the spent nuclear fuel and high-level radioactive waste in each region. Such a site does not exist, but DOE used it for this analysis. To ensure that the calculated results of the regional analyses reflected the appropriate inventory, facility and material degradation, and radionuclide transport, DOE developed the spent nuclear fuel and high-level radioactive waste inventories, engineered barriers, and environmental parameters for the hypothetical site from data from the actual sites in that region. Weighting criteria accounted for the different amounts and types of spent nuclear fuel and high-level radioactive waste at each site, so the results of the analyses of the hypothetical site were representative of the sum of the results if DOE had modeled each actual site independently. If there are no storage areas in a particular part of a region, DOE did not analyze the environmental parameters of that part (for example, there are no storage facilities in the Upper Peninsula of Michigan, so the analysis for Region 3 did not include environmental parameters from cities in the Upper Peninsula). In addition, if the storage area would not affect drinking water (for example, groundwater near the Calvert Cliffs Nuclear Generating Plant outcrops to the Chesapeake Bay), the regional hypothetical storage facility did not include their fuel inventories.

The following climate parameters are important to material degradation times and rates of release:

- Precipitation rate (amount of precipitation per year)
- Rain days (percent of days with measurable precipitation)
- Wet days (percent of year that included rain days and days when the relative humidity was greater than 85 percent)
- Temperature
- Precipitation chemistry (pH, chloride anions, and sulfate anions)

Table 3-48 lists the regional values for each parameter. Appendix K contains more information on the selection and analysis of these parameters.



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

Symbols do not reflect precise locations.

Note: None of the facilities evaluated are located in Alaska or Hawaii.

Source: Modified from Poe (1998b, page 2).

Figure 3-27. Commerical and DOE sites in each No-Action Alternative analysis region.

Table 3-48. Regional environmental parameters.

Region	Precipitation rate (centimeters per year)[a]	Percent rain days (per year)	Percent wet days (per year)	pH	Precipitation chemistry: Chloride anions (weight percent)	Precipitation chemistry: Sulfate anions (weight percent)	Average temperature (ºC)[b]
1	110	30	31	4.4	6.9×10^{-5}	1.5×10^{-4}	11
2	130	29	54	4.7	3.9×10^{-5}	9.0×10^{-5}	17
3	80	33	42	4.7	1.6×10^{-5}	2.4×10^{-4}	10
4	110	31	49	4.6	3.5×10^{-5}	1.1×10^{-4}	17
5	30	24	24	5.3	2.1×10^{-5}	2.5×10^{-5}	13

a. To convert centimeters to inches, multiply by 0.3937.

b. To convert degrees Centigrade to degrees Fahrenheit, add 17.78 and then multiply by 1.8.

3.3.2 GROUNDWATER PARAMETERS

Most of the radioactivity and metals from degraded material would seep into the groundwater and flow with it to surface outcrops to rivers or streams. Therefore, the analysis had to account for the groundwater characteristics at each site, including the time it takes the water to move through the unsaturated zone and the aquifer. The analysis assumed that the storage facilities would be 490 meters (1,600 feet) up the groundwater gradient from the hypothetical reactor and used this assumption to calculate the time it would take contaminants to reach surface water. Table 3-49 lists the ranges of groundwater flow times in each region. Appendix K contains more information on the sources of groundwater data.

Table 3-49. Ranges of flow time (years) for groundwater and contaminants in the unsaturated and saturated zones in each region.

Region	Contaminant K_d[a] (milliliters per gram)	Unsaturated zone: Water flow time	Unsaturated zone: Contaminant flow time	Saturated zone: Groundwater flow time	Saturated zone: Contaminant flow time	Total contaminant flow time
1	0[b] - 100	0.7 - 4.4	0.4 - 2,100	0.3 - 56	10 - 5,000	10 - 6,000
2	10 - 250	0.6 - 10	35 - 5,000	3.3 - 250	11 - 310,000	460 - 310,000
3	10 - 250	0.5 - 14	32 - 1,500	1.3 - 410	9 - 44,000	65 - 45,000
4	10 - 100	0.2 - 7.1	110 - 2,300	3.9 - 960	300 - 520,000	460 - 520,000
5	0 - 10	0.9 - 73	14 - 4,700	1.7 - 170	0 - 25,000	200 - 26,000

a. K_d = equilibrium adsorption coefficient.

b. The K_d would be 0 if there was no soil at the site.

3.3.3 AFFECTED WATERWAYS

Most of the estimated population dose for the No-Action Alternative would be a result of drinking contaminated surface water. The first step in determining the population dose was to identify the waterways that receive groundwater from beneath existing storage facilities (Figure 3-28) and the number of public drinking water systems that draw water from the potentially contaminated waterways (Table 3-50). DOE calculated the river flow past each population center (Section 3.3.4) along each river, and used this number in the calculation to determine dose to the population.

Table 3-50. Public drinking water systems and the populations that use them in the five regions.[a]

Region	Drinking water systems	Population
1	85	10,000,000
2	150	5,600,000
3	150	12,000,000
4	95	600,000
5	6	2,800,000
Totals	**486**	**31,000,000**

a. Sources: Based on current information and the 1990 census.

Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

Symbols do not reflect precise locations.

Source: Modified from Poe (1998b, page 13).

Figure 3-28. Major waterways near commercial and DOE sites.

3.3.4 AFFECTED POPULATIONS

After identifying the affected waterways, DOE identified the populations that get their drinking water from those waterways. The total population using the river was expressed as number of people per cubic foot per second. If a river system traverses more than one region (for example, the Mississippi drains three regions), weighting criteria accounted for materials received from storage facilities upstream of the region that would flow past several downstream population centers, as necessary. Table 3-50 lists the number of people using the public drinking water systems potentially affected by the degradation of radioactive materials.

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4

Environmental Consequences of Repository Construction, Operation and Monitoring, and Closure

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4. ENVIRONMENTAL CONSEQUENCES OF REPOSITORY CONSTRUCTION, OPERATION AND MONITORING, AND CLOSURE

This chapter describes short-term environmental consequences that could result from the implementation of the Proposed Action, which is to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. *Short-term* refers to the period up to and during the completion of repository closure. For purposes of analysis, the duration that the repository would remain open varied between 50, 100, and 300 years after receipt of the first spent nuclear fuel or high-level radioactive waste shipment. Chapters 5 and 6 discuss the environmental consequences of long-term repository performance and transportation, respectively. Chapter 7 discusses the environmental consequences of the No-Action Alternative.

Section 4.1 describes potential environmental impacts from required activities at the repository site to implement the Proposed Action, including continued site investigations (called *performance confirmation*), offsite manufacturing of disposal containers and shipping casks, and a floodplain assessment. The implementation of the Proposed Action could require performance confirmation in support of a U.S. Nuclear Regulatory Commission licensing process. Section 4.2.1 describes potential environmental impacts of retrieval if such an option became necessary. Section 4.2.2 describes the environmental impacts associated with the receipt of waste prior to the start of emplacement.

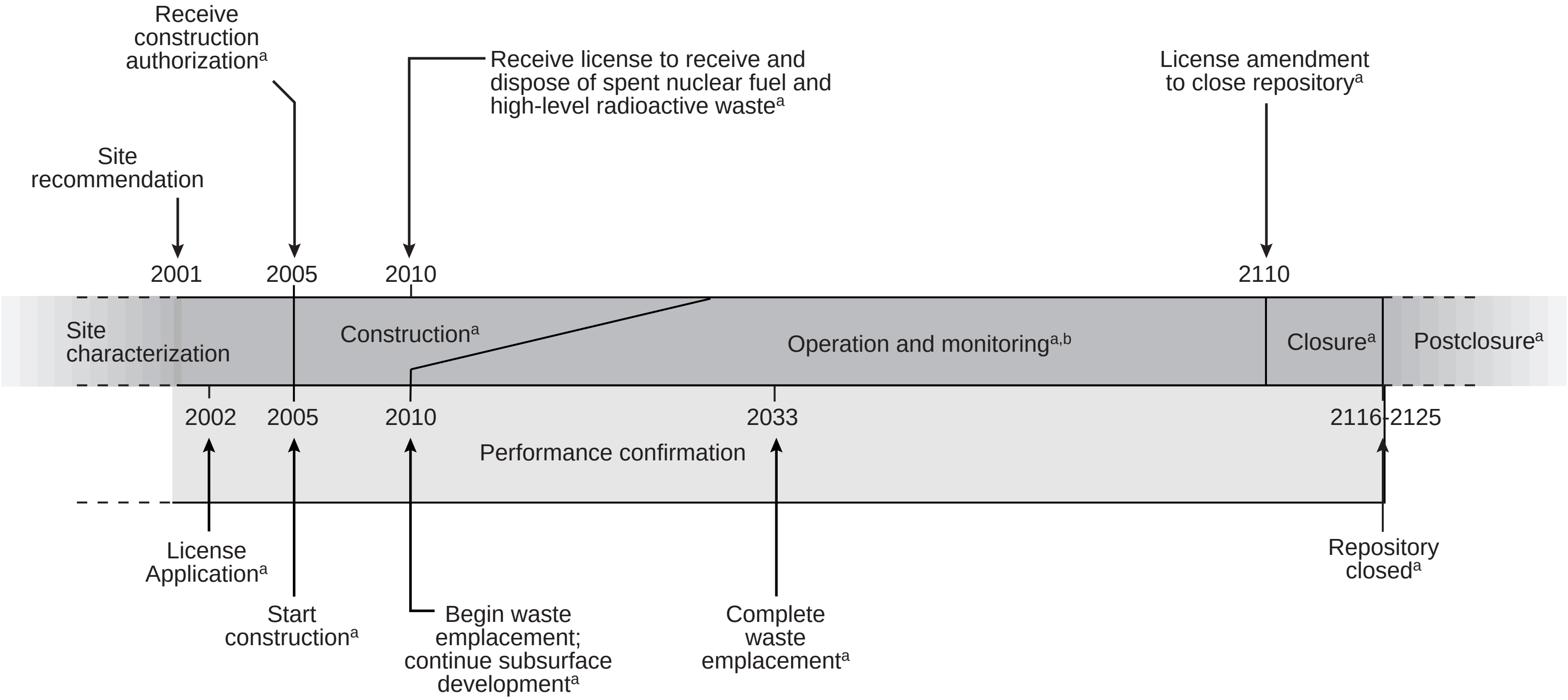
The U.S. Department of Energy (DOE) has developed the information about the potential environmental impacts that could result from either the Proposed Action or the No-Action Alternative to inform the Secretary of Energy’s determination whether to recommend Yucca Mountain as the site of this Nation’s first monitored geologic repository for spent nuclear fuel and high-level radioactive waste. This chapter contains information about short-term environmental impacts that would be directly associated with the construction, operation and monitoring, and eventual closure of a repository. In addition, DOE analyzed packaging and thermal load scenarios to cover a reasonable range of possible impacts.

4.1 Short-Term Environmental Impacts of Performance Confirmation, Construction, Operation and Monitoring, and Closure of a Repository

This section describes the short-term environmental impacts associated with the Proposed Action. DOE has described the environmental impacts according to the phases of the Proposed Action—construction, operation and monitoring, and closure—and the activities (some of which overlap) associated with them. The following paragraphs summarize the phases and activities that would occur, and the analytic scenarios evaluated in this environmental impact statement (EIS). Chapter 2 describes these scenarios in detail. Figure 4-1 shows the expected timeline for these phases. In addition, this section describes the impacts from the performance confirmation activities that DOE would perform before the start of repository construction in support of a Nuclear Regulatory Commission licensing process. These activities, which would continue through repository closure, could require surface or subsurface excavations and drill holes, testing, and environmental monitoring. As these activities revealed more scientific data, DOE would expect their level of effort to decrease.

PRECONSTRUCTION PERFORMANCE CONFIRMATION ACTIVITIES (2001 TO 2005)

The performance confirmation program would continue the current site characterization activities—tests, experiments, and analyses—for as long as required. DOE would continue these activities during all the phases of the repository project to evaluate the accuracy and adequacy of the information it used to



a. If Yucca Mountain is approved.

b. The EIS analysis assumed that waste emplacement would occur over a 24-year period ending in 2033.

Source: Modified from TRW (1999b, Figure 1.5-1, page 1-3).

Figure 4-1. Expected monitored geologic repository milestones.

determine with reasonable assurance that the repository would meet the performance objective for the period after permanent closure.

INITIAL CONSTRUCTION ACTIVITIES (2005 TO 2010)

The construction of facilities would begin when and if the Nuclear Regulatory Commission authorized DOE to build the repository. Assuming this authorization, construction would begin in about 2005. Site preparation, including the layout and grading of surface facility locations, would be part of the initial construction activities; DOE would construct new surface facilities or modify facilities built to support site characterization. Initial subsurface construction would prepare the first emplacement drifts for the start of emplacement activities in 2010. As mentioned above, performance confirmation activities would be ongoing during this period.

CONTINUING CONSTRUCTION ACTIVITIES AND REPOSITORY OPERATION AND MONITORING (2010 TO 2110)

Repository operations would begin after DOE received a license from the Nuclear Regulatory Commission to receive and dispose of spent nuclear fuel and high-level radioactive waste. Assuming DOE received the license, emplacement of these materials in the repository would be likely to begin in 2010 and end in 2033. The development (construction) of the subsurface would continue during waste emplacement, and would end in about 2031 for the high or intermediate thermal load scenario or about 2032 for the low thermal load scenario.

Monitoring of the emplaced material and maintenance of the repository would start with the first emplacement of waste packages and would continue through the closure phase. After the completion of emplacement, DOE would maintain the repository in a configuration that would enable continued monitoring and inspection of the waste packages, continued investigations in support of predictions of long-term repository performance (the ability to isolate waste from the accessible environment), and the retrieval of waste packages, if necessary.

Monitoring activities would begin with the emplacement of the first waste package in 2010 and would last between 50 and 300 years. Future generations would need to decide whether to continue to maintain the repository in this open monitored condition or to close it. To ensure flexibility for future decisionmakers, DOE is designing the repository with the capability for closure as early as 50 years after the start (26 years after the completion) of waste emplacement or as late as 300 years after the start (276 years after the completion) of emplacement. However, the Department expects that a repository could be maintained in an open monitored condition, with appropriate maintenance, for as long as 300 years after the start of emplacement. For this analysis, the EIS evaluates closure starting 100 years after the start of emplacement, but also assesses impacts for closure starting 50 and 300 years after the start of emplacement.

As mentioned above, DOE would continue its performance confirmation activities during the construction, waste emplacement, and monitoring activities.

CLOSURE PHASE (2110 TO 2116 OR 2125)

Repository closure would occur after DOE applied for and received a license amendment from the Nuclear Regulatory Commission. Closure would take from 6 to 15 years, depending on the thermal load scenario. The closure of the repository facilities would include the following activities:

- Removing and salvaging valuable equipment and materials
- Potentially backfilling the main drifts, access ramps, ventilation shafts, and connecting openings

- Constructing monuments to mark the area
- Decommissioning and demolishing surface facilities
- Restoring the surface to its approximate condition before repository construction
- Continuing performance confirmation activities as necessary

REPOSITORY ANALYTIC SCENARIOS

As discussed in Chapter 2, the repository design is conceptual and continues to evolve. This evolution will continue throughout the process established by the Nuclear Regulatory Commission for license application and construction authorization. To present the range of short-term environmental impacts that could occur, DOE has selected a set of repository design scenarios (thermal loads) for evaluation in this EIS. Because it cannot predict the specific transportation option or mode (truck or rail) or the packaging option (canistered or uncanistered) for each shipment of spent nuclear fuel and high-level radioactive waste to the proposed repository, DOE has also identified a set of transportation and packaging scenarios for evaluation. Whether canistered or uncanistered, each shipment of spent nuclear fuel and high-level radioactive waste would be in a Nuclear Regulatory Commission-certified shipping cask.

DOE is considering three thermal load scenarios to represent the potential thermal loads that could be part of a license application to the Nuclear Regulatory Commission. These scenarios include a relatively high emplacement density of spent nuclear fuel and high-level radioactive waste (high thermal load), a relatively low emplacement density (low thermal load), and an emplacement density between the high and low thermal loads (intermediate thermal load). The emplacement density of spent nuclear fuel and high-level radioactive waste in the repository is referred to as the *areal mass loading* (the amount of material in a given area). The spacing of the emplacement drifts and the waste packages in those drifts would control the thermal load of the repository. The additional spacing required for lower thermal loads would increase the amount of subsurface area needed and, therefore, would require more excavation.

Because the specific mix of canistered and uncanistered spent nuclear fuel that would arrive at the repository is not known at this time, this EIS analyzes the following packaging scenarios to address the potential range of environmental impacts from surface facility operations:

- A mostly legal-weight truck, uncanistered commercial fuel receipt scenario (uncanistered scenario)
- A mostly rail, canistered commercial fuel receipt scenario (canistered scenario) that includes:
  - A disposable canister scenario
  - A dual-purpose canister scenario

4.1.1 IMPACTS TO LAND USE AND OWNERSHIP

This section describes potential land-use and ownership impacts from the performance confirmation, construction, operation and monitoring, and closure activities. DOE determined that information useful in an evaluation of land-use and ownership impacts should identify the current ownership of the land that repository-related activities could disturb, and the present and anticipated future uses of the land. The region of influence for land-use and ownership impacts is a land withdrawal area that DOE used for the EIS analysis. Congress would have to define the actual land withdrawal area. The analysis considered impacts from direct disturbances related to repository construction and operation. It also considered impacts from the transfer of lands to DOE control.

4.1.1.1 Impacts to Land Use and Ownership During Performance Confirmation and from Land Withdrawal

Performance confirmation activities would occur primarily on land managed by the Federal Government. As with site characterization, these activities would occur in the land withdrawal area that DOE analyzed in the EIS (see Section 3.1.1). DOE would seek to maintain the current administrative land withdrawal of 20 square kilometers (4,900 acres), current right-of-way reservations N-47748 [210 square kilometers (52,000 acres)] and N-48602 [about 75 square kilometers (19,000 acres)], and the existing management agreement between the Yucca Mountain Site Characterization Office and the DOE Nevada Operations Office (as described in Section 3.1.1) until Congress approved a permanent land withdrawal. The Nevada Operations Office operates the Nevada Test Site.

To develop the proposed Yucca Mountain Repository, DOE would need to obtain permanent control of the land surrounding the repository site. The Department believes that an area of approximately 600 square kilometers (150,000 acres) on Bureau of Land Management, U.S. Air Force, and DOE lands in southern Nevada would be sufficient (see Section 3.1).

Nuclear Regulatory Commission licensing conditions for a repository (10 CFR 60.121) include a requirement that DOE either own or have permanent control of the lands for which it is seeking a repository license. As noted above, portions of the area proposed for the repository are lands controlled by the Bureau of Land Management, the Air Force, and the DOE Nevada Operations Office.

Only Congress has the power to withdraw Federal lands permanently for the exclusive purposes of specific agencies. Through legislative action, Congress can authorize and direct a permanent withdrawal of lands such as those proposed for the Yucca Mountain Repository. In addition, Congress would determine any conditions associated with the land withdrawal. Nuclear Regulatory Commission regulations require that repository operations areas and postclosure controlled areas be free and clear of all encumbrances, if significant, such as (1) rights arising under the general mining laws, (2) easements or rights-of-way, and (3) all other rights arising under lease, rights of entry, deed, patent, mortgage, appropriation, prescription, or otherwise. If Congress approved withdrawal of lands for repository purposes, any other use of those lands would be subject to conditions of the withdrawal.

Repository construction, operation and monitoring, and closure activities would require the active use of a maximum of about 3.5 square kilometers (870 acres) composed of small noncontiguous areas in the larger 600-square-kilometer (150,000-acre) land withdrawal area used for purposes of analysis.

Chapter 2 describes activities that DOE would conduct in the Yucca Mountain site active-use area and the land withdrawal area.

The amount of land that DOE would need to support repository activities would vary little between the thermal load and packaging scenarios. Most of the surface facilities and disturbed land would be in the North and South Portal Operations Areas. Repository activities would not conflict with current land uses on adjacent Bureau of Land Management, Air Force, or Nevada Test Site lands.

4.1.1.2 Impacts to Land Use and Ownership from Construction, Operation and Monitoring, and Closure

During the construction and operation and monitoring phases, DOE would disturb or clear land for repository and surface facility construction. The Department would use this land for surface facilities, performance confirmation activities, and excavated rock storage. DOE does not expect conflicts with uses on surrounding lands because repository operations would occur in a confined, secure area over which DOE would have permanent control. Furthermore, this is public land, much of which has been used for site characterization for nearly two decades.

As described in Section 4.1, surface activities associated with closure would include constructing monuments, decommissioning and decontaminating facilities, and restoring the surface to its approximate preconstruction condition. DOE could use material from the excavated rock pile to backfill the repository tunnels (excluding the emplacement drifts), and would recontour the excavated material remaining after backfill and subsurface closure activities and cover it with topsoil. During closure, the Department would restore disturbed areas to their approximate condition before repository construction.

4.1.2 IMPACTS TO AIR QUALITY

This section describes possible nonradiological and radiological impacts to air quality from performance confirmation, construction, operation and monitoring, and closure. Sources of nonradiological air pollutants at the proposed repository site would include fugitive dust emissions from land disturbances and excavated rock handling, nitrogen dioxide, sulfur dioxide, and particulate matter emissions from fossil fuel consumption, and fugitive dust emissions from concrete batch plant operations. DOE used the Industrial Source Complex computer program to estimate annual and short-term (24-hour or less) nonradiological air quality impacts (EPA 1995, all). Nonradiological impacts evaluated include those from four criteria pollutants: nitrogen dioxide, sulfur dioxide, carbon monoxide, and particulate matter with an aerodynamic diameter of 10 micrometers or less (PM_{10}). In addition, potential impacts were evaluated for the possibly harmful mineral cristobalite, a form of silica dust that is the causative agent for silicosis and might be a carcinogen. The analysis did not consider the two other criteria pollutants, lead and ozone. There would be no sources of airborne lead at the repository, and very small sources of volatile organic carbon compounds, which are ozone precursors. The analysis did make a qualitative comparison to the new National Ambient Air Quality Standard for particulate matter with an aerodynamic diameter of 2.5 micrometers or less ($PM_{2.5}$). A Federal appeals court recently struck down the Environmental Protection Agency's new national ambient air quality standards for particulate matter (American Trucking v. EPA 1999, all). The Environmental Protection Agency has announced that it will appeal the decision. The EIS used these standards, among other air quality standards that were not at issue in that case, in analyzing the air quality impacts discussed in this section.

Radiological air quality impacts could occur from releases of radionuclides, primarily naturally occurring radon-222 and its radioactive decay products, from the rock into the subsurface facility and then into the ventilation air during all phases of the repository project. Radioactive noble gases, principally krypton-85, would be released from surface facilities during the handling of spent nuclear fuel. DOE used dose factors from NCRP (1996, Volume 1, pages 113 and 125) and ICRP (1994, page 24) to estimate doses to noninvolved workers (workers who could be exposed to air emissions from repository activities but who would not be directly associated with those activities) and offsite individuals from such releases. Appendix G provides more details on the methods used for air quality analysis.

The air quality analysis evaluated nonradiological air quality impacts at the potential locations of maximally exposed members of the public. It estimated radiological air quality impacts as the doses to maximally exposed individuals and populations of the public and to noninvolved workers. The analysis did not consider involved workers because they would be exposed in the workplace, as discussed in Section 4.1.7. Overall, the impacts to regional air quality from performance confirmation, repository construction, operation and monitoring, and closure would be small. Exposures of maximally exposed individuals to airborne pollutants would be a small fraction of applicable regulatory limits. Appendix G describes the methods, procedures, and basis of the analysis.

4.1.2.1 Impacts to Air Quality from Performance Confirmation (2001 to 2005)

Performance confirmation activities would generate particulate and gaseous emissions. Particulates would be generated by drilling, blasting, rock removal and storage, batch concrete plant operation, surface grading and leveling, wind erosion, and vehicle travel on paved and unpaved roads. Gaseous air pollutant emissions would consist of carbon monoxide, nitrogen oxides, sulfur oxides, and hydrocarbons. These pollutants would be produced by diesel- and gasoline-powered construction equipment and motor vehicles and by diesel-powered drilling engines and electric generators.

Air quality measurements at the repository site and in the repository site vicinity (see Section 3.1.2) have shown that site characterization activities similar to those described above have had a very small impact on the concentration levels of PM_{10} and of gaseous pollutants (carbon monoxide, nitrogen oxides, sulfur oxides, ozone). This analysis assumed that site characterization activities are representative of performance confirmation activities. As described in Section 3.1.2, pollutant levels have been below applicable National Ambient Air Quality Standards. Based on this experience, DOE does not expect large impacts to air quality from performance confirmation activities.

4.1.2.2 Impacts to Air Quality from Construction (2005 to 2010)

This section describes potential radiological and nonradiological air quality impacts during the initial construction of the Yucca Mountain Repository, which would last 5 years, from 2005 to 2010. Activities during this phase would include subsurface excavation to prepare the repository for initial emplacement operations and construction of surface facilities at the North Portal, South Portal, Emplacement Shaft, and Development Shaft Operations Areas.

4.1.2.2.1 *Nonradiological Impacts to Air Quality from Construction*

During the initial construction, repository activities would result in emissions of air pollutants. Subsurface excavation would release dust (particulate matter) from the ventilation exhaust (South Portal). The excavation of rock would generate dust in the drifts. The dust would be vented from the subsurface through the South Portal. Construction activities on the surface would result in the following air emissions:

- Fugitive dust from the placement and maintenance of excavated rock at a surface storage site
- Gaseous criteria pollutants (nitrogen dioxide, sulfur dioxide, etc.) and particulate matter from the operation of construction vehicles
- Gaseous criteria pollutants and particulate matter from a diesel-fueled boiler at the South Portal Operations Area
- Particulate matter from a concrete batch plant at the South Portal Operations Area
- Fugitive dust from land-disturbing activities on the surface

Table 4-1 lists the maximum estimated impacts to air quality at the boundary of the land withdrawal area used for purposes of analysis in this EIS. As listed in this table, maximum offsite concentrations of nitrogen dioxide, sulfur dioxide, carbon monoxide, and PM_{10} would be small. Criteria pollutant concentrations would be less than 2 percent of the applicable regulatory limits for all cases except one: the 24-hour PM_{10} concentrations for the three thermal load scenarios would be about 4 percent of the

Table 4-1. Estimated maximum construction phase concentrations of criteria pollutants and cristobalite at the analyzed land withdrawal area boundary (micrograms per cubic meter).[a]

			Thermal load					
			Maximum concentration[c]			Percent of regulatory limit		
Pollutant	Averaging time	Regulatory limit[b]	High	Intermediate	Low	High	Intermediate	Low
Nitrogen dioxide	Annual	100	0.36	0.36	0.39	0.36	0.36	0.39
Sulfur dioxide	Annual	80	0.088	0.088	0.091	0.11	0.11	0.12
	24-hour	365	1.0	1.0	1.0	0.28	0.28	0.29
	3-hour	1,300	6.3	6.3	6.5	0.49	0.49	0.50
Carbon monoxide	8-hour	10,000	3.8	3.8	4.1	0.037	0.037	0.040
	1-hour	40,000	23	23	25	0.058	0.058	0.062
PM_{10} ($PM_{2.5}$)	Annual	50 (15)	0.66	0.70	0.65	1.3	1.4	1.3
	24-hour	150 (65)	6.1	6.4	6.0	4.0	4.3	4.0
Cristobalite	[Annual[d]]	[10[d]]	0.022	0.026	0.011	0.22	0.26	0.11

a. All numbers except regulatory limits are rounded to two significant figures.

b. Regulatory limits for criteria pollutants are from 40 CFR 50.4 through 50.11, and Nevada Administrative Code 445B.391 (see Table 3-5).

c. Sum of highest concentrations at the accessible land withdrawal boundary regardless of direction. See Appendix G, Section G.1, for additional information.

d. There are no regulatory limits for public exposure to cristobalite, a form of crystalline silica. An Environmental Protection Agency health assessment (EPA 1996a, page 1-5) states that the risk of silicosis is less than 1 percent for a cumulative exposure of 1,000 (micrograms per cubic meter) × years. Using a 70-year lifetime, an approximate annual average concentration of 10 micrograms per cubic meter was established as a benchmark for comparison.

regulatory limit. In addition, DOE expects levels of $PM_{2.5}$ to be well below the applicable standard because a large fraction of the particulates for PM_{10} would be larger than 2.5 micrometers. The analysis did not consider standard construction dust suppression measures, which DOE would implement and which would further lower projected PM_{10} concentrations by reducing fugitive dust from surface-disturbing activities. These measures would not have a major effect on concentrations of $PM_{2.5}$ because fugitive dust is not a major source of $PM_{2.5}$.

Emissions of nitrogen dioxide, sulfur dioxide, and carbon monoxide would be somewhat higher under the low thermal load scenario during the construction phase because of higher consumption of diesel fuel and resultant vehicle emissions around the South Portal Operations Area. The additional consumption and emissions would be related mainly to the preparation and maintenance of the excavated rock pile. Under this scenario, the rock pile would be about 5 kilometers (3 miles) east of the South Portal Operations Area, rather than in that operations area as it would be for the high and intermediate thermal load scenarios. Because the pile would be away from the South Portal Operations Area, it would not be subject to the operations area height restrictions. DOE could make a higher pile, reducing the area that would be disturbed and creating a more favorable surface-to-volume ratio for limiting fugitive dust emissions. This pile location would also be 5 kilometers farther from the location of the maximally exposed individual, which would result in lower PM_{10} concentrations. The PM_{10} contribution from surface disturbance activities would be about the same for the three thermal load scenarios. Overall, the slight differences in estimated concentrations do not provide meaningful distinctions between the scenarios.

Cristobalite is one of several naturally occurring crystalline forms of silica (silicon dioxide) that occur in Yucca Mountain tuffs. Cristobalite is principally a concern for involved workers who could inhale it during subsurface excavation operations (see Section 4.1.7). Prolonged high exposure to crystalline silica might cause silicosis, a disease characterized by scarring of lung tissue. Research has shown an increased cancer risk to humans who already have developed adverse noncancer effects from silicosis, but the cancer risk to otherwise healthy individuals is not clear (EPA 1996a, page 1-5). The evaluation of exposure to cristobalite encompassed potential impacts from exposure to other forms of crystalline silica, including quartz and tridymite, that occur at Yucca Mountain. See Appendix F, Section F.1, for more information.

Cristobalite would be emitted from the subsurface in exhaust ventilation air during excavation operations and would be released as fugitive dust from the excavated rock pile, so members of the public and noninvolved workers could be exposed. Fugitive dust from the excavated rock pile would be the largest potential source of cristobalite exposure to the public. The analysis assumed that 28 percent of the fugitive dust released from this pile and from subsurface excavation would be cristobalite, reflecting the cristobalite content of the parent rock, which ranges from 18 to 28 percent (TRW 1999b, page 4-81). Using the parent rock percentage probably overestimates the airborne cristobalite concentration because studies of both ambient and occupational airborne crystalline silica have shown that most is coarse and not respirable, and that larger particles will rapidly deposit on the surface (EPA 1996a, page 3-26). Table 4-1 lists estimated cristobalite concentrations at the analyzed land withdrawal area boundary during the construction phase.

There are no regulatory limits for public exposure to cristobalite. An Environmental Protection Agency health assessment (EPA 1996a, page 1-5) states that the risk of silicosis is less than 1 percent for a cumulative exposure of 1,000 (micrograms per cubic meter) × years. Over a 70-year lifetime, this cumulative exposure benchmark would correspond to an annual average exposure concentration of about 14 micrograms per cubic meter. For added conservatism, this analysis used an annual concentration of 10 micrograms per cubic meter as the benchmark for comparison. The postulated annual average exposure of the hypothetical maximally exposed member of the public to cristobalite from construction activities would be small, about 0.025 microgram per cubic meter or less for the thermal load scenarios. DOE would use common dust suppression techniques (water spraying, etc.) to further reduce releases of fugitive dust from the excavated rock pile.

4.1.2.2.2 *Radiological Impacts to Air Quality from Construction*

No releases of manmade radionuclides would occur during the construction phase because such materials would not be present until the repository began operations. However, the air exhausted from the subsurface would contain naturally occurring radon-222 and its radioactive decay products. (Further references to radon in this discussion include its radioactive decay products.) Radon-222 is a noble gas and decay product of uranium-238 that occurs naturally in the rock. Exposure to radon-222 is ubiquitous (that is, it occurs everywhere). As described in Section 3.1.8, exposure to naturally occurring radon-222 results in an annual average individual dose in the United States of about 200 millirem. In the subsurface, radon-222 would leave the rock and enter the drifts, from which it would be exhausted as part of repository ventilation. The analysis based potential releases of radon-222 on observed concentrations of the gas in the Exploratory Studies Facility during working hours when the ventilation system was operating. The concentrations ranged from 0.65 to 163 picocuries per liter, with a median concentration of 24 picocuries per liter. Total estimated radon releases of 1,500, 1,600, or 1,600 curies would occur during the construction phase for the high, intermediate, or low thermal load scenario, respectively. These releases, and the potential doses that resulted from them, would be similar because the excavated volume of the repository and the repository flowrate would be similar under each scenario. Appendix G, Section G.2, describes the methods, procedures, and basis of analysis.

The dose to the offsite maximally exposed individual, about 20 kilometers (12 miles) south of the repository, would be no more than 2.1, 2.5, or 2.5 millirem for the 5-year initial construction period under the high, intermediate, or low thermal load scenario, respectively. As a point of reference, the annual dose to the offsite maximally exposed individual would be about 5 percent of the 10-millirem-per-year regulatory limit (40 CFR Part 61), although this limit does not apply to releases of radon. The offsite population dose would be 11, 13, or 13 person-rem, respectively. The median dose to the maximally exposed noninvolved repository worker would range from 4.7 to 5.4 millirem annually during the initial construction period for the three thermal load scenarios. The analysis assumed that this worker, while at the site, would be in an office about 100 meters (330 feet) from the South Portal. The noninvolved worker population exposed to radon-222 from exhaust ventilation would include all of the repository workers on the surface. Workers at the South Portal Operations Area, who would be near the ground-level releases of radon from this portal, would receive most of the population dose. The dose to the noninvolved worker population from the air pathway would not exceed 10 person-rem for any thermal load scenario (see Appendix G, Section G.2).

Table 4-2 lists estimated annual and initial construction period doses from radon-222 for the maximally exposed individuals (both public and noninvolved surface worker) and potentially affected populations from the air pathway. Section 4.1.7 discusses potential human health impacts from these doses.

Table 4-2. Estimated radiation doses to maximally exposed individuals and populations from subsurface radon-222 releases during initial construction period.[a,b]

	Thermal load					
	High		Intermediate		Low	
Impact	Total	Annual	Total	Annual	Total	Annual
Dose to public						
Offsite MEI[c] (millirem)	2.1	0.43	2.5	0.49	2.5	0.49
80-kilometer population[d] (person-rem)	11	2.3	13	2.6	13	2.6
Dose to noninvolved (surface) workers						
Maximally exposed noninvolved (surface) worker[e] (millirem)	23	4.7	27	5.4	27	5.4
Yucca Mountain noninvolved (surface) worker population[g] (person-rem)	9.0[f]	1.8[f]	10[f]	2.0[f]	10[f]	2.0[f]
Nevada Test Site noninvolved worker population[h] (person-rem)	0.012	0.0025	0.014	0.0028	0.014	0.0028

a. Numbers are rounded to two significant figures.
b. These releases were estimated using the average repository volume during the construction phase.
c. MEI = maximally exposed individual; public MEI location would be 20 kilometers (12 miles) south of the repository.
d. The population includes about 28,000 individuals within 80 kilometers (50 miles) of the repository (see Section 3.1.8).
e. The maximally exposed noninvolved worker location would be in the South Portal Operations Area.
f. Values are for the uncanistered packaging scenario. The dual-purpose and disposable canister packaging scenario values would be somewhat lower, due to differences in the number of surface facility construction workers.
g. The analysis included noninvolved workers at both the North and South Portal Operations Areas.
h. DOE workers at the Nevada Test Site [6,600 workers (DOE 1996f, page 5-14) 50 kilometers (30 miles) east-southeast near Mercury, Nevada].

4.1.2.3 Impacts to Air Quality from Continuing Construction, and Operation and Monitoring (2010 to 2110)

This section describes potential nonradiological and radiological air quality impacts from routine operation and monitoring at the Yucca Mountain Repository, which would last from 2010 to 2110. Activities during this phase would include the continued excavation of subsurface drifts (2010 to 2033), the receipt and packaging (handling) of spent nuclear fuel and high-level radioactive waste at the North Portal surface facilities (2010 to 2033), the emplacement of disposal containers in the repository (2010 to 2033), and the continued monitoring of the disposal containers and maintenance of repository facilities (2034 to 2110).

4.1.2.3.1 *Nonradiological Impacts to Air Quality from Continuing Construction, and Operation and Monitoring*

DOE evaluated nonradiological air quality impacts from activities from 2010 to 2033, when handling and continued subsurface development and emplacement activities would occur simultaneously. Continued subsurface development would result in the release of dust (particulate matter) from the ventilation exhaust (at the South Portal). Activities on the surface would result in the following air emissions during this period:

- Fugitive dust emissions from the placement and maintenance of excavated rock at a surface storage pile
- Gaseous criteria pollutants (nitrogen dioxide, sulfur dioxide, carbon monoxide) and particulate matter from vehicle operation
- Gaseous criteria pollutants and particulate matter from oil-fed boilers at the North and South Portal Operations Areas
- Particulate matter from a concrete batch plant at the South Portal Operations Area
- Cristobalite emissions from subsurface excavations and the excavated rock storage pile

The level of emissions would vary among the thermal load and packaging scenarios. The lower thermal loads would result in larger excavated rock piles on the surface, which in turn would result in larger fugitive dust emissions and necessitate larger vehicle fleets for operation and maintenance. The uncanistered packaging scenario would require larger facilities at the North Portal Operations Area, which would necessitate a larger boiler for heating.

Table 4-3 lists estimated maximum concentrations at the analyzed land withdrawal area boundary for the high, intermediate, and low thermal load scenarios. These impacts are based on surface facilities built for the uncanistered packaging scenario. Other packaging scenarios would have similar or slightly smaller impacts because they would require smaller boilers.

As listed in Table 4-3, the maximum offsite concentrations of nitrogen dioxide, sulfur dioxide, carbon monoxide, and PM_{10} would be very small. For all three thermal load scenarios, the public maximally exposed individual would receive no more than 1 percent of the applicable regulatory limits, with one exception: the 24-hour PM_{10} value would be about 2 percent. In addition, levels of $PM_{2.5}$ should be well below the applicable standard because a large fraction of the particulates listed for PM_{10} would be larger than 2.5 micrometers. The analysis did not consider standard construction dust suppression measures, which DOE would implement and which would further lower projected PM_{10} concentrations by reducing fugitive dust from surface-disturbing activities. The concentrations of $PM_{2.5}$ would not be as affected by these suppression measures because fugitive dust is not a major source of $PM_{2.5}$.

Table 4-3 also lists cristobalite concentrations at the analyzed land withdrawal area boundary. As discussed for the initial construction period (see Section 4.1.2.2.1), the analysis of the continuing construction, operation, and monitoring period assumed that 28 percent of the fugitive dust released from the excavated rock pile would be cristobalite. There are no public limits for exposure to cristobalite, so the analysis used an approximate annual average concentration of 10 micrograms per cubic meter as a benchmark. The estimated exposures to cristobalite from repository operations would be small, about 0.015 microgram per cubic meter or less for all three thermal load scenarios.

Table 4-3. Estimated maximum criteria pollutant and cristobalite concentrations at the analyzed land withdrawal area boundary from emplacement, receipt and packaging, and development activities (2010 to 2033) during the operation and monitoring phase (micrograms per cubic meter).[a]

Pollutant	Averaging time	Regulatory limit[b]	Maximum concentration[c]			Percent of regulatory limit		
			High	Intermediate	Low	High	Intermediate	Low
Nitrogen dioxide	Annual	100	0.45	0.45	0.82	0.46	0.46	0.83
Sulfur dioxide	Annual	80	0.14	0.14	0.16	0.18	0.18	0.23
	24-hour	365	1.8	1.8	2.1	0.50	0.50	0.57
	3-hour	1,300	11	11	13	0.87	0.87	1.0
Carbon monoxide	8-hour	10,000	4.2	4.2	7.3	0.041	0.041	0.072
	1-hour	40,000	28	28	46	0.070	0.070	0.11
PM_{10} ($PM_{2.5}$)	Annual	50 (15)	0.22	0.22	0.27	0.43	0.44	0.54
	24-hour	150 (65)	3.0	3.1	3.4	2.0	2.1	2.3
Cristobalite	[Annual[d]]	[10[d]]	0.0097	0.012	0.015	0.097	0.12	0.15

a. All numbers except regulatory limits are rounded to two significant figures.

b. Regulatory limits for criteria pollutants are from 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391 (see Table 3-5).

c. Sum of highest concentrations at the accessible land withdrawal boundary regardless of direction. See Appendix G, Section G.1, for additional information.

d. There are no regulatory limits for public exposure to cristobalite, a form of crystalline silica. An Environmental Protection Agency health assessment (EPA 1996a, page 1-5) states that the risk of silicosis is less than 1 percent for a cumulative exposure of 1,000 (micrograms per cubic meter) × years. Using a 70-year lifetime, an approximate annual average concentration of 10 micrograms per cubic meter was established as a benchmark for comparison.

Concentrations would differ between the construction phase and the emplacement and development activities. The rate of fugitive dust release and the subsequent PM_{10} concentrations would be higher during the construction phase than during emplacement and development activities because of the differing amount of land surface disturbance. Concentrations of cristobalite would be somewhat higher during construction because of the higher rate of excavation. Concentrations of gaseous criteria pollutants would increase during emplacement and development activities because two boilers rather than one would be operating, even though vehicle emissions would decrease during emplacement and development. The exception would be emissions of carbon monoxide, which would be related more to vehicle emissions than boiler emissions. For all pollutants, the slight differences in estimated concentrations do not provide meaningful distinctions between the scenarios.

After the completion of emplacement activities, DOE would continue monitoring and maintenance activities (from 2034 to 2110) at the repository until closure. During this period, air pollutant emissions would decrease. Subsurface excavation and handling activities would be complete, resulting in a lower level of emissions. Pollutant concentrations at the analyzed land withdrawal area boundary, therefore, would be lower than those listed in Table 4-3.

4.1.2.3.2 *Radiological Impacts to Air Quality from Continuing Construction, and Operation and Monitoring*

The handling of spent nuclear fuel and continued subsurface ventilation would result in radionuclide releases during the early years of the operation and monitoring phase (2010 to 2033). Radionuclides would be released during transfer of fuel assemblies from transportation casks to disposal containers. Releases of naturally occurring radon-222 from subsurface ventilation would continue.

After the completion of handling and emplacement operations, DOE would continue monitoring repository facility maintenance activities (2034 to 2110). During this period, the Department would continue to ventilate the subsurface. Releases of naturally occurring radon-222 from subsurface ventilation would continue.

Handling, Emplacement, and Continuing Development Activities (2010 to 2033). The main radionuclide released to the atmosphere from the handling of spent nuclear fuel assemblies in the Waste Handling Building would be krypton-85, a radioactive noble gas (NRC 1979, page 4-10). From 90 to 2,600 curies would be released annually, depending on the packaging scenario (TRW 1999a, page 75). Releases of other noble gas radionuclides would be very small. Estimated annual releases would be about 1.0×10^{-6} curie of krypton-81, 3.3×10^{-5} curie of radon-219, 1.4×10^{-2} curie of radon-220, 4.6×10^{-6} curie of radon-222, and very small quantities of xenon-127 (TRW 1999a, page 75). Releases of these radionuclides, which are noble gases, would not be affected by facility filtration systems. No releases of particulate or soluble radionuclides would be likely. These radionuclides would be captured in the water of the transfer pool or the Waste Handling Building air filtration system.

A continuing source of dose to members of the public and noninvolved (surface) workers would be releases of naturally occurring radon-222 from the subsurface. Estimated radon emissions during the continuing construction, operation, and monitoring period would be greater than those during the initial construction period because of the larger excavated volume, with more radon emanations from the repository walls and greater quantities exhausted by ventilation. The estimated differences in radon releases between the thermal load scenarios would be a function of the excavated repository volume, the exhaust ventilation flowrate, and the repository air exchange rate; the packaging scenario would not affect radon releases. The low thermal load scenario would have the largest excavated volume, largest exhaust flowrates and, therefore, the largest radon release. Appendix G, Section G.2, contains more information on repository volume, flowrates, and radon releases for the three thermal load scenarios.

Table 4-4 lists estimated annual doses and doses from 24 years of emplacement activities to the maximally exposed individuals (public and noninvolved worker) and potentially affected populations from radionuclide releases from surface and subsurface facilities. Appendix G, Section G.2, discusses the methods for calculating the doses, and Section 4.1.7 discusses potential human health impacts from these doses. Krypton-85 and the other noble gas radionuclides released from the surface facilities would be small contributors to the overall public dose in comparison to radon-222 decay products from the subsurface facilities. All the radionuclides released from the surface facilities would be very small contributors to the overall public dose with the largest, krypton-85, contributing less than 0.001 percent of the dose to the public and noninvolved workers.

The dose to the offsite maximally exposed individual, about 20 kilometers (12 miles) south of the repository, would be 19, 22, or 44 millirem for the 24 years of emplacement and development activities under the high, intermediate, or low thermal load scenario, respectively. For comparison, the annual dose to the offsite maximally exposed individual would be about 8, 9, or 18 percent, respectively, of the 10-millirem-per-year regulatory limit (40 CFR Part 61), although this limit does not apply to radon releases. The population dose would be 99, 120, or 230 person-rem, respectively. The dose to members of the public would vary by thermal load scenario but not by packaging scenario because naturally occurring radon-222 released from the subsurface would be the dominant dose contributor. Releases from surface facilities during spent nuclear fuel handling would make very small differences in the dose received.

The median dose to the maximally exposed noninvolved (surface) worker in an office about 100 meters (330 feet) from the South Portal would be about 82 millirem for 24 years of emplacement activities,

Table 4-4. Estimated radiation doses for maximally exposed individuals and populations during handling, emplacement, and development activities during operation and monitoring phase.[a,b]

	Thermal load					
	High		Intermediate		Low	
Impact	Total	Annual average[c]	Total	Annual average	Total	Annual average
Dose to public						
Offsite MEI[d] (millirem)	19	0.78	22	0.93	44	1.8
80-kilometer population[e] (person-rem)	99	4.1	120	4.9	230	10
Dose to noninvolved (surface) workers						
Maximally exposed noninvolved (surface) worker[f] (millirem)	82	3.4	82	3.4	82	3.4
Yucca Mountain noninvolved (surface) worker population[g] (person-rem)						
Uncanistered scenario	63	2.6	75	3.1	140	5.7
Disposable canister scenario	62	2.6	74	3.1	130	5.6
Dual-purpose canister scenario	62	2.6	74	3.1	130	5.6
Nevada Test Site noninvolved worker population[h] (person-rem)	0.12	0.005	0.14	0.0059	0.27	0.012

a. Numbers are rounded to two significant figures.

b. Emplacement activities during the operation and monitoring phase would last 24 years, from 2010 to 2033. Continued subsurface development activities would last 22 years.

c. Annual average values reflect the increasing repository volume and radon release during subsurface development.

d. MEI = maximally exposed individual; about 20 kilometers (12 miles) south of the repository.

e. The population includes about 28,000 individuals within 80 kilometers (50 miles) of the repository (see Section 3.1.8).

f. Maximally exposed noninvolved worker location would be in the South Portal Operations Area.

g. The analysis considered noninvolved workers at both the North and South Portal Operations Areas.

h. DOE workers at the Nevada Test Site [6,600 workers (DOE 1996f, page 5-14) 50 kilometers (30 miles) east-southeast near Mercury, Nevada].

regardless of the thermal load scenario. The doses would be constant across the thermal load scenarios because the volume of the development area ventilated in each scenario would be similar. The estimated number of noninvolved workers at the repository site, whom the analysis assumed would all be at the North Portal Operations Area, would vary among the packaging scenarios. The dose to the noninvolved worker population would vary in proportion to (1) the amount of radon-222 released from the subsurface, because radon-222 would dominate the radiation doses, and (2) the number of noninvolved (surface) workers. At the North Portal Operations Area, there would be about 1,300 workers for the uncanistered packaging scenario and about 1,000 workers for the disposable canister and dual-purpose canister packaging scenarios. There would be an estimated 70 additional workers at the South Portal Operations Area regardless of packaging scenario. The combination of the low thermal load scenario (which would have the largest radon release) and the uncanistered packaging scenario would result in the highest noninvolved worker population dose, 140 person-rem over the 24-year emplacement period. Workers at the South Portal Operations Area, who would be near the ground-level releases of radon from this portal, would receive most of the population dose. Section 4.1.7 discusses impacts to workers directly involved in handling, emplacement, and continuing development activities.

Monitoring and Maintenance Activities (2034 to 2110). Monitoring would continue and maintenance would begin immediately after the completion of emplacement activities. One of the first activities would be the decontamination of the surface material handling facilities. This activity, which would last 3 years, would have minimal potential impact on air quality during monitoring and maintenance activities, except there would be a larger population of noninvolved workers employed for decontamination and these workers would be exposed to naturally occurring radon ventilated from the subsurface. The potential for releases of radionuclides from the surface facilities during these activities would be minimal and impacts would be very small.

Table 4-5 lists estimated annual doses and total doses that would occur over the 76 years of monitoring and maintenance activities to maximally exposed individuals and potentially affected populations from subsurface radon releases. Section 4.1.7 discusses potential radiological impacts from these doses. The dose over the 70-year lifetime of the hypothetical offsite maximally exposed individual, about 20 kilometers (12 miles) south of the repository, would be 30, 36, or 88 millirem during monitoring and maintenance activities of the high, intermediate, or low thermal load scenario, respectively. For comparison, the annual dose to the offsite maximally exposed individual would be about 4, 5, or 13 percent, respectively, of the 10-millirem-per-year regulatory limit (40 CFR Part 61), although this limit would not apply to repository radon releases. The hypothetical offsite maximally exposed individual would receive a higher dose than the noninvolved worker maximally exposed individual because air would be removed from the repository through exhaust shafts, which would result in more radon being carried to the exposure point for the offsite individual than to that for the noninvolved worker.

Table 4-5. Estimated radiation doses to maximally exposed individuals and populations from radon-222 releases from subsurface monitoring and maintenance activities (including decontamination) during operation and monitoring phase.[a,b]

	Thermal load					
	High		Intermediate		Low	
Impact	Total	Annual	Total	Annual	Total	Annual
Dose to public						
Offsite MEI[c] (millirem)	30	0.43	36	0.51	88	1.3
80-kilometer population[d] (person-rem)	160	2.1	190	2.5	470	6.2
Dose to noninvolved (surface) workers						
Maximally exposed noninvolved (surface) worker[e] (millirem)	2.0	0.039	2.3	0.046	5.8	0.12
Yucca Mountain noninvolved (surface) worker population (person-rem)						
Uncanistered scenario	0.14	0.025, 0.00087[f]	0.16	0.029, 0.0010[f]	0.40	0.072, 0.0026[f]
Disposable canister scenario	0.12	0.018, 0.00087[f]	0.14	0.021, 0.0010[f]	0.34	0.052, 0.0026[f]
Dual-purpose canister scenario	0.12	0.019, 0.00087[f]	0.14	0.022, 0.0010[f]	0.35	0.055, 0.0026[f]
Nevada Test Site noninvolved worker population[g] (person-rem)	0.27	0.0035	0.32	0.0042	0.79	0.010

a. Numbers are rounded to two significant figures.

b. Decontamination of surface facilities during the operation and monitoring phase would last 3 years at the beginning of the 76 years of monitoring and maintenance activities, which would last until 2110.

c. MEI = maximally exposed individual; about 20 kilometers (12 miles) south of the repository. Values are for a 70-year lifetime.

d. The population includes about 28,000 individuals within 80 kilometers (50 miles) of the repository (see Section 3.1.8).

e. Maximally exposed noninvolved worker location would be at the South Portal Operations Area. Values are for a 50-year onsite working lifetime.

f. First value is for the 3 years of decontamination activities; second value is for the 73 years of monitoring and maintenance.

g. DOE workers at the Nevada Test Site [6,600 workers (DOE 1996f, page 5-14) 50 kilometers (30 miles) east-southeast near Mercury, Nevada].

The population dose for 76 years of monitoring and maintenance activities would be 160, 190, or 470 person-rem, respectively. The dose to the maximally exposed noninvolved (surface) worker, who would be at the South Portal, would be 2.0, 2.3, or 5.8 millirem for a 50-year working lifetime during monitoring and maintenance activities for the high, intermediate, or low thermal load scenario, respectively. The dose over 76 years to the repository noninvolved (surface) worker population, which would include all surface workers (most of whom would be at the North Portal Operations Area), would vary depending on the thermal load scenario and the packaging scenario. The combination of the low thermal load scenario (largest radon release) and the uncanistered packaging scenario (largest noninvolved worker population) would result in the highest noninvolved (surface) worker population dose, 0.40 person-rem for the 76-year monitoring and maintenance period. The extension of monitoring and maintenance activities to 276 years would extend these impacts to future generations of workers and the public. Section 4.1.7 discusses impacts to workers directly involved in monitoring and maintenance activities.

4.1.2.4 Impacts to Air Quality from Closure (2110 to 2125)

This section describes potential nonradiological and radiological air quality impacts during the closure phase of the proposed Yucca Mountain Repository, which would begin in 2110 and last 6, 6, or 15 years for the high, intermediate, or low thermal load scenario, respectively. Activities during this phase would include the closure of subsurface repository facilities, the decommissioning of surface facilities, and the reclamation of remaining disturbed lands.

4.1.2.4.1 *Nonradiological Impacts to Air Quality from Closure*

During the closure phase, nonradiological air emissions would result from the backfilling and sealing of the repository subsurface and the reclamation of disturbed surface lands. Air emission sources would include the following:

- Fugitive dust emissions from the handling, processing (in a backfill preparation plant), and transfer of excavated rock to the subsurface

- Releases of gaseous criteria pollutants (nitrogen dioxide, sulfur dioxide, etc.) and particulate matter from fuel consumption

- Particulate matter from a concrete batch plant

- Fugitive dust releases from demolishing buildings, removing debris, and reclaiming land

- Cristobalite releases associated with handling and storing excavated rock

Table 4-6 lists potential impacts at the location of the offsite maximally exposed individual from the closure of the repository for the high, intermediate, and low thermal load scenarios.

Gaseous criteria pollutants would result primarily from vehicle exhaust. The low thermal load scenario would have somewhat higher emissions because of a larger vehicle fleet. During the closure phase, the maximum offsite concentrations of nitrogen dioxide, sulfur dioxide, carbon monoxide, and PM_{10} would be small, with the gaseous criteria pollutant concentrations being less than 1 percent of the applicable regulatory limits. The 24-hour PM_{10} concentrations would be about 5 percent of the regulatory limit for all three thermal load scenarios. Levels of $PM_{2.5}$ should also be well below the applicable standard, because a large fraction of the particulates listed for PM_{10} would be larger than 2.5 micrometers. The analysis did not consider standard construction dust suppression measures, which DOE would implement and which would further lower projected PM_{10} concentrations by reducing fugitive dust from surface-disturbing activities. These measures would not affect the concentrations of $PM_{2.5}$ because fugitive dust is not a major source of $PM_{2.5}$.

As discussed for the construction phase (see Section 4.1.2.2.1), the analysis of the closure phase assumed that 28 percent of the fugitive dust released from the muck pile would be cristobalite. Table 4-6 lists

Table 4-6. Estimated maximum criteria pollutant and cristobalite concentrations at the analyzed land withdrawal area boundary during closure phase (micrograms per cubic meter).[a]

			Maximum concentration[c]			Percent of regulatory limit		
			Thermal load			Thermal load		
Pollutant	Averaging time	Regulatory limit[b]	High	Intermediate	Low	High	Intermediate	Low
Nitrogen dioxide	Annual	100	0.080	0.13	0.12	0.080	0.13	0.12
Sulfur dioxide	Annual	80	0.0076	0.013	0.011	0.097	0.016	0.014
	24-hour	365	0.57	0.093	0.082	0.016	0.025	0.022
	3-hour	1,300	0.045	0.74	0.66	0.035	0.057	0.050
Carbon monoxide	8-hour	10,000	0.67	1.1	0.98	0.0065	0.011	0.0095
	1-hour	40,000	4.1	6.6	5.9	0.010	0.017	0.015
PM_{10} ($PM_{2.5}$)	Annual	50 (15)	0.52	0.56	0.53	1.0	1.1	1.1
	24-hour	150 (65)	6.5	6.8	6.6	4.3	4.5	4.4
Cristobalite	[Annual[d]]	[10[d]]	0.010	0.014	0.0053	0.10	0.14	0.053

a. All numbers except regulatory limits are rounded to two significant figures.

b. Regulatory limits from 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391 (see Table 3-5).

c. Sum of the highest concentrations at the accessible land withdrawal boundary regardless of direction.

d. There are no regulatory limits for public exposure to cristobalite, a form of crystalline silica. An Environmental Protection Agency health assessment (EPA 1996a, page 1-5) states that the risk of silicosis is less than 1 percent for a cumulative exposure of 1,000 (micrograms per cubic meter) × years. Using a 70-year lifetime, an approximate annual average concentration of 10 micrograms per cubic meter was established as a benchmark for comparison.

estimated cristobalite concentrations to which the offsite maximally exposed individual would be exposed during closure. As noted in Section 4.1.2.2.1, there are no public limits for exposure to cristobalite, so the analysis used an approximate annual average concentration of 10 micrograms per cubic meter as a benchmark. The postulated exposure to cristobalite from closure activities would be small, about 0.014 microgram per cubic meter or less for all three thermal load scenarios. For all pollutants, the slight differences in estimated concentrations do not provide meaningful distinctions between any of the scenarios.

4.1.2.4.2 *Radiological Impacts to Air Quality from Closure*

During the closure phase the only doses from releases of radionuclides to the atmosphere would be from naturally occurring radon-222 and its radioactive decay products released from the continued ventilation of subsurface facilities. The analysis assumed that subsurface ventilation would continue for the duration of the closure phase, lasting 6, 6, or 15 years for the high, intermediate, or low thermal load scenario, respectively. Exposure to the noninvolved (surface) worker population and the public would occur during the 6-year period while this group was working on surface facility closure. For the low thermal load scenario, exposures to members of the public and noninvolved workers would occur during a 15-year period.

Table 4-7 lists estimated annual doses and total doses from radon-222 during the closure phase to maximally exposed individuals and potentially affected populations from radionuclide releases from subsurface facilities. Section 4.1.7 discusses potential radiological impacts from these doses. The total dose to the offsite maximally exposed individual about 20 kilometers (12 miles) south of the repository would be 2.6, 3.0, or 19 millirem for the 6, 6, or 15 years of closure activities under the high, intermediate, or low thermal load scenario, respectively. Although the limit does not apply to releases of radon, the annual dose to the offsite maximally exposed individual would be about 4, 5, or 12 percent, respectively, of the 10 millirem-per-year regulatory limit (40 CFR Part 61). The population dose would be 13, 15, or 93 person-rem, respectively, for the closure phase. The dose to the maximally exposed noninvolved (surface) worker at the South Portal would be 0.24, 0.28, or 1.7 millirem, respectively, for

Table 4-7. Estimated radiation doses to maximally exposed individuals and populations from radon-222 releases from the subsurface during closure phase.[a,b]

	Thermal load					
	High		Intermediate		Low	
Release	Total	Annual	Total	Annual	Total	Annual
Dose to public						
MEI[c] (millirem)	2.6	0.43	3.0	0.50	19	1.2
80-kilometer population[d] (person-rem)	13	2.1	15	2.5	93	6.2
Dose to noninvolved (surface) workers						
Maximally exposed noninvolved (surface) worker[e] (millirem)	0.24	0.039	0.28	0.046	1.7	0.12
Yucca Mountain noninvolved (surface) worker population (person-rem)						
Uncanistered scenario	0.041	0.0068	0.048	0.0080	0.12	0.020
Disposable canister scenario	0.029	0.0049	0.035	0.0058	0.086	0.014
Dual-purpose canister scenario	0.032	0.0053	0.037	0.0062	0.093	0.016
Nevada Test Site noninvolved worker population[f] (person-rem)	0.021	0.0035	0.025	0.0042	0.16	0.010

a. Numbers are rounded to two significant figures.

b. The closure phase would begin in 2110 and last 6, 6, or 15 years for the high, intermediate, or low thermal load scenario, respectively.

c. MEI = maximally exposed individual; public MEI location would be 20 kilometers (12 miles) south of the repository.

d. The population includes about 28,000 individuals within 80 kilometers (50 miles) of the repository (see Section 3.1.8).

e. Maximally exposed noninvolved worker location would be at the South Portal Operations Area.

f. DOE workers at the Nevada Test Site [6,600 workers (DOE 1996f, page 5-14) 50 kilometers (30 miles) east-southeast near Mercury, Nevada].

the entire closure phase. The dose to the noninvolved repository (surface) worker population would vary depending on the thermal load and packaging scenarios. The combination of the low thermal load scenario (largest radon releases) and the uncanistered packaging scenario (largest noninvolved worker population) would result in the highest total noninvolved worker population dose, 0.12 person-rem.

4.1.3 IMPACTS TO HYDROLOGY

The following sections describe environmental impacts to the hydrology of the Yucca Mountain region, first from performance confirmation activities (Section 4.1.3.1), then from construction, operation and monitoring, and closure actions. The latter actions are presented in terms of surface water (Section 4.1.3.2) and groundwater (Section 4.1.3.3). Chapter 5 discusses long-term postclosure impacts resulting from repository performance.

The analysis evaluated surface-water and groundwater impacts separately. The attributes used to assess surface-water impacts were the potential for introduction and movement of contaminants, potential for changes to runoff and infiltration rates, alterations in natural drainage, and potential for flooding to aggravate or worsen any of these conditions. The region of influence for surface-water impacts included areas near construction and operation activities that would be susceptible to erosion, areas affected by permanent changes in flow, and downstream areas that would be affected by eroded soil or potential spills of contaminants. The analysis of surface-water impacts considered known perennial and intermittent lakes, surface streams, and washes.

The analysis assessed groundwater impacts to determine the potential for a change in infiltration rates that could affect groundwater, the potential for introduction of contaminants, the availability of groundwater for use during construction and operations, and the potential that such use would affect other users. The region of influence for this analysis included aquifers under the areas of construction and operations that DOE could use to obtain water and downstream aquifers that repository use or long-term releases from the repository could affect. The evaluation of groundwater impacts considered perennial yields of groundwater resources in comparison to known uses and requirements.

The conclusions of the evaluations discussed in this section are as follows:

- Repository operation would result in minor changes to runoff and infiltration rates.
- Water demand under scenarios with the highest consumption would be below the Nevada State Engineer's ruling of perennial yield (the amount that can be withdrawn annually without depleting reserves) for the Jackass Flats groundwater basin. However, the highest demand scenario in combination with ongoing Nevada Test Site demand from the same basin would exceed the lowest estimates of perennial yield.
- The combined water demand of the repository and the Nevada Test Site would, at most, have minor impacts on the availability of groundwater in the Amargosa Desert in comparison to the quantities of water already being withdrawn there.
- The potential for flooding at the repository site is extremely small.

4.1.3.1 Impacts to Hydrology from Performance Confirmation

Performance confirmation activities would be unlikely to cause large impacts to the surface hydrology at the Yucca Mountain site, where there are no perennial streams or other permanent surface-water bodies. As during site characterization, DOE would design roads or other surface disturbances to minimize alterations to natural flowpaths and nearby washes (such as Drill Hole Wash). (See Section 4.1.4.2 and Chapter 11 for discussions of protection of waters of the United States.)

The performance confirmation studies would not adversely affect groundwater quality because DOE would use only limited quantities and types of hazardous materials, and activities involving such materials would be in strict accordance with applicable regulations and DOE Orders. State and Federal environmental, health, and safety regulations, as well as its own internal rules would require DOE to manage hazardous materials carefully and to clean up and report any measurable spills or releases promptly. Thus, the control of hazardous materials would be such that the potential for groundwater contamination would be very low.

DOE would use existing groundwater wells to support performance confirmation activities (for example, wells J-12 and J-13). In addition, it could use the existing C-well complex for aquifer testing and for a backup water supply. The Department expects water use from wells J-12 and J-13 to be similar to or less than that experienced during site characterization, which averaged about 0.093 million cubic meters (75 acre-feet) a year from 1993 through 1997 (not including test pumping at the C-well complex) (see Table 3-15). This would equal approximately 2 to 9 percent of the estimated perennial yield of the hydrographic basin (Jackass Flats) of 1.1 million to 4.9 million cubic meters (880 to 4,000 acre-feet) a year (see Table 3-11). Therefore, adverse effects on the quantity of groundwater resources would be unlikely. DOE could conduct pump tests of the aquifer at the C-well complex during performance confirmation activities. Under such tests, the amount pumped probably would be similar to that pumped during site characterization [about 0.23 million cubic meters (190 acre-feet) per year]. Even with this additional quantity, water demand would still be well below the lowest estimates of the basin's perennial yield, and DOE would manage water withdrawn from the C-well complex as part of aquifer testing in the same manner it has used for site characterization activities (that is, discharged to a spreading basin with State of Nevada concurrence and credit for groundwater recharge).

4.1.3.2 Impacts to Surface Water from Construction, Operation and Monitoring, and Closure

There are no perennial streams or other permanent surface-water bodies in the Yucca Mountain vicinity. The occurrence of natural surface water is limited to short periods when precipitation lasts long enough or is of high enough intensity to generate runoff to the natural drainage channels. In rare instances, runoff from the area of the proposed repository and support facilities could reach such channels as Drill Hole Wash, then flow to Fortymile Wash, and eventually reach the Amargosa River underground. Under most precipitation events, however, water simply soaks into the ground and is usually lost to evapotranspiration or, if there is enough to accumulate in drainage channels, soaks into the dry washes before traveling far, becoming potential recharge in these localized areas. Other potential sources of surface water associated with the Proposed Action, such as the water used for dust suppression, would be a result of pumping groundwater to the surface.

The surface-water impacts of primary concern are related to the following:

- Introduction and movement of contaminants
- Changes to runoff or infiltration rates
- Alterations of natural drainage
- Impacts to floodplains

Discharges of Water to the Surface

During the 5-year initial construction period (2005 to 2010), and during the emplacement and development activities of the continuing construction, operation, and monitoring period that would follow (2010 to 2033), sources of surface water other than precipitation would be limited primarily to the water DOE would use for dust suppression on the surface and below ground (with accumulations pumped back to the surface). Sanitary sewage, which would be piped to septic tank and drainage field systems, would not produce surface water. In addition, DOE would pump fresh water (groundwater) at the site and store it in tanks.

DOE has evaluated dust suppression actions during characterization efforts at the Yucca Mountain site for their potential to cause deep infiltration of water (DOE 1997i, pages 51 to 53 and 73). The evaluation concluded that the amount of water actually used for dust suppression activities during site characterization did not cause water to penetrate the underlying rock. Studies at the site on infiltration capacities of natural soils (Flint, Hevesi, and Flint 1996, pages 57 to 59), when combined with application rates measured during site characterization, show that runoff or deep infiltration would not occur as a result of water applications for dust suppression. DOE would establish controls as necessary to ensure that water application for subsurface and surface dust control did not affect repository performance or result in large impacts.

Water would be pumped from the surface facilities to the subsurface during the construction phase and operation and monitoring phase while subsurface development continued. DOE would collect excess water from dust suppression applications and water percolating into the repository drifts, if any, and pump it to the surface, generating another source of surface water. Water pumped from the subsurface would go to an evaporation pond at the South Portal Operations Area. The pond would be lined with heavy plastic to prevent infiltration or water loss. Table 4-8 lists discharge estimates to the South Portal

Table 4-8. Annual water discharges to South Portal evaporation pond for thermal load scenarios.[a,b]

Phase	High thermal load	Intermediate thermal load	Low thermal load
Construction			
Discharge (cubic meters)[c]	8,400	10,000	10,000
Duration (years)	5	5	5
Operation and monitoring			
Discharge (cubic meters)	7,900	9,500	33,000
Duration (years)	22	22	22

a. Source: TRW (1999b, pages 6-9 and 6-18).

b. Estimated at 13 percent of the process water pumped to the subsurface based on Exploratory Studies Facility construction experience.

c. To convert cubic meters to gallons, multiply by 264.18.

evaporation pond for the three thermal load scenarios. During the operation and monitoring phase, the quantity of water discharged would vary in proportion to the amount of subsurface excavation. DOE would also investigate the feasibility of recycling all, or a portion, of this water.

The operation of heating and air conditioning systems at the North Portal Operations Area would result in the generation of wastewater (primarily from cooling tower blowdown and water softener regeneration) that DOE would discharge to the North Portal evaporation pond, which would be lined with heavy plastic. Water collected from the emplacement side of the subsurface area, if any, would also be pumped to this pond after verification that it was not contaminated. Table 4-9 lists discharge estimates to the North Portal evaporation pond for each packaging scenario during the operation and monitoring phase.

Table 4-9. Annual water discharges to North Portal evaporation pond during operation and monitoring phase for each packaging scenario.[a]

	Packaging scenario[b]		
Factor	UC	DISP	DPC
Discharge (million liters)[c]	30	25	25
Duration (years)	24	24	24

a. Source: TRW (1999a, page 75).

b. UC = uncanistered; DISP = disposable canister; DPC = dual-purpose canister.

c. To convert liters to gallons, multiply by 0.26418.

The South Portal evaporation pond would be double-lined with polyvinyl chloride and would have a leak detection system (TRW 1998f, page 16). The North Portal evaporation pond, which is intended primarily for cooling and heating process water, would, at a minimum, have a polyvinyl chloride liner (TRW 1998f, pages 16 and 28). With proper maintenance, both ponds should remain intact and would have no effect on the site. Section 4.1.4.2 discusses impacts to wildlife that could result from the presence of these ponds. Chapter 9 discusses mitigation measures associated with the Proposed Action.

Other uses of water during the continuing construction, operation, and monitoring period would occur in the repository facilities and would have little, if any, potential to generate surface water. These sources include the washdown stations and the pools in the Waste Handling Building. Water from either of these sources would be managed as liquid low-level radioactive waste and treated in the Waste Treatment Building. Water from the treatment process would be recycled to the extent practicable, and residues and solids would be prepared for offsite shipment and disposal.

The quantity of water discharges to the surface from monitoring and maintenance activities and from closure would be similar to or less than those discussed for the initial construction period and emplacement and development activities. The evaporation ponds would no longer be in use but other manmade sources of surface water should be very similar; water storage tanks would still be in use, there would be sanitary sewage, and dust suppression activities would occur.

Potential for Contaminant Spread to Surface Water

The potential for contaminants to reach surface water would generally be limited to the occurrence of a spill or leak followed by a rare precipitation or snow melt event large enough to generate runoff. DOE would design each facility that would contain radioactive material at the repository site such that flooding would not threaten material in the facility. Consistent with DOE Order 6430.1A, *General Design Criteria*, Nuclear Regulatory Commission licensing requirements, and national standards such as those of the American National Standards Institute, facilities in the Restricted Area (for the management of radioactive materials) would be built to withstand the probable maximum flood. For example, if the footprint of a facility in the Restricted Area was within the predicted natural inundation level of the probable maximum flood, one way to protect the facility would be to build up its foundation so it would be above the flood level and associated debris flows (TRW 1998f, pages 32 to 37). Other facilities would be designed and built to withstand a 100-year flood, consistent with common industrial practice. However, the inundation levels expected from a 100-year, 500-year, or regional maximum flood would represent little hazard to the proposed repository, the portals of which would be at higher elevations than the flood-prone areas (TRW 1999h, page 2-7).

DOE would minimize the potential for a contaminant spread by managing spills and leaks in the proper and required manner. Activities at the site would adhere to a spill prevention, control, and countermeasures plan [Kiewit (1997, all) is an example] to comply with environmental regulations and to ensure best management practices. The plan would describe the actions DOE would take to prevent, control, and remediate spills. It would also describe the reporting requirements that would accompany the identification of a spill. As an additional measure to reduce the potential for contaminant release to surface water, DOE would build two stormwater retention basins near the North Portal Operations Area, one for the Restricted Area and one for the balance-of-plant facilities. The basin for the Restricted Area would contain the runoff from a storm consistent with the probable maximum flood. The basin for the balance-of-plant area would contain the runoff from a storm consistent with a 100-year flood.

The primary sources of potential surface-water contaminants during both the construction and the operation and monitoring phases would be the fuels (diesel and gasoline) and lubricants (oils and greases) needed for equipment. Both the South and North Portal Operations Areas would contain fuel-oil storage tanks. These tanks would be in place relatively early in the construction phase. Each would be constructed with an appropriate containment structure (consistent with 40 CFR Part 112). Other organic materials such as paints, solvents, strippers, and concrete additives would be present during the construction phase but in smaller quantities and much smaller containers.

The operation and monitoring phase would involve the use of other chemicals, particularly in the Waste Treatment Building, where the liquid low-level radioactive waste treatment process, for example, would include the use of liquid sodium hydroxide and sulfuric acid. In addition, this phase would require relatively small quantities of cleaning solvents [about 480 to 1,300 liters (130 to 330 gallons) a year] (TRW 1999a, page 74). Because these materials would be used and stored inside buildings and managed in accordance with applicable environmental, health, and safety standards and best management practices, there would be little potential for contamination to spread through contact with surface water.

In addition, liquid low-level radioactive waste present in the Restricted Area would be treated in the Waste Treatment Building to stabilize such material with cement or grout before it left the facility. Similarly, hazardous waste and mixed waste would be maintained and moved in closed containers. These conditions would minimize the potential for spills and leaks that could lead to contaminant spread.

Radioactive materials present during the continuing construction, operation, and monitoring period would be managed in the Restricted Area of the North Portal Operations Area. This would include the

Carrier Parking Area and Carrier Preparation Building across Midway Valley Wash to the northeast. The radiological materials would always be in containers or casks except when they were in the Waste Handling and Waste Treatment Buildings. In those buildings, facility system and component design would prevent inadvertent releases to the environment; drainlines would lead to internal tanks or catchments, air emissions would be filtered, fuel pools would have secondary containment and leak detection, and other features would have similar safety or control components.

During the continuing construction, operation, and monitoring period a surface environmental monitoring system would monitor the surface areas and groundwater for radioactive and hazardous substance release (DOE 1998a, Volume 2, page 4-37). It would also monitor facility effluents and testing wells for the presence of radiological or other hazardous constituents that could indicate a release from an operation activity. The combination of minor sources of surface water and the prevention and control of contaminant releases would limit the potential for contaminant spread by surface water.

Monitoring and maintenance activities after the completion of emplacement would involve a decrease in general activities at the site and, accordingly, less potential for spills or releases to occur. Decontamination actions that would follow emplacement could present other risks, due to the possible presence of decontamination chemicals and the start of new work activities. DOE would continue to use controls, monitoring, response plans and procedures, and regulatory requirements to limit the potential for spills or releases to occur from these activities.

The potential for contaminant spread would be limited during the closure phase and would be reduced further during postclosure care of the site. As in the other phases, engineering controls, monitoring, and release response requirements would limit the potential for contaminants to reach surface water.

Potential for Changes to Surface Water Runoff or Infiltration Rates

Construction activities that disturbed the land surface would alter the rate at which water could infiltrate the disturbed areas. A maximum of about 2 square kilometers (500 acres) of land would be disturbed during the construction and operation and monitoring phases (see Chapter 2). Depending on the type of disturbance, the infiltration rate could increase (for example, in areas with loosened soil) or decrease (for example, in areas where construction activities had compacted the soil or involved the installation of relatively impermeable surfaces like asphalt pads, concrete surfaces, or buildings). Most of the land disturbance during construction would result in surfaces with lower infiltration rates; that is, the surfaces would be less permeable than natural soil conditions and would cause an increase in runoff. However, DOE expects the change in the amount of runoff actually reaching the drainage channels to be relatively minor, because repository construction would affect a relatively small amount of the natural drainage area. For example, one side of the proposed North Portal facilities is drained by Midway Valley Wash and the other is drained by Drill Hole Wash. The 0.6 square kilometer (150 acres) of disturbance at the North Portal area (of the total 2 square kilometers disturbed) would be small (less than 4 percent) in comparison to the estimated 18 square kilometers (4,400 acres) that comprise the drainage area for the Midway Valley and Drill Hole Washes by the time they reach the North Portal area (Bullard 1992, Table 5).

Monitoring and maintenance activities would not disturb additional land and, therefore, would have no notable impacts to runoff rates in the area. Reclamation of previously disturbed land would restore preconstruction runoff rates.

DOE anticipates that closure activities would disturb only land that had been previously disturbed during earlier phases. The removal of structures and impermeable surfaces would decrease runoff from these areas and should put them in a condition closer to that of the surrounding natural surfaces. Reclamation efforts such as topsoil replacement and revegetation should help restore the disturbed areas to nearly natural conditions in relation to infiltration and runoff rates. The construction of monuments as long-lasting markers of the site use would be likely to make their locations impervious to infiltration but, as described above, change in runoff from the relatively small impervious areas would be small in comparison to the total drainage area.

Potential for Altering Natural Surface-Water Drainage

Construction activities can alter natural drainage systems if they (1) increase the erosion and sedimentation process (material eroded from one location in the drainage system is subsequently deposited in another location), or (2) place a structure, facility, or roadway in a drainage channel or flood zone. Section 4.1.4.4 discusses erosion issues. The focus of this section is the planned construction of structures, facilities, or roadways over natural drainage channels.

Pursuant to Executive Order 11988, *Floodplain Management*, each Federal agency is required, when conducting activities in a floodplain, to take action to reduce the risk of flood damage; minimize the impact of floods on human safety, health, and welfare; and restore and preserve the natural and beneficial values served by floodplains. DOE regulations implementing this Executive Order are at 10 CFR Part 1022.

If DOE received authorization to construct, operate and monitor, and close a geologic repository at Yucca Mountain, it would ship spent nuclear fuel and high-level radioactive waste to the repository for a period of about 24 years beginning in 2010. Some transportation-related construction, operation, and maintenance actions associated with the DOE proposal would occur in the floodplains of as many as four washes in the Yucca Mountain vicinity. Other construction, operation, and maintenance actions could occur in floodplains or wetlands elsewhere in Nevada along one of five alternative rail corridors DOE could select to transport spent nuclear fuel and high-level radioactive waste to the repository. Construction, operation, and maintenance actions could also occur in floodplains or wetlands at one of three alternative intermodal transfer station sites in Nevada if DOE chose a heavy-haul truck route for transportation.

Construction, operation, and maintenance of a rail line, roadways, and bridges in the Yucca Mountain vicinity could affect the 100- and 500-year floodplains of Fortymile Wash, Busted Butte Wash, Drill Hole Wash, and Midway Valley Wash at Yucca Mountain. The floodplains affected and the extent of activities in the floodplains would depend on the route DOE selected.

Appendix L contains a floodplain/wetlands assessment that describes in detail the actions that DOE could take to construct, operate, and maintain a branch rail line or highway route in the Yucca Mountain vicinity. The assessment analyzed the potential effects of these actions on the floodplains of Fortymile Wash, Busted Butte Wash, Drill Hole Wash, and Midway Valley Wash. The analysis indicated that consequences of the actions DOE could take in or near the floodplains of these four washes would be minor and unlikely to increase the impacts of floods on human health and safety or harm the natural and beneficial values of the affected floodplains. It also indicated that there are no delineated wetlands at Yucca Mountain.

The assessment in Appendix L presents a programmatic comparison of what is known about the floodplains, springs, and riparian areas along the five alternative rail routes and at the three alternative intermodal transfer station sites. In general, wetlands have not been delineated along the rail routes or at the three station sites. If DOE selected a rail corridor or heavy-haul truck route to transport spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site, it would prepare a detailed floodplain/wetlands assessment of the selected alternative.

Repository-related structures could affect small drainage channels or washes. DOE expects to address these other washes with minor diversion channels, culverts, or similar drainage control techniques.

Closure of the repository should involve no actions that would alter natural drainage beyond those from the other phases. Areas where facilities were removed would be graded to match the natural topography to the extent practicable. Monuments would not be constructed in locations where they would alter important drainage channels or patterns and, in the process, back up or divert any meaningful volume of runoff.

4.1.3.3 Impacts to Groundwater from Construction, Operation and Monitoring, and Closure

This section identifies potential impacts to groundwater. Section 3.1.4 describes existing groundwater characteristics and uses in the Yucca Mountain vicinity. The potential impacts discussed in this section would be associated with the relatively short duration of the active life of the repository, which would include construction, operation and monitoring, and closure. The following impacts would be of primary concern during the active life of the repository:

- The potential for a change in infiltration rates that could increase the amount of water in the unsaturated zone and adversely affect the performance of waste containment in the repository, or decrease the amount of recharge to the aquifer

- The potential for contaminants to migrate to the unsaturated or saturated groundwater zones during the active life of the repository

- The potential for water demands associated with the repository to deplete groundwater resources to an extent that could affect downgradient groundwater use or users

This section discusses these potential impacts in general terms, primarily in relation to changes from existing conditions.

Infiltration Rate Changes

As discussed in Section 4.1.3.2, surface-disturbing construction activities would alter infiltration rates in the repository area. In the Yucca Mountain environment, water rarely travels long distances on the surface before infiltrating into the ground or evaporating. If construction activities resulted in disturbed land that was loose or broken up, local infiltration would increase and the amount of runoff reaching nearby drainage channels would decrease accordingly. Conversely, completed construction that involved either compacted soil or facility surfaces (concrete pads, asphalt surfaces, etc.) would result in less local infiltration and more water available to reach the drainage channels and then infiltrate into the ground. However, the location where infiltration takes place can have an effect on what happens to the water. That is, in some locations the water would be more likely to contribute to deep infiltration and possibly even to recharge to the aquifer.

In the semiarid environment in the Yucca Mountain vicinity, surface areas where meaningful recharge to the aquifer can occur are generally places such as Fortymile Wash (Section 3.1.4.2.2), which collects runoff from a large drainage area. Enough water can accumulate there to cause deep infiltration and occasional recharge. There is not enough precipitation or runoff in most other areas to generate infiltration deep enough to prevent its loss to evapotranspiration between precipitation events. In general, this will be the case even when land disturbance causes an increase in local infiltration. The most likely way that recharge could be affected would be for land disturbance to cause additional runoff (as from constructed facilities) that could accumulate in areas such as Fortymile Wash, and the effect would be a potential for increased recharge. However, given the dry climate and relatively small amount of potentially disturbed area in relation to the surrounding unchanged areas, the net change in infiltration would be small.

Surface disturbances could change infiltration rates in areas where the layer of unconsolidated material is thin and the disturbance resulted in the exposure of fractured bedrock. Cracks and crevices in the bedrock could provide relatively fast pathways for the movement of water to deep parts of the unsaturated zone (TRW 1999h, pages 2-19 to 2-21), where the water would be less susceptible to evapotranspiration. These effects would be applicable to the Emplacement and Development Shaft Operations Areas, which would be on steeper terrain, uphill from the North and South Portal Operations Areas, where the depth of unconsolidated material is likely to be thin. However, the amount of disturbed land would be small in comparison to the surrounding undisturbed area, and any net change in infiltration would be small.

Subsurface activities would have the potential to affect the amount of water in the unsaturated zone that could infiltrate more deeply, possibly even as recharge to the aquifer. These activities would include measures to minimize the quantities of standing or infiltrating water in the repository by pumping it to the surface for evaporation. Potential sources of this water could include water percolating in from the unsaturated zone and water pumped from the surface for underground dust control measures. The latter should involve the largest volume by far, much of which would be brought to the surface with the excavated rock generated by tunnel boring machines. Excess water in the subsurface would evaporate (the underground areas would be ventilated), be collected and pumped to the surface, or be lost as infiltration to cracks and crevices in the rock. During excavation of the Exploratory Studies Facility, DOE tracked water use and used water tracers to help track its movement. The purpose of these actions was to minimize loss of this water to the subsurface environment and to ensure that subsurface water use did not adversely affect either future repository performance or ongoing site investigations (DOE 1997j, all). This careful use of water in the subsurface would continue during repository construction activities. Given the mechanisms to remove the water (excavated rock removal, ventilation, and pumping) and the careful use of water in the subsurface, along with the relatively minor importance of Yucca Mountain recharge to the local and regional groundwater system, DOE expects perturbations in recharge through Yucca Mountain to be small and of minimal consequence to the local and regional groundwater system.

No additional land disturbance would occur from monitoring and maintenance activities and, therefore, there would be no notable impacts to infiltration rates in the area. There would be no additional land disturbance during closure. The implementation of soil reclamation and revegetation would accelerate a return to more natural infiltration conditions. If DOE built a monument (or monuments) to provide a long-lasting marker for the site, its location could be impermeable and thus could generate minor amounts of additional runoff to drainage channels.

Potential for Contaminant Migration to Groundwater

Section 4.1.3.2 discusses the types of potential contaminants that could be present at the repository surface facilities during the various phases of its active life. It also discusses the possibility of spills or releases of these materials to the environment.

To pose a threat to groundwater, a contaminant would have to be spilled or released and then carried down either by its own volume or with infiltrating water. The depth to groundwater, the thickness of alluvium in the area, and the arid environment would combine to reduce the potential for a large contaminant migration, as would adherence to regulatory requirements and plans such as a Spill

Prevention Control and Countermeasure Plan (see Section 4.1.3.2). Section 4.1.8 further discusses the potential for onsite accidents that could involve a release of contaminants.

Groundwater Resources

The quantity of water necessary to support the Proposed Action would be greatest during the initial construction period and the continuing construction, operation, and monitoring period. Peak demand would occur while DOE was emplacing nuclear material in completed drifts (tunnels) at the same time it was developing other drifts. Table 4-10 summarizes the estimated water demands during these two phases and during closure. Water demand during construction would depend on the thermal load scenario because the emplacement of less spent nuclear fuel (that is, low thermal load) per foot of repository tunnel would require more excavation. Water demand during these phases would also depend on the packaging scenario.

Table 4-10. Annual water demand for construction, operation and monitoring, and closure.[a]

Phase	Proposed schedule	Water demand (acre-feet)[b] by thermal load		
		High	Intermediate	Low
Construction	2005 - 2010	150[c]	170[c]	170[c]
Operation and monitoring (by packaging scenario)				
Emplacement and development activities[d]	2010 - 2033			
Uncanistered		250	260	480
Disposable canister		220	230	450
Dual-purpose canister		220	230	450
Monitoring activities[e]	2033 - 2036			
Uncanistered		200	200	200
Disposable canister		160	160	160
Dual-purpose canister		160	160	160
Closure	2110 to varies			
Each packaging scenario		80	90	90

a. Source: TRW (1999a, pages 71, 74, 78, and 81); TRW (1999b, pages 6-3, 6-14, 6-21, 6-27, 6-28, and 6-37).

b. To convert acre-feet to cubic meters, multiply by 1,233.49.

c. Does not include water needed to construct a potential rail line.

d. Construction (or development) of the subsurface area during the operation and monitoring phase would take 22 years for the Proposed Action (emplacement would continue another 2 years). The values shown represent the highest demands projected for this phase and would occur during the period when both subsurface development and nuclear material emplacement were underway.

e. Values shown for monitoring activities are only applicable to the first 3 years (as shown by the schedule), when decontamination of surface facilities would be performed. Water demand for the 73 years that follow would be minimal.

As listed in Table 4-10, water demand during initial construction would range from about 0.19 million to about 0.21 million cubic meters (150 to 170 acre-feet) per year, depending on the thermal load scenario. Further, depending on the thermal load and packaging scenarios, demand during the emplacement and development period of the operation and monitoring phase could range from about 0.27 million to about 0.59 million cubic meters (220 to 480 acre-feet) per year. The first 3 years of the monitoring portion of the operation and monitoring phase would require water at a rate varying from 0.2 million to 0.25 million cubic meters (160 to 200 acre-feet) per year. The closure phase would require about 0.099 million to 0.11 million cubic meters (80 to 90 acre-feet) per year.

The water demand would be met by pumping from wells in the Jackass Flats hydrographic area, using existing wells J-12, J-13, and the C-well complex. Nevada Test Site activities in this same area also withdraw water from this hydrographic area. This ongoing demand from Nevada Test Site activities has an effect on the affected environment and would continue to represent part of the demand from the

Jackass Flats hydrographic area. Consequently, this additional water demand is discussed here and as part of the cumulative impacts in Chapter 8.

DOE evaluated potential impacts of the water demands on area groundwater resources by two methods:

- Consideration of impacts observed or measured during past water withdrawals
- Comparison of the proposed demand to the perennial yield of the aquifer supplying the water

During the initial construction period, the estimated water demand from the Jackass Flats Hydrographic Area would be about 0.53 million to about 0.55 million cubic meters (430 to 450 acre-feet) a year, including the ongoing demand from Nevada Test Site activities [projected to be 0.34 million cubic meters (280 acre-feet) a year (DOE 1998n, Table 11-2, page 11-6)]. This quantity is very similar to the roughly 0.49 million cubic meters (400 acre-feet) withdrawn from the Jackass Flats basin in 1996 (see Chapter 3, Table 3-15). The level of water demand during the construction phase probably would result in declines in water levels in the production wells and nearby. DOE expects the amount of decline to be similar to the groundwater level fluctuations discussed in Chapter 3, Section 3.1.4.2.2 (see Table 3-16), during which elevation decreases as large as 12 centimeters (4.8 inches) occurred in the production wells over a 6-year period. However, this decline would diminish to undetectable levels as the distance from the repository increased and would result in very small effects to the overall groundwater system.

During the continuing construction, operation, and monitoring period, groundwater withdrawal rates would increase as listed in Table 4-10. When combined with the ongoing demand from the Nevada Test Site, these rates would be sufficiently larger than those tracked from current activities (see Chapter 3, Table 3-15).

Perennial yield is the estimated quantity of groundwater that can be withdrawn annually from a basin without depleting the reservoir. As discussed in Chapter 3, Section 3.1.4.2, the estimated perennial yield of the aquifer in the Jackass Flats hydrographic area is between 1.1 million and 4.9 million cubic meters (880 and 4,000 acre-feet) (Thiel 1997, page 8). However, as indicated in footnote f to Table 3-11 in Chapter 3, the low estimate of perennial yield for Jackass Flats is accompanied by the qualification that 0.37 million cubic meters (300 acre-feet) is attributed to the eastern one-third of the area, and 0.72 million cubic meters (580 acre-feet) is attributed to the western two-thirds where wells J-12 and J-13 are located. This distinction was made to be consistent with the belief of some investigators that the two portions of Jackass Flats have different general flow characteristics. Assuming this is correct, the most conservatively low estimate of perennial yield applicable to the location of wells J-12 and J-13 would be 0.72 million cubic meters (580 acre-feet). The highest estimated water demand during the continuing construction, operation, and monitoring period would not exceed this lowest estimate of perennial yield, and it would represent only about 12 percent of the higher estimate of perennial yield.

A past DOE application for a water appropriation from Jackass Flats resulted in a State Engineer's ruling (Turnipseed 1992, pages 9 to 11) that described the perennial yield of Jackass Flats (Hydrographic Area 227A) as 4.9 million cubic meters (4,000 acre-feet). The same ruling identified the estimated annual recharge for the western two-thirds of this hydrographic area as 0.72 million cubic meters (580 acre-feet). Based on this information, the estimates of perennial yield for this hydrographic area range from consideration of only the amount of recharge that occurs in the area to inclusion of underflow that enters the area from upgradient groundwater basins. If the groundwater is basically in equilibrium under current conditions (which should be a reasonable assumption based on the stability of the water table elevation), then withdrawing more than 0.72 million cubic meters probably would result in additional underflow entering the immediate area to maintain the equilibrium level. Under this scenario, pumping more than 0.72 million cubic meters from the western portion of Jackass Flats would be unlikely to cause a depletion of the reservoir, and instead could result in shifting of the general groundwater flow patterns. Because the amount pumped would be much less than the upper estimates of perennial yield (that is, the total amount of available water moving through the area, not just the recharge from precipitation), changes in general flow patterns probably would be too small to estimate or detect.

With the addition of repository water usage to the baseline demands from Nevada Test Site activities, the highest estimated demand from the Jackass Flats area during the initial construction period would be about 0.55 million cubic meters (450 acre-feet) per year. This demand would be below the lowest estimate of the area's perennial yield [0.72 million cubic meters (580 acre-feet) for the western two-thirds of Jackass Flats]. However, repository water demands during the emplacement and development period (Table 4-10), when combined with the baseline demands from Nevada Test Site activities, would exceed the lowest perennial yield estimate under the low thermal load scenario for all packaging scenarios. The combined water demand under either the high or intermediate thermal load scenario would not exceed the lowest estimates of perennial yield. None of the water demand estimates would approach the high estimates of perennial yield [4.9 million cubic meters (4,000 acre-feet)].

On a regional basis in the Alkali Flat-Furnace Creek Ranch sub-basin, the heaviest water demand is in the Amargosa Desert. Over the long term, additional water consumption in upgradient hydrographic areas would to some extent decrease the availability of water in the valley (Buqo 1999, pages 37 and 51). That is, consumption would not necessarily exceed the perennial yield of the Jackass Flats hydrographic area, but it could reduce the long-term amount of underflow that would reach the Amargosa Desert, effectively decreasing the perennial yield of that hydrographic area. However, the maximum projected demands for the repository and the Nevada Test Site during the construction phase [about 0.55 million cubic meters (450 acre-feet) a year] and the operation and monitoring phase [about 0.93 million cubic meters (750 acre-feet)] would be small in comparison to the 17 million cubic meters (14,000 acre-feet) pumped in the Amargosa Desert annually from 1995 through 1997 (see Table 3-11). The demand of the repository and the Nevada Test Site would be even a smaller fraction of the perennial yield of 30 million to 40 million cubic meters (24,000 to 32,000 acre-feet) in the Amargosa Desert.

Water demand for monitoring and maintenance activities would be much less than that for emplacement and development activities, particularly after the completion of decontamination activities. Routine monitoring and maintenance activities would involve minimal water needs and, from a duration standpoint, would occupy most of the operation and monitoring phase.

The annual demand during closure for the high thermal load would be about one-third of that described for the high thermal load during the continuing construction, operation, and monitoring period and, similarly, would have minor impacts on groundwater resources.

4.1.4 IMPACTS TO BIOLOGICAL RESOURCES AND SOILS

The evaluation of impacts to biological resources considered the potential for affecting sensitive species (plants and animals) and their habitats, including areas of critical environmental concern; sensitive, threatened, or endangered species, including their habitats; jurisdictional waters of the United States, including wetlands; and riparian areas. The evaluation also considered the potential for impacts to migratory patterns and populations of game animals. DOE expects the overall impacts to biological resources to be very small. Biological resources in the Yucca Mountain region include species typical of the Mojave and Great Basin Deserts and generally are common throughout those areas. Neither the removal of vegetation from the small area required for the repository nor the very small impacts to some species would affect regional biodiversity and ecosystem function.

Section 4.1.4.1 describes potential impacts to biological resources and soils from performance confirmation activities. Section 4.1.4.2 describes potential impacts to biological resources from construction, operation and monitoring, and closure. Section 4.1.4.3 describes the evaluation of the severity of potential impacts to biological resources. Section 4.1.4.4 describes potential impacts to soils from construction, operation and monitoring, and closure.

4.1.4.1 Impacts to Biological Resources and Soils from Performance Confirmation

Performance confirmation activities could require additional land disturbance, and current vehicle traffic at the site of the proposed repository would continue. Impacts to biological resources from additional land disturbance and sustained traffic could consist of the loss of a small amount of available habitat for terrestrial plant and animal species, including desert tortoises, in widely distributed land cover types and the deaths of a small number of individuals of some terrestrial species. The actual amount of additional land disturbance, if any, is uncertain. DOE expects it to be much less than the quantity of disturbance during site characterization.

The limited habitat loss from additional land disturbance would have little impact on plant and animal populations because habitats similar to those at Yucca Mountain are widespread locally and regionally. Similarly, the deaths of small numbers of individuals of some species, primarily burrowing species of small mammals and reptiles, would have little impact on the regional populations of those species. The animal species at the Yucca Mountain site are generally widespread throughout the Mojave or Great Basin Deserts.

The desert tortoise, a threatened species, would continue to receive special consideration during land-disturbing activities at the site. DOE would continue to work with the Fish and Wildlife Service and implement the terms and conditions of the Biological Opinion for site characterization activities (Buchanan 1997, pages 19 to 24) to minimize impacts to desert tortoises at the site.

The potential for soil impacts such as erosion would increase slightly, but erosion control measures, such as dust suppression, would ensure that impacts were very small.

4.1.4.2 Impacts to Biological Resources from Construction, Operation and Monitoring, and Closure

This section describes potential short-term impacts to biological resources at the Yucca Mountain site from construction, operation and monitoring, and closure activities. The primary sources of such impacts would be related to habitat loss or modification during facility construction and operations and to human activities, such as increased traffic, associated with the repository. In addition, this section identifies and evaluates potential impacts to vegetation; wildlife; special status species; and jurisdictional waters of the United States, including wetlands, over the projected life of the project and during each phase of the project.

Routine releases of radioactive materials from the repository would consist of radioactive noble gases, principally isotopes of krypton and radon (TRW 1999a, page 75; see Section 4.1.2). These gases do not accumulate in the environment. The small quantities released would result in very small doses to plants and animals as the gases dispersed in the atmosphere. Estimated doses to humans working and living near the site would be very small (as described in Section 4.1.7). In a similar manner, assumed doses to plants and animals would be small and impacts from those doses would be unlikely to affect the population of any species because the doses would be much lower than the 100-millirad-per-day limit [for which there is no convincing evidence that chronic radiation exposure will harm plant or animal populations (IAEA 1992, page 54)]. Therefore, no detectable impacts to biological resources would occur as a result of normal releases of radioactive materials from the repository, and the following sections do not consider these releases.

Impacts to Vegetation

The construction of surface facilities and the disposition of rock excavated during subsurface construction would remove or alter vegetation. Much of the construction would occur in areas in which site characterization activities had already disturbed the vegetation; however, construction would also occur in undisturbed areas near the previously disturbed areas. Subsurface construction would continue after emplacement operations began, and the disposal of excavated rock would eliminate vegetation in the area covered by the excavated rock pile. The total amount of land cleared of vegetation would vary between the thermal load scenarios (Table 4-11).

Table 4-11. Land cover types in the analyzed land withdrawal area and the amount of each that repository construction and disposal of excavated rock would disturb (square kilometers).[a,b]

	Total area		Area to be disturbed[d]		
Land cover type[c]	In Nevada	In the analyzed withdrawal area	Low thermal load	Intermediate thermal load	High thermal load
Blackbrush	9,900	140	0.36	0.02	0.02
Creosote-bursage	15,000	300	1.11	0.72	0.62
Mojave mixed scrub	5,700	120	0.03	0.86	0.80
Sagebrush	67,000	16	0	0	0
Salt desert scrub	58,000	20	0	0	0
Previously disturbed	NA[e]	4	0.48	0.37	0.37
Totals[f]	**NA**	**600**	**2.0**	**2.0**	**1.8**

a. Source: Facility diagrams from TRW (1999b, all) and land cover types maps (Utah State University 1996, Gap Data) and vegetation associations (TRW 1998c, page 9) using a Geographic Information System.

b. To convert square kilometers to acres, multiply by 247.1.

c. A small area (0.016 square kilometer) of the pinyon-juniper-2 land cover type occurs in the analyzed land withdrawal area, but would not be affected.

d. As described in Chapter 2, the excavated rock pile would be in a different location for the low thermal load scenario.

e. NA = not applicable.

f. Totals might differ from sums due to rounding.

Six of the 65 different land cover types (defined primarily by dominant vegetation) identified in the State of Nevada (Utah State University 1996, Gap Data) occur in the approximately 600-square-kilometer (230-square-mile) analyzed land withdrawal area around the repository site (Table 4-11). Surface disturbances resulting from repository activities would occur in three of these land cover types and in previously disturbed areas (Table 4-11). Repository construction would disturb less than 1 percent of the withdrawal area, which would be an extremely small percentage of the undisturbed vegetation available in the withdrawal area.

Repository construction, including the disposal of material in the excavated rock pile after the start of emplacement, would occur primarily in areas dominated by creosote-bursage and Mojave mixed scrub or blackbrush (under the low thermal load scenario) land cover types. These types are widespread in the analyzed land withdrawal area.

Studies from 1989 to 1997 indicated that site characterization activities had very small effects on vegetation adjacent to the activities (TRW 1999k, pages 2-2 through 2-4). Therefore, impacts to vegetation from repository construction probably would occur only as a result of direct disturbance, such as during site clearing. Little or no disturbance of additional vegetation would occur as a result of monitoring and maintenance activities before closure. DOE would reclaim lands no longer needed for repository operation.

Activities associated with the closure of the repository could involve the removal of structures and reclamation of areas cleared of vegetation for the construction of surface facilities. Closure would involve minimal, if any, new disturbance of vegetation. Reclamation activities would enhance the recovery of vegetation in disturbed areas.

Impacts to Wildlife

The construction of surface facilities and excavated rock disposal would lead to habitat losses for some terrestrial species (Chapter 3, Section 3.1.5); however, habitats similar to those at Yucca Mountain (identified by land cover type) are widespread locally and regionally. In addition to habitat loss, the conversion of undisturbed land to industrial uses associated with the repository would result in the localized deaths of individuals of some species, particularly burrowing species of small mammals and reptiles. Birds, carnivores, and ungulates (mule deer or burros) at the repository site would be less likely to be killed during construction because they would be able to move away from areas of human activity.

The construction of new roads, surface facilities, and other infrastructure would lead to fragmentation of previously undisturbed habitat. Nevertheless, DOE anticipates impacts to wildlife populations to be very small because large areas of undisturbed and unfragmented habitat would be available away from disturbed areas.

Animal species present at the repository location are generally widespread throughout the Mojave or Great Basin Deserts and the deaths of some individuals due to repository construction and habitat loss would have little impact on the regional populations of those species. Site characterization activities had no detectable effect on populations of small mammals, side-blotched lizards, and desert tortoises in areas adjacent to the activities (TRW 1999k, pages 2-4, 2-5, 2-7, and 3-10 to 3-12).

In addition to direct losses due to the construction of surface facilities and excavated rock disposal, individuals of some species would be killed by vehicles traveling to and from the Yucca Mountain site during the construction, operation and monitoring, and closure phases (TRW 1999k, page 3-12). These losses would have a very small effect on populations because species at the site are widespread. No species would be threatened with extinction, either locally or globally.

Noise and ground vibrations generated during repository construction and operations could disturb wildlife and cause some animals to move away from or avoid the source of the noise. Impacts to wildlife from noise and vibration, if any, would decline as the distance from the source of the noise (the repository) increased. Noise levels would drop below the limit of human hearing at a distance of about 6 kilometers (3.7 miles) from the repository (see Section 4.1.9) and no noise-related impacts to wildlife would be likely at that distance. Animals may acclimate to the noise, limiting the area affected by repository-related noise to the immediate vicinity of the source of the noise (heavy equipment, diesel generators, ventilation fans, etc.).

Several animals classified as game species by the State of Nevada (Gambel’s quail, chukar, mourning doves, and mule deer) are present in low numbers in the analyzed Yucca Mountain land withdrawal area. Adverse impacts to these species would be unlikely, and offsite hunting opportunities probably would not decline.

DOE would dispose of industrial wastewater in lined evaporation ponds in the North and South Portal Operations Areas. Wildlife would be attracted to the water in these ponds to take advantage of this otherwise scarce resource. Individuals of some species could benefit from the water, but some animals could become trapped in the ponds, depending on the depth and the slope of the sides. Monitoring at similar lined evaporation ponds on the Nevada Test Site has shown that a wide variety of animal species use the ponds and that DOE could avoid losses of animals by reducing the slopes of the ponds or by providing an earthen ramp at one corner of the lined pond (Bechtel 1997, page 31). Appropriate engineering would minimize potential losses to wildlife.

DOE does not anticipate adverse effects on wildlife that used the nonhazardous, nontoxic wastewater discharged to the evaporation ponds. Industrial wastewater routed to the evaporation pond at the North Portal would be nonhazardous. DOE anticipates that the primary chemical constituents in the water would be sodium and calcium carbonates, with smaller amounts of chlorides, sulfates, and fluorides. Metal constituents could include potassium, zinc, iron, magnesium, and manganese. Wastewater discharged to the South Portal evaporation pond would be nontoxic wastewater derived from dust suppression activities; it would contain small particles of mined rock along with Portland Cement and fine aggregate particles from concrete mix plants. DOE would maintain the pH of the water within a defined range through the addition of acceptable additives. Water quality would be monitored and appropriate measures to protect wildlife would be implemented.

DOE would construct a landfill for construction debris and sanitary solid waste. The landfill could attract scavengers such as coyotes and ravens. Frequent covering of the sanitary waste disposed of in the landfill could minimize use by scavenger species.

After the completion of emplacement, human activities and vehicle traffic would decline, as would impacts of those actions on wildlife, with further declines in activities and impacts after repository closure. Animal species would reoccupy the areas reclaimed during closure activities.

Impacts to Special Status Species

The desert tortoise is the only resident animal species in the analyzed land withdrawal area listed as threatened under the Endangered Species Act of 1973 (16 USC 1531, *et seq.*). There are no endangered or candidate animal species and no species that are proposed for listing (TRW 1999k, pages 3-11 and 3-12). Repository construction would result in the loss of a very small portion of the total amount of desert tortoise habitat at the northern edge of the range of this species in an area where the abundance of desert tortoises is low (TRW 1997b, pages 6 to 12; TRW 1999k, page 3-12).

Based on past experience, DOE anticipates that human activities at the site could directly affect individual desert tortoises. During site characterization activities, 28 tortoises and two tortoise nests were relocated because of threats from construction activities (TRW 1998h, pages 3 to 17; TRW 1999k, page 3-12). All but one of the 28 individual relocations and both nest relocations were successful. From 1989 to 1998, five tortoises (including the one unsuccessful relocation) were killed as a result of site characterization activities; all were killed by vehicles on roads (TRW 1999k, page 3-12). DOE would conduct surveys and would move tortoises that it found; however, based on experience from site characterization, DOE anticipates the deaths of small numbers of individual tortoises from vehicle traffic and construction activities during the repository construction, operation and monitoring, and closure phases. As required by Section 7 of the Endangered Species Act, DOE has initiated consultations with the Fish and Wildlife Service on the desert tortoise. The result of these consultations will be a Fish and Wildlife Service Biological Opinion containing terms and conditions for protection of the desert tortoise during repository construction and operation.

The bald eagle (threatened) and peregrine falcon (endangered, but proposed for delisting) have been observed once each on the Nevada Test Site and might migrate through the Yucca Mountain region. If present at all, these species would be transient and would not be affected.

Several animal species considered sensitive by the Bureau of Land Management [two bats—the long-legged myotis and fringed myotis—and the western chuckwalla, burrowing owl, and Giuliani's dune scarab beetle; (see Chapter 3, Section 3.1.5)] occur in the analyzed land withdrawal area. Impacts to the bat species would be very small because of their low abundance on the site and broad distribution. Impacts to the Western chuckwalla and burrowing owl would be very small because they are widespread regionally and are not abundant in the land withdrawal area. Giuliani's dune scarab beetle has been reported only in the southern portion of the land withdrawal area, away from any proposed disturbances.

Monitoring and closure activities at the repository would have little impact on desert tortoises, or Bureau of Land Management sensitive species. Over time, vegetation would recover on disturbed sites and indigenous species would return. As the habitat recovered over the long term, desert tortoises and other special status species at the repository site would recolonize areas abandoned by humans.

Impacts to Wetlands

There are no known naturally occurring jurisdictional wetlands (that is, wetlands subject to permitting requirements under Section 404 of the Clean Water Act) on the repository site, so no impacts to such wetlands would occur as a result of repository construction, operation and monitoring, or closure. In addition, repository construction, operation and monitoring, and closure would not affect the four manmade well ponds in the Yucca Mountain region. Repository-related structures could affect as much as 2.8 kilometers (1.7 miles) of ephemeral washes, depending on the size and location of such facilities as the excavated rock storage area. Although no formal delineation has been undertaken, some of these washes might be waters of the United States. After selecting the location of facilities, DOE would conduct a formal delineation, as appropriate, to confirm there are no wetlands at Yucca Mountain; formally delineate waters of the United States near the surface facilities; and, if necessary, develop a plan to avoid when possible, and otherwise minimize, impacts to those waters. If repository activities would affect waters of the United States, DOE would consult with the U.S. Army Corps of Engineers and obtain permit coverage for those impacts. If the activities were not covered under a nationwide permit, DOE would apply to the Corps of Engineers for a regional or individual permit. By implementing the mitigation plan and complying with other permit requirements, DOE would ensure that impacts to waters of the United States would be minimized.

4.1.4.3 Evaluation of Severity of Impacts to Biological Resources

DOE evaluated the magnitude of impacts to biological resources and classified the severity of potential impacts as none, very low, low, moderate, or high, as listed and described in Table 4-12.

4.1.4.4 Impacts to Soils from Construction, Operation and Monitoring, and Closure

This section identifies potential consequences to soils as a result of the Proposed Action. Soil-related issues associated with the Proposed Action include the following:

- Potential consequences of soil loss in disturbed areas, either from erosion or displacement
- Soil recovery from disturbances

Table 4-12. Impacts to biological resources.

Phase or period	Flora	Fauna	Special status species	Wetlands	Overall
Initial construction	Very low/low; removal of vegetation from as much as 2 square kilometers[a] in widespread communities	Very low; loss of small amount of habitat and some individuals of some species	Low; loss of small amount of desert tortoise habitat and small number of individual tortoises	None	Very low/low; loss of small amount of widespread but undisturbed habitat and small number of individuals
Construction, operation, and monitoring					
Emplacement and development	Very low/low; disturbance of vegetation in areas adjacent to disturbed areas	Very low; deaths of small number of individuals due to vehicle traffic and human activities	Low; potential deaths of very few individuals due to vehicle traffic	None	Very low new impacts to biological resources
Monitoring and maintenance	Very low; no new disturbance of natural vegetation	Very low; same as for operation, but smaller due to smaller workforce	Very low; same as for operation, but smaller due to smaller workforce	None	Very low; small numbers of individuals of some species killed by vehicles
Closure	Very low; decline in impacts due to reduction in human activity	Very low; decline in number of individuals killed by traffic annually	Very low; decline in number of individuals killed by traffic annually	None	Very low; decline in impacts due to reduction of human activity
Overall rating of impacts	Very low/low	Very low	Very low/low	None	Very low

a. 2 square kilometers = 500 acres.

- Potential for spreading contamination by relocating contaminated soils (if present)
- Structural stability of existing soils and their ability to support the proposed activities

Overall, impacts to soils would be minimal. DOE would use erosion control techniques to minimize erosion. Because soil in disturbed areas would be slow to recover, during the closure phase DOE would revegetate the area that it had not reclaimed after the temporary disturbances following construction.

Soil Loss

Land disturbed at the repository site could, at least for a short period, experience increased erosion. Erosion is a two-step process of (1) breaking away soil particles or small aggregates and (2) transporting those particles or aggregates. Land disturbance that removes vegetation or otherwise breaks up the natural surface would expose more small materials to the erosion process, making the soil more susceptible to wind and water erosion. Activities at the repository during the construction and operation and monitoring phases would disturb no more than about 2 square kilometers (500 acres) of land, including the excavated rock (see Chapter 2).

Site characterization activities at Yucca Mountain included a reclamation program with a goal to return the disturbed land to a condition similar to its predisturbance state (TRW 1999l, pages 6 and 7). One of the benefits of achieving such a goal would be the minimization of soil erosion. The program included the implementation and evaluation of topsoil stockpiling and stabilization efforts that would enable the use of topsoil removed during excavation in future reclamation activities. The results were encouraging enough to recommend that these practices continue. This action would reduce the construction loss of the most critical type of soil. Fugitive dust control measures including water spraying and chemical treatment would be used as appropriate to minimize wind erosion of the stockpiled topsoil and excavated rock. Based on site characterization experience and the continued topsoil protection and erosion control programs, DOE does not anticipate much soil erosion during the phases of the project.

If the Proposed Action was implemented, program planning developed for site characterization (DOE 1989a, pages 2 and 20) specifies that reclamation would occur in all areas disturbed during characterization activities that are not needed for the operation of the repository. As a result, prior land disturbances should represent minimal soil erosion concern during the Proposed Action.

Recovery

Studies performed during the Yucca Mountain site characterization effort (DOE 1989a, all; DOE 1995g, all) looked at the ability of the soil ecology to recover after disturbances. These studies and experience at the Nevada Test Site indicate that natural succession on disturbed arid lands would be a very slow process (DOE 1989a, page 17; DOE 1995g, page 1-5). Left alone, and depending on the type or degree of disturbance and the site-specific environmental conditions, the recovery of predisturbance conditions in this area could take decades or even centuries. With this in mind, soil recovery would be unlikely without reclamation. In general, soil disturbances would generally remain as areas without vegetation and, with the exception of built-up areas, would have an increased potential for soil erosion throughout the construction and operation and monitoring phases.

SOIL RECOVERY

The return of disturbed land to a relatively stable condition with a form and productivity similar to that which existed before any disturbance.

Contamination

Based on characterization efforts and activities that took place in the past (Chapter 3, Section 3.1.5.2), radiological and nonradiological characteristics of the site soils are consistent with the area background. Therefore, there would be no need for restrictions or concerns about contamination migration during construction or as a result of soil erosion. There would be a potential for spills or releases of contaminants to occur under the Proposed Action (as discussed in Section 4.1.3), but DOE would continue to implement a spill prevention and control plan [Kiewit (1997, all) is an example] to prevent, control, and remediate soil contamination.

4.1.5 IMPACTS TO CULTURAL RESOURCES

This section describes impacts to cultural resources from performance confirmation, operation and monitoring, and closure activities. The evaluation of such impacts considered the potential for disrupting or modifying the character of archaeological or historic sites and other cultural resources. The evaluation placed particular emphasis on identifying the potential for impacts to historic sites and other cultural resources important to sustaining and preserving Native American cultures. The region of influence for the analysis included land areas that repository activities would disturb and areas in the analyzed land withdrawal area where impacts could occur.

DOE assessed potential impacts to cultural resources from these activities by (1) identifying project activities that could directly or indirectly affect archaeological, historic, and traditional Native American resources possibly eligible for listing on the *National Register of Historic Places*; (2) identifying the known or likely eligible resources in areas of potential impact; and (3) determining if a project activity would have no effect, no adverse effect, or an adverse effect on potentially eligible resources (36 CFR 800.9). Direct impacts would be those from ground disturbances or activities that would destroy or modify the integrity of a given resource considered eligible for listing on the National Register. Indirect impacts would result from activities that could increase the potential for adverse impacts, either intentional or unintentional (for example, increased human activity near potentially eligible resources could result in illicit collection or inadvertent destruction).

4.1.5.1 Impacts to Cultural Resources from Performance Confirmation

Land disturbances associated with performance confirmation activities could have direct impacts to cultural resources in the Yucca Mountain region. Before activities began, therefore, DOE would identify and evaluate archaeological or cultural resources sites in affected areas for their importance and eligibility for inclusion in the *National Register of Historic Places*. DOE would avoid such sites if possible or, if it was not possible, would conduct a data recovery program of the sites in accordance with applicable regulatory requirements and input from the official tribal contact representatives and document the findings. The artifacts from and knowledge about the site would be preserved. Improved access to the area could lead to indirect impacts, which could include unauthorized excavation or collection of artifacts. Workers would have required training on the protection of these resources from excavation or collection.

4.1.5.2 Impacts to Cultural Resources from Construction, Operation and Monitoring, and Closure

Impacts to archaeological and historic sites could occur during the initial construction period and the continuing construction, operation, and monitoring period, when ground-disturbing activities would take place. Indirect impacts to archaeological and historic sites could occur during all phases of the Proposed Action.

Archaeological and Historic Resources

Potential impacts to *National Register*-eligible cultural resources from surface facility construction could occur in areas where ground-disturbing activities would take place. Repository development would disturb a maximum of about 2 square kilometers (500 acres) of previously undisturbed land at the site.

Archaeological investigations conducted in the immediate vicinity of the proposed surface facilities in support of previous and ongoing characterization studies and infrastructure construction have identified 826 archaeological and historic sites. These investigations have identified resource localities and provided mitigative relief for resources potentially subject to direct impacts (TRW 1999m, Table 2). In addition, ground-disturbing activities associated with potential nearby project actions (for example, upgrades to utility and road rights-of-way, rail access facilities, muck and other onsite storage areas) would occur in areas that had undergone field inventories and evaluations of cultural resources. Because the proposed locations of facilities and support areas are away from known archaeological sites, no direct impacts to known resources would occur.

Increases in both surface activities and numbers of workers at the repository site could increase the potential for indirect impacts at archaeological sites near repository surface facilities. Preliminary results from the monitoring of archaeological sites in the vicinity of Yucca Mountain activities since 1991 indicate that human activities and increased access could result in harmful effects, both advertent and inadvertent, to these fragile resources (TRW 1999m, Chapter 1). Indirect impacts are difficult to quantify and control, but they can include loss of surface artifacts due to illicit collection and inadvertent destruction (TRW 1999m, Chapter 1).

Even though there could be some indirect adverse impacts, the overall effect of the repository on the long-term preservation of the archaeological and historic sites in the analyzed land withdrawal area would be beneficial. Cultural resources in the area would be protected from most human intrusion.

Excavation activities at the repository site could unearth additional materials and features in areas that past archaeological surveys have examined only at the surface. Past surveys in the Yucca Mountain area indicated buried cultural materials at some sites with surface artifacts (TRW 1999m, Chapter 1). Thus, excavation activities could unearth previously undetected subsurface features or artifacts. If this happened, work would stop until a cultural resource specialist evaluated the importance of the discovery.

Native American Viewpoints

DOE would continue the existing Native American Interaction Program (see Chapter 3, Section 3.1.6.2) throughout the Proposed Action. This program promotes a government-to-government relationship with associated tribes and organizations. Continuance of this program during the Proposed Action would enhance the protection of archaeological sites and cultural items important to Native Americans.

The Native American view of resource management and preservation is holistic in its definition of "cultural resource," incorporating all elements of the natural and physical environment in an interrelated context. Moreover, this view includes little or no differentiation between types of impacts (direct versus indirect), but considers all impacts to be adverse and immune to mitigation. Section 4.1.13.4 contains an environmental justice discussion of a Native American viewpoint on the Proposed Action.

Previous studies (Stoffle et al. 1990, all; AIWS 1998, all) have delineated several Native American sites, areas, and resources in or immediately adjacent to the analyzed land withdrawal area. Construction activities for repository surface facilities would have no direct impacts on these locations. However, because of the general level of importance attributed to these places by Native Americans, and because they are parts of an equally important integrated cultural landscape, Native Americans consider the intrusive nature of the repository to be an adverse impact to all elements of the natural and physical environment (AIWS 1998, Chapter 2). In their view, the establishment of the protected area boundary and construction of the repository would continue to restrict the free access of Native American people to these areas. On the other hand, the Consolidated Group of Tribes and Organizations has recognized that past restrictions on public access due to site characterization have resulted in generally beneficial and protective effects for cultural resources, sacred sites, and potential traditional cultural properties (AIWS 1998, Chapter 2).

The potential for indirect impacts from construction activities and more workers in the area would increase, particularly to the physical evidence of past use of the cultural landscape (artifacts, cultural features, archaeological sites, etc.) important to Native American people. DOE would continue to provide training to workers to minimize the potential for indirect impacts.

Eventual closure of the repository would have the beneficial effect of returning much of the disturbed landscape to a natural setting. Some additional impacts could occur to resources or areas important to Native Americans if changes in land status or management that occurred after closure led to increased access by the public. The presence of a permanently entombed repository would represent an intrusion into what Native Americans consider an important cultural and spiritual place. Long-term monitoring features or activities would continue to affect these cultural viewpoints.

4.1.6 SOCIOECONOMIC IMPACTS

This section describes potential socioeconomic impacts from performance confirmation, construction, operation and monitoring, and closure activities. The evaluation of the socioeconomic environment in communities near the proposed repository site considered changes to employment, economic measures, population, housing, and public services. The evaluation used the Regional Economic Models, Inc. (REMI) model to estimate baseline socioeconomic conditions and economic and population changes caused by the Proposed Action. The potential for changes in the socioeconomic environment would be greatest in the Yucca Mountain region and in the communities where most of the repository workers would live. As discussed in Chapter 3, Section 3.1.7, this region of influence consists of Clark, Lincoln, and Nye Counties in southern Nevada.

DOE established a bounding case to examine the maximum potential employment levels it would need to implement design features and packaging scenarios. The combination of the low thermal load scenario and the uncanistered packaging scenario would produce the highest incremental change in employment and have the greatest potential to affect the environment.

The analysis determined that no great socioeconomic impacts to any of the areas in the region of influence would be likely. Employment and population changes in the region of influence would not exceed one-half of 1 percent between the projected baseline (employment without the repository project) and the increase from the maximum employment case of the project.

4.1.6.1 Socioeconomic Impacts from Performance Confirmation

The level of employment for performance confirmation activities would be similar to or less than the current level for site characterization, as described in Chapter 3, Section 3.1.7. Because population and employment changes between ongoing site characterization activities and future performance confirmation activities would be imperceptible, there would be no meaningful impacts to housing or community services.

4.1.6.2 Socioeconomic Impacts from Construction, Operation and Monitoring, and Closure

4.1.6.2.1 *Impacts to Employment*

In 2006 and 2007, the peak years of employment during the initial construction period, about 1,640 workers would be employed on the Yucca Mountain Repository Project. Figure 4-2 shows composite (direct and indirect) employment changes by place of residence during the construction phase. Incremental

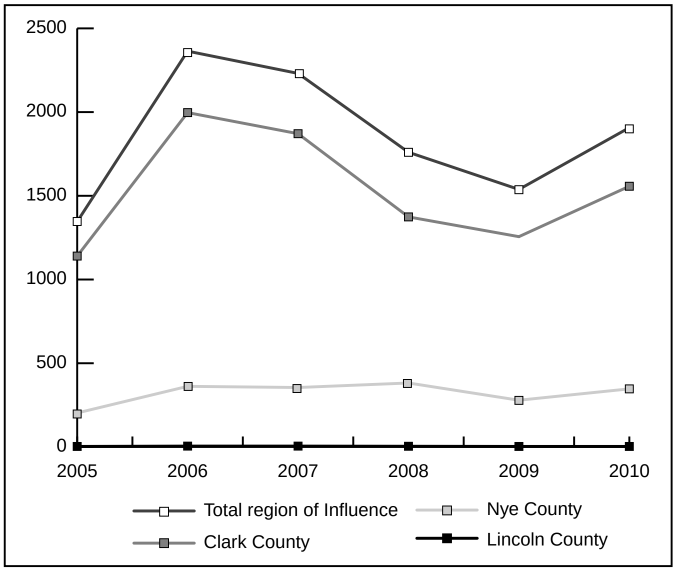


Figure 4-2. Increases in regional employment by place of residence during construction phase and onset of operation and monitoring phase: 2005 to 2010.

employment increases during the construction phase attributable to the repository would peak in 2006 with the addition of about 2,360 workers to the region of influence. This would increase overall employment in the region of influence from the projected baseline (employment without the repository project) of approximately 946,000 to slightly less than 948,000, a change of less than one-quarter of 1 percent. Table 4-13 summarizes repository peak year employment during the initial construction period by employment category. Table 4-14 lists the expected residential distribution of construction phase workers, which in the first year would exceed 1,600 workers (2006). The table also lists the estimated peak number of indirect jobs created in these communities. These tables do not list Lincoln County because historically no workers have resided there. DOE expects that few, if any, repository employees would live in Lincoln County due to the long commute (TRW 1998d, all).

Table 4-13. Expected peak year (2006) increase in construction employment by place of residence in selected communities in Nye and Clark Counties.[a,b,c]

Location	Direct jobs	Indirect jobs	Total jobs
Clark County			
Indian Springs	48	29	72
Rest of Clark County	1,270	780	1,925
Clark subtotals	*1,318*	*809*	*1,997*
Nye County			
Amargosa Valley	22	5	25
Beatty	3	1	4
Pahrump area	294	68	333
Nye subtotals	*319*	*74*	*362*
Totals	***1,637***	***883***	***2,359***[d]

a. Employment and population impacts distributed using residential patterns of Nevada Test Site and Yucca Mountain employees from DOE (1994b, all).

b. DOE anticipates approximately 80 percent of repository workers would live in Clark County and approximately 20 percent in Nye County; includes approximately 5 indirect jobs in Lincoln County.

c. Employment in 2006 includes 161 current workers.

d. Does not include the 161 current workers.

Table 4-14. Repository direct workforce during construction phase by expected county of residence: 2005 to 2009.[a,b]

County	2005	2006	2007	2008	2009
Clark	795	1,317	1,093	1,093	1,128
Nye	193	320	311	267	274
Totals	**988**	**1,637**	**1,404**	**1,360**	**1,402**

a. Sources: TRW (1999a, Section 6); TRW (1999b, Section 6).

b. DOE anticipates approximately 80 percent of repository workers would live in Clark County and approximately 20 percent in Nye County.

Construction employment would begin to decline in 2008; in 2010 operational employment would start to increase and would peak in 2012. Employment after 2012 would be essentially stable with an average annual workforce of about 1,600 through 2035. Although operational phase peak employment would occur in 2012 (about 1,780 workers), the overall peak in incremental regional employment related to repository activities would occur earlier, in 2010. Usually the creation of indirect jobs and associated population increases occur after the creation of direct jobs. In this case, the region would still be experiencing the results of the incremental jobs created during the initial construction period. The net increase of about 140 peak year operational jobs over the peak year construction employment level would not affect the regional economy as noticeably as when the relatively small number of site characterization workers increased to more than 1,600 construction workers.

As mentioned above, in 2012, the peak year of employment during the continuing construction, operation, and monitoring period, about 1,780 workers would be employed on the Yucca Mountain Repository Project (TRW 1999a, Section 6; TRW 1999b, Section 6). As a consequence, the analysis included information on repository residential distribution and employment levels for 2010.

Table 4-15 lists the expected residential distribution of repository workers in the peak year, 2010. The table also lists the estimated number of indirect jobs created in these communities during 2010. The direct and indirect employment in the region of influence would peak with the addition of approximately 1,900 workers. This would result in a total increase in employment from the projected baseline of about 1,002,000 to about 1,004,000, a change of less than one-quarter of 1 percent. Table 4-16 summarizes repository employment through the first 35 years of the operation and monitoring phase by employment category. These tables do not list Lincoln County because historically no workers have resided there. As mentioned above, DOE expects that few workers would live in Lincoln County due to the long commute (TRW 1998d, all). Figure 4-3 shows the direct and indirect regional employment differences between the maximum employment case and the projected baseline.

Table 4-15. Expected peak year (2010) increases in operations employment in selected communities in Nye and Clark Counties.

Location	Direct jobs[a]	Indirect jobs	Total jobs
Clark County			
Indian Springs	64	11	56
Rest of Clark County	1,326	286	1,501
Clark subtotals	*1,421*	*297*	*1,557*
Nye County			
Amargosa Valley	23	3	24
Beatty	3	0	3
Pahrump	311	37	319
Nye subtotals	*337*	*40*	*346*
Totals	***1,727***	***337***	***1,903***[b]

a. Employment in 2010 includes 161 current workers.
b. Does not include the 161 current workers.

Table 4-16. Repository direct employment during operation and monitoring phase by county of residence: 2010 to 2035.

County	2010	2015	2020	2025	2030	2035
Clark total	1,390	1,365	1,379	1,365	1,322	1,161
Nye total	337	332	335	332	322	282
Totals	**1,727**	**1,697**	**1,714**	**1,697**	**1,644**	**1,443**

The completion of emplacement activities would result in a decline from about 1,560 emplacement workers in 2031 to about 1,440 decontamination and decommissioning workers from 2034 to about 2036 to 120 monitoring and maintenance workers from 2037 to 2110 employed at the Yucca Mountain site. However, even without the repository, the baseline projection predicts a continued increase in employment in the region of influence. If the present economic growth continued in the region of influence, it could absorb declines in the repository workforce.

After the completion of emplacement and decontamination of surface facilities, an annual employment of about 120 workers would be required for ongoing monitoring and maintenance activities. These activities could last as few as 26 years or as many as 276 years. This study assumed that monitoring would end in 2110, 100 years after the start of emplacement. Because monitoring and maintenance activities would require so few workers, no socioeconomic impacts would be likely.

The closure phase would be from 2110 to between 2116 and 2124, depending on the thermal load scenario. Projected peak employment for this phase would be approximately 520 workers (TRW 1999a, Section 6; TRW 1999b, Section 6). Employment would be far less than the peak during the operation and monitoring phase and, therefore, would be unlikely to generate changes to the labor force and economic measures of less than one-half of 1 percent. There probably would be no perceptible repository-induced changes to the baseline employment in the region of influence. Regional impacts during the closure phase probably would be small.

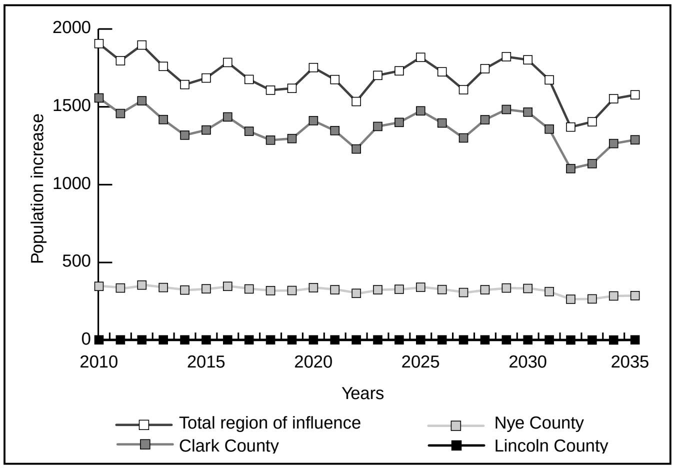


Figure 4-3. Increases in regional employment from operation and monitoring phase: 2010 to 2035.

4.1.6.2.2 *Impacts to Population*

From 2010, the projected year of peak employment, through 2035, the projected regional population will grow from about 1.9 million to more than 2.7 million people. The peak year population contribution attributable to the repository would be fewer than 4,000 people, a very small fraction of 1 percent. As a consequence, the Yucca Mountain Repository Project would be unlikely to alter the population growth to a great degree in the region of influence. Figure 4-4 shows the projected population increase as a result of the repository project.

Table 4-17 lists estimated incremental population increases that would occur as a result of repository activities to Clark and Nye Counties based on historic Nevada Test Site residential distribution patterns. As mentioned above, repository workers would be unlikely to reside in Lincoln County. The incremental population increase in Clark County would be almost imperceptible.

Table 4-17. Maximum expected population increase (2030).

Location	Population increase
Clark County	
Indian Springs	108
Rest of Clark County	2,882
Clark total	**2,990**
Nye County	
Amargosa Valley	50
Beatty	7
Pahrump	669
Nye total	**726**

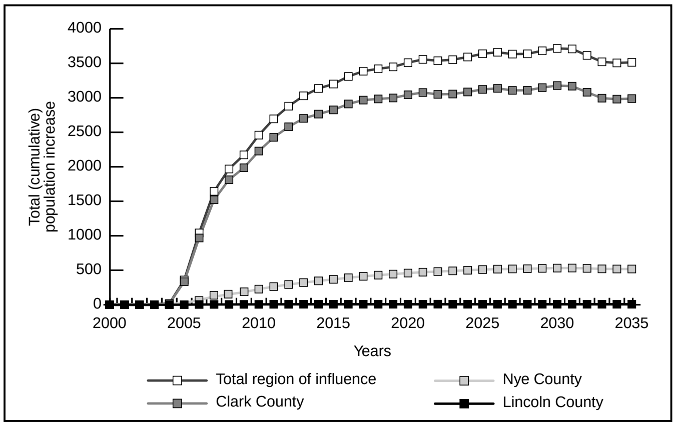


Figure 4-4. Regional population increases from construction and operations: 2000 to 2035.

The increase in the Nye County population would be less than 2 percent of the projected total population for the peak year for potential repository impacts. The Yucca Mountain Repository would not alter the population growth rate in Clark County in a measurable degree. Population growth associated with the repository would be more evident in Nye County. However, because the increases would occur over a long period, about 25 years, Nye County could accommodate them.

4.1.6.2.3 *Impacts to Economic Measures*

Table 4-18 lists changes in economic measures that would result from repository activities during the construction phase (expressed in 1992 dollars). The increases in real disposable income would peak in 2007 with an increase of about $57 million, while increases in Gross Regional Product would peak in 2006 at about $98 million. Regional expenditures by state and local governments would peak at $5.8 million in 2009. Economic measures for the region of influence would increase by less than one-quarter of 1 percent over the projected baseline (economic measures without the repository project).

Table 4-18. Increases in economic measures from repository construction: 2005 to 2009 (thousands of dollars).[a]

Jurisdiction	2005	2006	2007	2008	2009
Clark County					
Personal income	28,000	52,100	53,500	44,600	43,500
Gross Regional Product	46,500	84,000	79,100	59,400	47,800
State and local government expenditures	800	2,500	4,000	4,700	5,300
Nye County					
Personal income	1,700	3,100	3,100	2,400	2,800
Gross Regional Product	7,600	13,800	13,300	10,600	9,500
State and local government expenditures	100	200	300	400	500
Lincoln County					
Personal income	100	200	200	200	200
Gross Regional Product	100	100	100	100	100
State and local government expenditures	0	0	0	0	0
Total region of influence					
Personal income	29,800	55,400	56,800	47,200	46,500
Gross Regional Product	54,200	97,900	92,500	70,100	57,400
State and local government expenditures	900	2,700	4,300	5,100	5,800

a. Totals might differ from sums due to rounding.

Table 4-19 lists the changes in economic measures that would result from the repository project during the operation and monitoring phase. Increases in Gross Regional Product and in real disposable income would peak in 2029-2030, at about $70 million and $83 million, respectively. Increases in regional expenditures by state and local governments under the maximum employment case would also peak in 2030 at about $11 million. Economic measures for the region of influence would increase by less than one-half of 1 percent over the projected baseline.

GROSS REGIONAL PRODUCT

Value of goods and services produced in the region of influence.

4.1.6.2.4 *Impacts to Housing*

Repository-generated impacts to housing availability from changes in the population in the region of influence would be small. Given the size of the regional workforce, the number of workers inmigrating to work on the repository would be unlikely to be measurable.

The region of influence has an adequate supply of undeveloped land to meet future demands. Throughout most of the 1990s, the Bureau of Land Management has conducted land exchanges in Clark County. These exchanges have typically involved a trade of environmentally sensitive land outside the county for Bureau land in the county. The land in Clark County moves to the private sector for sale to land developers. This policy has helped to accommodate the population growth in the Las Vegas area.

Table 4-19. Increases in economic measures from emplacement and development activities: 2010 to 2035 (thousands of dollars).[a]

Jurisdiction	2010	2015	2020	2025	2030	2035
Clark County						
Personal income	53,200	57,400	64,300	70,300	74,700	73,000
Gross Regional Product	53,000	46,900	52,100	56,500	57,800	49,000
State and local government expenditures	5,900	7,700	8,400	8,800	9,100	8,800
Nye County						
Personal income	4,000	5,400	6,700	7,600	8,300	8,500
Gross Regional Product	11,000	10,600	11,400	11,900	11,800	10,000
State and local government expenditures	700	1,100	1,400	1,600	1,700	1,700
Lincoln County						
Personal income	200	200	200	200	300	200
Gross Regional Product	100	100	100	100	100	100
State and local government expenditures	0	100	100	100	100	100
Total region of influence						
Personal income	57,400	63,000	71,200	78,100	83,300	81,700
Gross Regional Product	64,100	57,600	63,600	68,500	69,700	59,100
State and local government expenditures	6,600	8,900	9,900	10,500	10,900	10,600

a. Totals might differ from sums due to rounding.

Workers and dependents who migrated to work on the repository probably would live in the many communities of Clark County, thereby dispersing the increased demand for housing. Southern Nye County, particularly Pahrump, would also experience some demand for housing. However, because the change in population would occur steadily over a long period, the county would be able to accommodate increases in housing demands. In Lincoln County, little or no demand would be likely, so housing availability would not be an issue.

4.1.6.2.5 *Impacts to Public Services*

Repository-generated impacts to public services from changes in the population in the region of influence would be small. Population changes in the region from the maximum repository-related employment case would be a small fraction of the anticipated job growth in the region. Even with the addition of repository jobs, the annual regional growth rate would increase by less than 2 percent, minimizing a possible need to alter plans already in place to meet projected growth.

As mentioned above, inmigrating workers probably would live in the many communities of Clark County, thereby dispersing the increased demand for public services. Southern Nye County, particularly Pahrump, also would experience some demand for public services. However, because the change in population would occur steadily over a long period, the county would be able to meet education, law enforcement, and fire protection demands. Impacts to public services would be unlikely in Lincoln County.

4.1.7 OCCUPATIONAL AND PUBLIC HEALTH AND SAFETY IMPACTS

This section describes short-term (prior to the completion of repository closure) health and safety impacts to workers (occupational impacts) and to members of the public from performance confirmation, construction, operation and monitoring, and closure activities. The analysis estimated health and safety impacts separately for involved workers and noninvolved workers for each repository phase. Involved workers are craft and operations personnel who would be directly involved in the activities related to facility construction and operations, including excavation activities; receipt, handling, packaging, and emplacement of spent nuclear fuel and high-level radioactive waste materials; and monitoring of the condition and performance of the waste packages. Noninvolved workers are managerial, technical, supervisory, and administrative personnel who would not be directly involved in construction, excavation, and operations activities.

The evaluation used engineering estimates of equivalent full-time years worked during each phase along with standard statistics on industrial accidents and incidents to estimate impacts to workers from nonradiological hazards. It used a similar approach for radiological worker hazards. The evaluation used engineering estimates of pollutant releases from repository operations along with standard modeling techniques to estimate impacts to members of the public.

The types of human health and safety impacts estimated for workers would include those from industrial hazards, exposure to radiation and radioactive material, and exposure to hazardous nonradioactive material. The hazardous nonradioactive materials would be cristobalite and erionite, naturally occurring minerals in the rock (welded tuff) of the planned repository location. All of the estimated human health impacts to members of the public are based on airborne exposures to naturally occurring radioactive and hazardous materials. The radiological doses and hazardous material concentrations on which the human health impacts are based are described in Section 4.1.2.

Appendix F describes the methodology, data, and data sources used for the calculations of health and safety impacts to workers and supporting detailed results. In addition, it contains a human health impacts primer.

4.1.7.1 Impacts to Occupational and Public Health and Safety from Performance Confirmation (2001 to 2005)

Performance confirmation activities would be similar to the activities performed during Yucca Mountain site characterization. Their purpose would be to ensure that systems, operations, and materials were functioning as predicted. These activities could include the construction of surface facilities to support performance confirmation, excavation of exploratory tunnels, and testing and monitoring activities in the drifts. Chapter 3 describes site characterization activities and the resulting affected environment.

Potential health and safety impacts that could occur during performance confirmation activities include those common to an industrial work setting, radiological impacts to the public and workers from exposure to radon-222 and its decay products, external radiation exposure of workers in the subsurface environment, and the potential for exposure to naturally occurring cristobalite and erionite generated by excavation activities. Section 4.1.7.2 contains additional information on these potential exposure pathways. No spent nuclear fuel and high-level radioactive waste would be present during performance confirmation activities, so radiation exposure of workers from this source would not occur.

Impacts are likely to be very small during performance confirmation activities. Incremental health and safety impacts to workers for the performance confirmation period would be less than 2 percent of those estimated for the construction, operations and monitoring, and closure phases, based on comparisons of worker activities and the number of worker-years between site characterization (TRW 1994a, all) and repository activities (see Appendix F). Potential radiological impacts to members of the public would be less than those estimated for the construction phase (Section 4.1.7.2). The probability of latent cancer fatality in the offsite maximally exposed individual would be about 0.000001. No latent cancer fatalities (less than 0.007) would be likely in the potentially exposed population (see Section 4.1.7.2.2).

4.1.7.2 Impacts to Occupational and Public Health and Safety from Initial Construction (2005 to 2010)

This section describes estimates of health and safety impacts to repository workers and members of the public for the 5-year initial construction period (2005 to 2010). During this period, DOE would build the surface facilities, excavate the main drifts, and excavate enough emplacement drifts to support initial emplacement activities. Potential health and safety impacts to workers would occur from industrial hazards, exposure to naturally occurring radionuclides, and exposure to naturally occurring cristobalite and erionite in the rock at the Yucca Mountain site. Potential health impacts to members of the public would be from exposure to airborne releases of naturally occurring radionuclides and hazardous materials.

4.1.7.2.1 *Occupational Health and Safety Impacts (Involved and Noninvolved Workers)*

Industrial Hazards. The analysis estimated health and safety impacts to workers from hazards common to the industrial setting (such as falling or tripping) in which they would be working using statistics for similar kinds of operations and estimates of the total number of full-time equivalent worker years that would be involved in the activities. The statistics that the analysis used are from the DOE Computerized Accident/Incident Reporting and Recordkeeping System (DOE 1999c, all). These statistics reflect recent DOE experience for these types of activities. Appendix F, Section F.2.2.2, contains more information on the selection of impact statistics.

The analysis based its estimates for the number of full-time worker years for the construction phase on the current repository design concepts described in Chapter 2. Estimates range from about 5,200 to about 6,300 worker years depending on the thermal load and packaging scenario (Appendix F, Table F-1). Table 4-20 lists estimated potential impacts from normal industrial hazards for involved and noninvolved workers for the construction phase. The table lists three types of industrial safety impacts: total recordable cases of injuries and illnesses that are work-related, total lost workday cases, and fatalities. (See the discussions in Appendix F, Section F.2.2.)

Table 4-20. Estimated impacts to workers from industrial hazards during initial construction period.[a,b]

Worker group and impact category	High thermal load			Intermediate thermal load			Low thermal load		
	UC[c]	DISP[d]	DPC[e]	UC	DISP	DPC	UC	DISP	DPC
Involved workers									
Total recordable cases	290	240	250	300	250	260	300	250	260
Lost workday cases	140	120	120	140	120	120	140	120	120
Fatalities	0.14	0.11	0.12	0.14	0.12	0.12	0.14	0.12	0.12
Noninvolved workers									
Total recordable cases	50	41	42	50	41	42	50	41	42
Lost workday cases	24	20	21	24	20	21	24	20	21
Fatalities	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
All workers (totals)[f]									
Total recordable cases	340	280	290	350	290	300	350	290	300
Lost workday cases	160	140	140	160	140	140	170	140	140
Fatalities	0.18	0.15	0.16	0.18	0.16	0.16	0.18	0.16	0.16

a. Source: Appendix F, Tables F-7 and F-8.

b. The analysis assumed that construction phase would last 44 months for surface activities and 60 months for subsurface activities.

c. UC = uncanistered packaging scenario.

d. DISP = disposable canister packaging scenario.

e. DPC = dual-purpose canister packaging scenario.

f. Totals might differ from sums due to rounding.

The surface facilities that would be required to handle each packaging scenario would be different, so the industrial safety impacts for construction would be different. Appendix F, Tables F-7 and F-8, contains industrial hazard impact tables for surface and subsurface workers.

Estimated fatalities would be of the magnitude of 0.2 for all scenarios. Industrial safety impacts (including total recordable cases and lost workday cases) would be largest for the uncanistered packaging scenario due to the more extensive surface facilities required and, hence, more worker years for construction.

Naturally Occurring Hazardous Materials. Two types of naturally occurring hazardous materials are present at the Yucca Mountain site—cristobalite, a form of crystalline silica (silicon dioxide, SiO_2), and erionite, a naturally occurring zeolite. Both occur in the subsurface rock at Yucca Mountain and have the potential to become airborne during repository operations. Cristobalite, which would occur at the repository level, would be released during tunneling operations. It could also be released with wind-blown dust from the excavated rock pile.

Dust generated during tunneling would come from welded tuff, which consists largely of silica-based minerals. Crystalline silica is a highly structured form of silica that includes quartz and cristobalite. It is a known causative agent for the disease called *silicosis*, which is a destructive lung condition caused by deposition of particulate matter in the lungs and characterized by scarring of lung tissue. It is contracted by prolonged exposure to high levels of respirable silica dust or to acute levels of respirable silica dust (EPA 1996a, Chapter 8). The welded tuff has an average cristobalite content of between 18 and 28 percent (TRW 1999b, page 4-81). Using the parent rock percentage probably will overestimate the airborne cristobalite concentration, because studies of both ambient and occupational airborne crystalline silica have shown that most airborne crystalline silica is coarse and not respirable, and that larger particles will deposit rapidly on the surface (EPA 1996a, page 3-26).

The International Agency for Research on Cancer has classified crystalline silica, when inhaled in the form of quartz or cristobalite from occupational sources, as a Class 1 (known) carcinogen (IARC 1997, pages 207 and 208). The Environmental Protection Agency has noted an increased cancer risk to humans who already have developed adverse noncancer effects from silicosis, but the cancer risk to otherwise healthy individuals is not clear (EPA 1996a, pages 8-7 to 8-9). To date, the Environmental Protection Agency has not issued the factors needed to estimate the risk of cancer from crystalline silica exposures.

The dust from mechanical rock excavation and dust pickup from the excavated rock pile would consist of a range of particle sizes. Dust particles with an aerodynamic diameter smaller than 10 micrometers have little mass and inertia in comparison to their surface area; therefore, they can remain suspended in dry air for long periods and humans can inhale them. DOE would use engineering controls during subsurface work to control exposures of workers to silica dust. Water would be applied during excavation activities to wet both the rock face and the broken rock to minimize airborne dust levels. Wet or dry dust scrubbers would capture dust that the water sprays did not suppress. The fresh air intake and the exhaust air streams would be separated to prevent increased dust concentrations in the drift atmosphere from recirculation. In addition, the ventilation system would be designed and operated to control ambient air velocities to minimize dust resuspension. DOE would monitor the working environment to ensure that workers were not exposed to dust concentrations higher than the applicable limits for cristobalite. If engineering controls were unable to maintain dust concentrations below the limits, subsurface workers would have to wear respirators until the engineering controls could establish acceptable conditions. Similar controls would be applied, if required, for surface workers. DOE expects that exposure of workers to silica dust would be below the applicable limits and potential impacts to subsurface and surface workers would be very small.

Erionite is a natural zeolite that occurs in the rock layers below the proposed repository level (see Chapter 3, Section 3.1.3). It might also occur in rock layers above the repository level but activities to date have not found it in those layers. Erionite could become a hazard during vertical boring operations if the operations passed through a rock layer containing erionite (which would be unlikely), and during excavation for access to the lower block as required for the low thermal load scenario. Erionite forms wool-like fibrous masses with a maximum fiber length of about 50 micrometers. The International Agency for Research on Cancer has determined that erionite is a carcinogen for humans, based on the very high mortality observed in three Turkish villages where erionite is mined (IARC 1987, all). DOE does not expect to encounter erionite layers either during vertical boring operations (which would be through rock layers above known erionite layers) or during excavation to provide access to the lower block and offset areas. Access excavation would be planned to avoid any identified layers of erionite (McKenzie 1998, all). If erionite was encountered during excavation for access to the lower block or during vertical boring operations, the engineering controls described above for cristobalite would be instituted and workers would be required to wear respiratory protection until acceptable conditions were reestablished. Appendix F, Section F.1.2, contains additional information on the impacts associated with inhalation of crystalline silica, cristobalite, and erionite.

Radiological Health Impacts. Potential radiological health impacts to involved and noninvolved workers in subsurface facilities during this phase would be from two sources: exposure to and inhalation of naturally occurring radon-222 and its decay products following emanation of the radon from the surrounding rock, and external radiation dose from naturally occurring radionuclides in the drift walls, principally potassium-40 and radionuclides in the uranium decay series (TRW 1999o, Sections 4 and 5). Radon-222 is a noble gas produced by the radioactive decay of naturally occurring uranium-238 in the rock. Because it is a noble gas, radon could emanate from the rock into the drifts, where elevated concentrations of radon-222 and its decay products could occur in the repository atmosphere (see Chapter 3, Section 3.1.8).

Studies during Exploratory Studies Facility activities indicated a dose rate from background sources of radionuclides in the drift walls of about 40 millirem per year, which is about the same as the cosmic and cosmogenic components from background radiation on the surface, 40 millirem per year in the Amargosa Valley region (see Chapter 3, Table 3-28). This analysis considers the underground ambient radiation dose to be part of the involved worker occupational exposure.

Workers in surface facilities would be exposed to airborne emissions of radon-222 and its decay products released in subsurface exhaust ventilation air. Spent nuclear fuel and high-level radioactive waste would not be present at the site during the construction phase and so would not contribute to radiological impacts.

Table 4-21 lists estimated potential doses and radiological health impacts for the 5 years of the construction phase to involved workers and noninvolved workers, and the sum for all workers. It lists estimated doses and radiological health impacts for the maximally exposed involved worker and for the involved worker population; radiological health impacts for the maximally exposed noninvolved worker and for the noninvolved worker population; and the estimated collective dose and radiological health impacts for the combined population of workers. Estimated doses were converted to estimates of latent cancer fatalities using a dose-to-risk conversion factor of 0.0004 latent cancer fatality per rem (see Appendix F, Section F.1.1.5). This conversion factor is based on a widely accepted international recommendation (ICRP 1991, page 22) and has been accepted for use by Federal agencies. The tables that follow list radiological health impacts for individuals as the increase in the probability of a latent cancer fatality occurring after the receipt of a dose for the maximally exposed individual worker.

Table 4-21. Estimated doses and radiological health impacts to workers during initial construction period.[a,b]

Worker group and impact category	High thermal load	Intermediate thermal load	Low thermal load
Involved workers			
Maximally exposed worker dose (millirem)	770	860	860
Latent cancer fatality probability	0.0003	0.0003	0.0003
Collective dose (person-rem)	350	420	420
Latent cancer fatality incidence	0.14	0.17	0.17
Noninvolved workers			
Maximally exposed worker dose (millirem)	580	640	640
Latent cancer fatality probability	0.0002	0.0003	0.0003
Collective dose (person-rem)	70	78	78
Latent cancer fatality incidence	0.03	0.03	0.03
All workers (totals)[c]			
Collective dose (person-rem)	420	500	500
Latent cancer fatality incidence	0.17	0.20	0.20

a. Source: Appendix F, Tables F-9 and F-10.
b. The construction phase would last 5 years. Results are for subsurface workers.
c. Totals might differ from sums due to rounding.

Radiological health impacts to populations are listed as the number of latent cancer fatalities estimated to occur in the exposed population.

During the initial construction period, radiological health impacts to the surface facility workforce would be much smaller than those to the subsurface facility workforce, so the numbers in Table 4-21 are those for subsurface workers (see Appendix F, Table F-5).

Table 4-21 indicates that the projected increase in the number of latent cancer fatalities for workers would be low (about 0.2); the calculated increase in the likelihood that an individual worker would die from a latent cancer fatality would also be low (less than about 0.0003).

4.1.7.2.2 *Public Health Impacts*

Naturally Occurring Hazardous Materials. Table 4-1 lists estimated annual average concentrations of cristobalite at the site boundary where members of the public could be exposed during the construction phase. The analysis estimated concentrations of less than 0.025 microgram per cubic meter for all thermal load scenarios, and health impacts to the public would be unlikely. Quantities and resultant concentrations of erionite, if present, would be much lower at locations of public exposure. Impacts would be very small.

Radiological Health Impacts. Potential radiological health impacts to the public during the construction phase would come from exposure to airborne releases of naturally occurring radon-222 and its decay products in the subsurface exhaust ventilation air. The analysis estimated doses and radiological health impacts for the offsite maximally exposed individual and the potentially involved population. The offsite maximally exposed individual is a hypothetical member of the public at a point on the land withdrawal boundary that would receive the largest annual dose and resultant radiological health impact. This location would be 20 kilometers (about 12 miles) south of the repository site. Section 4.1.2.2.2 provides additional information on the estimates of public doses. Estimated doses to members of the public were converted to estimates of latent cancer fatalities using a dose-to-risk conversion factor of 0.0005 latent cancer fatality per rem for members of the public (see Chapter 3, Section 3.1.8).

Table 4-22 lists the estimated doses and radiological health impacts to members of the public from the 5-year initial construction period. The values in the table indicate that radiological health impacts to the public from repository construction would be very small (0.006 latent cancer fatality for each of the thermal load scenarios). The estimated individual risk of contracting a latent cancer fatality for the maximally exposed individual would be about 0.000001 over the 5-year phase.

Table 4-22. Estimated doses and radiological health impacts from radon-222 to the public during the initial construction period.[a,b]

Dose or health effect	High thermal load	Intermediate thermal load	Low thermal load
Maximally exposed individual[c] dose (millirem)	2.1	2.5	2.5
Latent cancer fatality probability	1.1×10^{-6}	1.2×10^{-6}	1.2×10^{-6}
Collective dose (person-rem)[d]	11	13	13
Latent cancer fatality incidence	0.0057	0.0066	0.0066

a. Source: Table 4-2.

b. The initial construction period would last 5 years.

c. The individual was assumed to maintain continuous residence 20 kilometers (12 miles) south of the repository.

d. Dose to approximately 28,000 individuals within about 80 kilometers (50 miles) of the repository.

4.1.7.3 Occupational and Public Health and Safety Impacts for the Continuing Construction, Operation, and Monitoring Period (2010 to 2110)

This section discusses estimates of health and safety impacts to workers and members of the public for the operation and monitoring phase. The analysis assumed a 24-year period for the receipt, handling, packaging, and emplacement of spent nuclear fuel and high-level radioactive waste. There would be a concurrent 22-year period for drift development. A 76-year monitoring period would begin after the completion of emplacement. However, the monitoring period could be as short as 26 years and as long as 276 years (see Section 4.1). Appendix F, Table F-24, lists radiological health impacts for the shorter and longer monitoring periods.

4.1.7.3.1 *Occupational Impacts (Involved and Noninvolved Workers)*

Industrial Hazards. Table 4-23 summarizes health and safety impacts from common industrial hazards for the operation and monitoring phase. DOE performed separate analyses for surface operations, subsurface emplacement operations, subsurface drift development operations, and monitoring activities, and summed the values to obtain the results listed in this table. Appendix F (Tables F-11, F-12, and F-13) contains results of the impact analysis for each subphase.

The analysis predicted a range of 1.3 to 1.6 fatalities for the various combinations of thermal load scenarios and packaging scenarios. The largest number of workers (see Appendix F, Table F-1) and, therefore, the largest industrial health and safety impacts would be associated with the uncanistered packaging scenario.

Naturally Occurring Hazardous Material. As discussed in Section 4.1.7.2.1 for the construction phase, DOE would use engineering controls and, if necessary, administrative worker protection measures such as respiratory protection to control and minimize impacts to workers from releases of cristobalite and erionite during the operation and monitoring phase.

Radiological Health Impacts. This section discusses the estimates of the radiological health impacts to workers for the operation and monitoring phase. The overall radiological health impacts, which are listed in Table 4-24, are a combination of impacts to surface workers during operation, impacts to subsurface workers during operations, and impacts to surface and subsurface workers during monitoring.

Table 4-23. Estimated impacts to workers from industrial hazards during the continuing construction, operation, and monitoring period.[a,b]

Worker group and impact category	High thermal load			Intermediate thermal load			Low thermal load		
	UC[c]	DISP[d]	DPC[e]	UC	DISP	DPC	UC	DISP	DPC
Involved									
TRC[f]	1,360	1,150	1,160	1,360	1,150	1,160	1,400	1,180	1,200
LWC[g]	710	610	620	710	610	620	730	640	640
Fatalities	1.1	0.88	0.89	1.1	0.88	0.89	1.1	0.90	0.92
Noninvolved									
TRC	500	450	450	500	450	450	500	450	450
LWC	250	220	220	250	220	220	250	220	220
Fatalities	0.49	0.43	0.43	0.49	0.43	0.43	0.49	0.42	0.43
All workers (totals)[h]									
TRC	1,860	1,590	1,600	1,860	1,600	1,610	1,900	1,630	1,650
LWC	960	830	840	960	840	840	980	860	860
Fatalities	1.6	1.3	1.3	1.6	1.3	1.3	1.6	1.3	1.4

a. Source: Appendix F; sum of impacts listed in Tables F-11, F-12, F-13, F-19, F-20, and F-21.
b. The operation and monitoring phase would last 100 years.
c. UC = uncanistered packaging scenario.
d. DISP = disposable canister packaging scenario.
e. DPC = dual-purpose canister packaging scenario.
f. TRC = total recordable cases of accident or injury.
g. LWC = lost workday cases.
h. Totals might differ from sums due to rounding.

Table 4-24. Estimated dose and radiological health impacts to workers for the continuing construction, operation, and monitoring period.[a,b]

Worker group and impact category	High thermal load			Intermediate thermal load			Low thermal load		
	UC[c]	DISP[d]	DPC[e]	UC	DISP	DPC	UC	DISP	DPC
Involved									
MEI dose[f]	16,240	16,240	16,240	18,940	18,940	18,940	17,610	17,610	17,610
LCF[g] probability	0.006	0.006	0.006	0.008	0.008	0.008	0.007	0.007	0.007
CD[h]	8,120	5,330	5,380	8,450	5,660	5,710	8,530	5,740	5,790
LCF incidence	3.2	2.1	2.2	3.4	2.3	2.3	3.4	2.3	2.3
Noninvolved									
MEI dose	6,200	6,200	6,200	7,550	7,550	7,550	8,000	8,000	8,000
LCF probability	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003
CD	350	330	330	380	360	360	400	390	390
LCF incidence	0.14	0.13	0.13	0.15	0.14	0.14	0.16	0.15	0.15
All workers (totals)[i]									
CD	8,470	5,660	5,710	8,830	6,020	6,070	8,930	6,130	6,180
LCF incidence	3.3	2.2	2.2	3.6	2.4	2.4	3.6	2.5	2.5

a. Source: The maximally exposed individual and latent cancer fatality probabilities are the maximums from Tables 4-25, 4-26, and 4-27. The collective dose and latent cancer fatality incidence are summed from the same tables.
b. The operation and monitoring phase would last 100 years.
c. UC = uncanistered packaging scenario.
d. DISP = disposable canister packaging scenario.
e. DPC = dual-purpose canister packaging scenario.
f. MEI dose = maximally exposed individual (worker) dose, in millirem. The subsurface facilities workers could incur the dose shown during the monitoring period.
g. LCF = latent cancer fatality.
h. CD = collective dose (person-rem).
i. Totals might differ from sums due to rounding.

With respect to overall radiological health impacts, the estimated health impacts to workers for the 100-year operation and monitoring phase would range from 2 to 4 latent cancer fatalities. Estimated radiological health impacts to the maximally exposed individual would be about the same as those from normal background radiation exposure in the Amargosa Valley region over a 70-year lifetime (about 25,000 millirem) during the 100-year operation and monitoring phase.

Tables 4-25 and 4-26 list health impacts to surface and subsurface workers, respectively, for 24 years of operations activities. Radiological health impacts to surface workers would be independent of the thermal load scenarios, and impacts to subsurface workers would be independent of the packaging scenario.

Table 4-25. Estimated dose and radiological health impacts to surface facility workers for the 24-year operation period.[a]

	Packaging scenario[b]		
Worker group and impact category	UC	DISP	DPC
Involved workers			
Maximally exposed worker dose (millirem)	9,600	9,600	9,600
LCF[c] probability	0.004	0.004	0.004
Collective dose (person-rem)	5,170	2,460	2,500
LCF incidence	2.1	1.0	1.0
Noninvolved workers			
Maximally exposed worker dose (millirem)	600	600	600
LCF probability	0.0002	0.0002	0.0002
Collective dose (person-rem)	100	90	90
LCF incidence	0.04	0.04	0.04
All workers (totals)[d]			
Collective dose (person-rem)	5,270	2,550	2,590
LCF incidence	2.1	1.0	1.0

a. Calculated from full-time equivalent worker year values in Appendix F, Table F-1 and dose rate values in Table F-5.

b. UC = uncanistered; DISP = disposable canister; DPC = dual-purpose canister.

c. LCF = latent cancer fatality.

d. Totals might differ from sums due to rounding.

Table 4-26. Estimated dose and radiological health impacts to subsurface facilities workers during the 24-year operation period.[a]

Worker group and impact category	High thermal load	Intermediate thermal load	Low thermal load
Involved			
Maximally exposed worker dose (millirem)[b]	7,010	7,630	7,630
LCF[c] probability	0.003	0.003	0.003
Collective dose (person-rem)	900	950	1,010
LCF incidence	0.36	0.38	0.40
Noninvolved			
Maximally exposed worker dose (millirem)[b]	980	1,270	2,280
LCF probability	0.0004	0.0005	0.0009
Collective dose (person-rem)	120	120	140
LCF incidence	0.05	0.05	0.06
All workers (totals)[d]			
Collective dose (person-rem)	1,020	1,070	1,150
LCF incidence	0.41	0.43	0.46

a. Source: Appendix F; sum of impacts listed in Tables F-14, F-15, F-16, F-17, and F-18. The impacts listed would result from work lasting 22 to 24 years.

b. The subsurface facilities emplacement workers could incur the dose shown during the 24-year operation period (the development worker's maximum worker dose would be lower).

c. LCF = latent cancer fatality.

d. Totals might differ from sums due to rounding.

The basic dose rate data (Appendix F, Table F-5) used to calculate radiological impacts are conservatively high, particularly for workers in surface facility operations, and tend to overestimate potential impacts. These estimates are sufficiently conservative to include potential doses from other activities such as handling low-level radioactive waste generated during repository operations. The principal contributors to radiological health impacts would be surface facility operations, which would involve the receipt, handling, and packaging of spent nuclear fuel and high-level radioactive waste for emplacement, and subsurface monitoring activities (see Tables 4-25, 4-26, and 4-27). Radiological health impacts to workers would be highest for the combination of the uncanistered package scenario and the low thermal load scenario, with estimated radiological health impacts varying by about 50 percent from highest to lowest. Radiological health impacts from this combination of scenarios would be highest because it would involve the highest number of worker years. The variations are not large for a given shipping package scenario because impacts to subsurface workers would not depend on the shipping package scenario.

The largest component of the radiological impacts to subsurface workers during emplacement would be from inhalation of radon-222 and its decay products, particularly during the postemplacement monitoring period (see Appendix F, Table F-23).

Decontamination, Monitoring, and Maintenance Activities (2034 to 2110). The monitoring and maintenance activities of the operation and monitoring phase would last for 76 years and involve two types of activities leading to potential radiological health impacts. They are the decontamination of the surface facilities, which would take 2 to 3 years at the beginning of the monitoring period, and subsurface monitoring and maintenance activities. Table 4-27 lists estimated dose and radiological health impacts to workers for the surface facilities decontamination activities and the 76-year monitoring period.

Table 4-27. Estimated dose and radiological health impacts to workers for the 3-year decontamination period and the 76-year monitoring and maintenance period.[a,b]

Worker group and impact category	High thermal load			Intermediate thermal load			Low thermal load		
	UC[c]	DISP[d]	DPC[e]	UC	DISP	DPC	UC	DISP	DPC
Involved									
MEI dose[f] (millirem)	16,240	16,240	16,240	18,940	18,940	18,940	17,610	17,610	17,610
LCF[g] probability	0.006	0.006	0.006	0.008	0.008	0.008	0.007	0.007	0.007
CD[h] (person-rem)	2,050	1,990	1,980	2,330	2,250	2,260	2,350	2,270	2,280
LCF incidence	0.9	0.9	0.9	1.0	1.0	1.0	1.1	1.0	1.0
Noninvolved									
MEI dose (millirem)	6,200	6,200	6,200	7,550	7,550	7,550	8,000	8,000	8,000
LCF probability	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003
CD (person-rem)	120	120	120	150	150	150	160	160	160
LCF incidence	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06
All workers (total)[i]									
CD (person-rem)	2,170	2,110	2,100	2,480	2,400	2,410	2,510	2,430	2,440
LCF incidence	1.0	1.0	1.0	2.1	1.0	1.0	1.1	1.0	1.0

a. Sources: Appendix F, Tables F-22 and F-23.

b. Monitoring period impacts would be independent of the packaging scenario; surface facility decontamination impacts would depend on the packaging scenario.

c. UC = uncanistered packaging scenario.

d. DISP = disposable canister packaging scenario.

e. DPC = dual-purpose canister packaging scenario.

f. MEI dose = maximally exposed individual (worker) dose, in millirem.

g. LCF = latent cancer fatality.

h. CD = collective dose.

i. Totals might differ from sums due to rounding.

Appendix F, Table F-22 lists the radiological health impacts associated with surface facility decontamination operations. The impacts would vary with the packaging scenario because of differences in the surface facility design to accommodate the different types of shipping packages.

Monitoring and maintenance would involve both surface and subsurface workers; however, the dose to surface workers would be very low in comparison to those to subsurface workers. Therefore, essentially all the radiological impacts would be to subsurface workers (see Appendix F, Table F-5 footnotes). Appendix F, Table F-23, lists doses and radiological health impacts to subsurface workers for the 76-year monitoring period. Estimated doses and radiological health impacts to the maximally exposed worker are based on a 50-year working lifetime. In addition, Appendix F describes dose and radiological health estimates for workers for a shorter monitoring period of 26 years and for a longer monitoring period of 276 years (see Appendix F, Table F-24).

4.1.7.3.2 *Public Health Impacts*

Naturally Occurring Hazardous Materials. Section 4.1.2.3.1 presents estimated annual average concentrations of cristobalite at the land withdrawal boundary where members of the public could be exposed during the operation and monitoring phase. The analysis estimated annual average concentrations of about 0.015 microgram per cubic meter or less for all thermal load scenarios. Health impacts to the public would be unlikely. Quantities and resultant concentrations of erionite, if present, would be much lower than for cristobalite at locations of public exposure. Impacts would be very small.

Radiological Health Impacts. Potential radiological health impacts to the public from the operation and monitoring phase could result from exposure to naturally occurring radon-222 and its decay products released in subsurface exhaust ventilation air, and from exposure to radioactive noble gas fission products, principally krypton-85, that could be released from the Waste Handling Building during spent nuclear fuel handling operations. Krypton-85 and other noble gas fission products would be very small contributors to dose and potential radiological impacts, less than 0.001 percent of the dose from radon-222 and its decay products (see Section 4.1.2.3.2).

Section 4.1.2.3.2 presents estimates of dose to the public for the continuing construction, operation, and monitoring period. Table 4-28 lists these doses and potential radiological health impacts to the public for that period.

Table 4-28. Estimated total dose and radiological health impacts over 50 years to the public for continuing construction, operation, and monitoring period.[a]

Impact category	High thermal load	Intermediate thermal load	Low thermal load
Maximally exposed individual[b] dose (millirem)	49	58	132
Latent cancer fatality probability	2.45×10^{-5}	2.3×10^{-5}	6.6×10^{-5}
Collective dose[c] (person-rem)	259	310	700
Latent cancer fatality incidence	0.13	0.15	0.35

a. Source: Tables 4-4 and 4-5.

b. Exposed for a 70-year lifetime; assumed first 24 years during operation and last 46 years during monitoring.

c. Dose to approximately 28,000 individuals within about 80 kilometers (50 miles) for 100 years of operation and monitoring.

Potential radiological health impacts to the public from radionuclides released during the operation and monitoring phase would be low, with 0.13 to 0.35 latent cancer fatality estimated for the thermal load scenarios. The probability of a latent cancer fatality to the maximally exposed individual would be about 0.00005 or less.

4.1.7.4 Impacts to Occupational and Public Health and Safety from Closure (2110 to 2125)

This section contains estimates of health and safety impacts to workers and to members of the public for the closure phase. The length of this phase would depend on the thermal load scenario. The values used for impact estimates are 6, 6, or 15 years for the high, intermediate, or low thermal load scenario, respectively.

4.1.7.4.1 *Occupational Impacts (Involved and Noninvolved Workers*)

Industrial Hazards. Table 4-29 lists impacts to workers from normal industrial workplace hazards for the closure phase.

Table 4-29. Estimated impacts to workers from industrial hazards during closure phase.[a,b]

Worker group and impact category	High thermal load			Intermediate thermal load			Low thermal load		
	UC[c]	DISP[d]	DPC[e]	UC	DISP	DPC	UC	DISP	DPC
Involved									
TRC[f]	180	150	150	180	150	150	300	270	270
LWC[g]	85	71	74	85	71	74	140	130	130
Fatalities	0.08	0.07	0.07	0.08	0.07	0.07	0.14	0.13	0.13
Noninvolved									
TRC	28	24	23	28	23	24	41	36	37
LWC	14	11	12	14	11	12	20	18	18
Fatalities	0.03	0.02	0.02	0.03	0.02	0.02	0.04	0.03	0.03
All workers (totals)[h]									
TRC	210	170	170	210	170	170	340	310	310
LWC	99	82	86	99	82	86	160	150	150
Fatalities	0.11	0.09	0.09	0.11	0.09	0.09	0.18	0.16	0.16

a. Source: Appendix F, Tables F-25 and F-26.
b. The closure phase would last for 6, 6, and 15 years for high, intermediate, and low thermal loads, respectively (Jessen 1999a).
c. UC = uncanistered packaging scenario.
d. DISP = disposable canister packaging scenario.
e. DPC = dual-purpose canister packaging scenario.
f. TRC = total recordable cases.
g. LWC = lost workday cases.
h. Totals might differ from sums due to rounding.

The estimated number of impacts from industrial hazards for the low thermal load scenario would be about double those for the intermediate and high thermal load scenarios because of the longer time required for closure and the associated larger number of worker years. The estimated number of fatalities would be much less than 1 for all thermal load scenarios.

Naturally Occurring Hazardous Material. Subsurface excavation would not occur during the closure phase, so the potential for exposure of workers to cristobalite and erionite would be much less. As necessary, DOE would use engineering controls and worker protection measures such as those discussed in Section 4.1.7.2.2 for the construction phase to control and minimize potential impacts to workers.

Radiological Health Impacts. During the closure phase, subsurface workers would be exposed to radon-222 in the drift atmosphere, to external radiation from radionuclides in the drift walls, and to external radiation emanating from the waste packages. Table 4-30 lists radiological impacts to workers for the closure phase. Because estimated doses and radiological impacts to surface workers would be

Table 4-30. Estimated dose and radiological health impacts to workers during closure phase.[a,b]

Worker group and impact category	High thermal load (6 years)	Intermediate thermal load (6 years)	Low thermal load (15 years)
Involved			
Maximally exposed individual dose[c] (millirem)	2,040	2,370	5,520
Latent cancer fatality probability	0.0008	0.0009	0.002
Collective dose (person-rem)	380	450	1,100
Latent cancer fatality incidence	0.15	0.18	0.44
Noninvolved			
Maximally exposed individual dose[c] (millirem)	1,090	1,340	3,540
Latent cancer fatality probability	0.0004	0.0005	0.001
Collective dose (person-rem)	48	59	160
Latent cancer fatality incidence	0.02	0.02	0.06
All workers (totals)[d]			
Collective dose (person-rem)	430	510	1,260
Latent cancer fatality incidence	0.17	0.20	0.50

a. Source: Appendix F, Tables F-27, F-28, and F-29.

b. Closure phase would last 6, 6, or 15 years for the high, intermediate, or low thermal load scenario, respectively (Jessen 1999a, all).

c. The subsurface facilities workers could incur the dose listed during the closure phase.

d. Totals might differ from sums due to rounding.

much smaller than those for subsurface workers (see Appendix F, Table F-5 footnotes), the impacts listed in this table are those for subsurface workers, which would be independent of the packaging scenario.

For the closure phase, the estimated number of latent cancer fatalities would range from 0.2 to 0.5. The probability of a latent cancer fatality for the maximally exposed individual worker would be 0.002 or less. The principal sources of exposure to subsurface workers would be from inhalation of radon-222 and its decay products.

4.1.7.4.2 *Public Health Impacts*

Naturally Occurring Hazardous Material. Section 4.1.2.4.1 presents estimated annual average concentrations of cristobalite during the closure phase at the land withdrawal boundary, where members of the public could be exposed. There would be no subsurface excavation during the closure phase, so cristobalite concentrations would be less than for earlier phases. Annual average concentrations of about 0.015 microgram per cubic meter or less were estimated for all thermal load scenarios, and health impacts to the public would be unlikely. Quantities and resultant concentrations of erionite, if present, would be much lower at locations of public exposure. Impacts would be very small.

Radiological Health Impacts. Potential radiation-related health impacts to the public from closure activities would result from exposure to radon-222 and its decay products released in the subsurface exhaust ventilation air. Section 4.1.2.4.2 presents estimates of dose to the public for the closure phase. Table 4-31 lists the estimated dose and radiological health impacts.

Radiological health impacts to the public would be low. The likelihood that the maximally exposed individual would experience a latent cancer fatality would be in the range of 0.000001 to 0.00001. The projected number of latent cancer fatalities would be 0.05 or less. The radiological health impacts to the public would be independent of the packaging scenario. Impacts to the public would be greatest for the low thermal load scenario, and would be about 6 to 7 times greater than for the intermediate and high thermal loads because of the larger radon release associated with the longer closure period for the low thermal load scenario.

Table 4-31. Estimated dose and radiological health impacts to public for the closure phase.[a]

Impact category	High thermal load	Intermediate thermal load	Low thermal load
Maximally exposed individual[b] dose (millirem)	2.6	3.1	19
Latent cancer fatality probability	1.3×10^{-6}	1.5×10^{-6}	9.4×10^{-6}
Collective dose (person-rem)[c]	13	15	93
Latent cancer fatality incidence	0.0064	0.0076	0.047

a. Source: Table 4-7.

b. For a person maintaining continuous residency during the entire closure phase.

c. Dose to approximately 28,000 individuals living within about 80 kilometers (50 miles).

4.1.7.5 Summary of Impacts to Occupational and Public Health and Safety

This section summarizes the potential human health and safety impacts to workers and members of the public from proposed activities at the Yucca Mountain repository. It describes the total impacts from activities during the construction, operation and monitoring, and closure phases for (1) impacts to workers from industrial hazards; (2) radiological health impacts to workers; and (3) radiological health impacts to members of the public. The three project phases would last 111, 111, and 120 years for the high, intermediate, and low thermal load scenarios, respectively. These differences in project duration are due to differences in the length of the closure phase for the three thermal load scenarios as described above.

4.1.7.5.1 *Impacts to Workers from Industrial Hazards in the Workplace for All Phases*

Table 4-32 lists the total impacts to workers from industrial hazards common to the workplace for all phases. For the approximately 110 to 120 years of repository activities, the estimated number of workplace fatalities would range from about 1.5 to 2. The estimated number of lost workday cases due to industrial injury or illness would range from about 1,060 to 1,280, depending on the combination of thermal load scenario and packaging scenario. About half of the industrial impacts would come from surface facility operations during the operation and monitoring phase because of the large number of worker years needed. The next largest contribution would be drift development during the operation and monitoring phase, which would account for as much as 15 percent of the impacts. The differences in impacts for the thermal load and shipping package combinations reflect differences in the number of full-time equivalent workers for the potential combinations.

4.1.7.5.2 *Radiological Impacts to Workers for All Phases*

Table 4-33 lists the total dose and radiological health impacts to workers for all phases. It lists dose and the potential radiological health impact to the maximally exposed individual worker for a 50-year working lifetime, and collective dose and potential radiological health impacts to the worker population for the 111, 111, or 120 years required to complete all phases for the high, intermediate, and low thermal load scenarios, respectively. The maximally exposed worker would have a probability of incurring a latent cancer fatality of 0.006 to 0.008 from radiation exposure over a 50-year working lifetime. The total estimated number of latent cancer fatalities in the repository workforce from the radiation exposure during all phases would range from about 2.5 to 4, depending on the combination of thermal load scenario and packaging scenario.

About 50 percent of the total worker radiation dose would be from the receipt, handling, and packaging of spent nuclear fuel in the surface facilities. Radiation from inhalation of radon-222 and its decay products by subsurface workers during construction, development, emplacement, monitoring, and closure

Table 4-32. Estimated impacts to workers from industrial hazards for all phases.[a]

Worker group and impact category	High thermal load			Intermediate thermal load			Low thermal load		
	UC[b]	DISP[c]	DPC[d]	UC	DISP	DPC	UC	DISP	DPC
Involved									
TRC[e]	1,820	1,540	1,560	1,830	1,550	1,570	1,990	1,700	1,730
LWC[f]	930	800	810	930	810	820	1,010	890	900
Fatalities	1.3	1.1	1.1	1.3	1.1	1.1	1.4	1.2	1.2
Noninvolved									
TRC	570	510	520	570	510	520	590	520	530
LWC	280	250	260	280	250	260	290	260	260
Fatalities	0.54	0.48	0.49	0.54	0.48	0.49	0.55	0.50	0.50
All workers (totals)[g]									
TRC	2,390	2,050	2,080	2,400	2,060	2,090	2,580	2,220	2,260
LWC	1,210	1,050	1,070	1,210	1,080	1,080	1,300	1,150	1,160
Fatalities	1.8	1.6	1.6	1.8	1.6	1.6	2.0	1.7	1.7

a. Source: Sum of impacts listed in Tables 4-20, 4-23, and 4-29.
b. UC = uncanistered packaging scenario.
c. DISP = disposable canister packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. TRC = total recordable cases.
f. LWC = lost workday cases.
g. Totals might differ from sums due to rounding.

Table 4-33. Estimated dose and radiological health impacts to workers for all phases.[a]

Worker group and impact category	High thermal load			Intermediate thermal load			Low thermal load		
	UC[b]	DISP[c]	DPC[d]	UC	DISP	DPC	UC	DISP	DPC
Involved									
MEI dose[e]	16,240	16,240	16,240	18,940	18,940	18,940	17,610	17,610	17,610
LCF[f] probability	0.006	0.006	0.006	0.008	0.008	0.008	0.007	0.007	0.007
CD[g]	8,850	6,060	6,110	9,320	6,530	6,580	10,060	7,270	7,320
LCF incidence	3.5	2.4	2.4	3.7	2.6	2.6	4.0	2.9	2.9
Noninvolved									
MEI dose[e]	6,200	6,200	6,200	7,550	7,550	7,550	8,000	8,000	8,000
LCF probability	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003
CD	460	450	450	510	500	500	640	620	620
LCF incidence	0.19	0.18	0.18	0.21	0.20	0.20	0.25	0.25	0.25
All workers (totals)[h]									
CD	9,310	6,510	6,560	9,830	7,030	7,080	10,700	7,890	7,940
LCF incidence	3.7	2.6	2.6	3.9	2.8	2.8	4.3	3.2	3.2

a. Source: Tables 4-21, 4-24, and 4-30.
b. UC = uncanistered packaging scenario.
c. DISP = disposable canister packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. MEI dose = maximally exposed individual (surface facility worker) dose, in millirem.
f. LCF = latent cancer fatality.
g. CD = collective dose (person-rem).
h. Totals might differ from sums due to rounding.

would account for about 25 percent of the total worker dose, with another 10 to 15 percent of the total dose coming from subsurface worker exposure to radiation emanating from the waste packages.

Estimated dose and radiological health impacts to workers would be highest for the low thermal load scenario, with estimates 30 to 40 percent higher than those for the high thermal load scenario, because of the larger number of projected worker years. Dose and radiological health impacts would be one-third more for the uncanistered packaging scenarios than those for the other packaging scenarios because of the larger number of projected worker years. Accordingly, the combination of the low thermal load scenario and the uncanistered packaging scenario would have the highest estimated collective worker dose (10,700 person-rem) and highest estimated radiological impacts (4.3 latent cancer fatalities) over 120 years of repository activities.

4.1.7.5.3 *Radiological Health Impacts to the Public for All Phases*

Table 4-34 lists the estimated dose and radiological health impacts to the public for all phases. It lists dose and the potential radiological impact to the offsite maximally exposed individual for a 70-year lifetime with continuous residency about 20 kilometers (12 miles) south of the repository, and collective dose and potential radiological health impacts to the population within about 80 kilometers (50 miles) for the 111, 111, or 120 years required to complete all phases for the high, intermediate, and low thermal load scenarios, respectively.

Table 4-34. Estimated dose and radiological impacts to the public for all phases.[a,b]

Impact category	High thermal load	Intermediate thermal load	Low thermal load
Maximally exposed individual[c] (millirem)	38	46	100
Latent cancer fatality probability	1.9×10^{-5}	2.3×10^{-5}	5.1×10^{-5}
Collective dose[d] (person-rem)	280	340	810
Latent cancer fatality incidence	0.14	0.17	0.41

a. Source: Tables 4-22, 4-28, and 4-31.

b. Values are rounded to two significant figures.

c. Dose over a 70-year lifetime of the operation and monitoring phase, with continuous residency about 20 kilometers (12 miles) south of the repository.

d. Over all phases, lasting a total of 110, 111, or 120 years for the high, intermediate, or low thermal load scenario, respectively.

The offsite maximally exposed individual would have an increase in the probability of incurring a latent cancer fatality ranging from about 0.00002 to 0.00005 from exposure to radionuclides released from the repository facilities over a 70-year lifetime. The total estimated number of latent cancer fatalities in the potentially exposed population would range from 0.14 to 0.41 for the three thermal load scenarios. All doses and estimated radiological impacts would be from exposure to naturally occurring radon-222 and its decay products released from the subsurface facilities in exhaust ventilation air.

For comparison, the average individual radiation doses from natural sources of background radiation for Amargosa Valley and for the population of the United States are about 340 and 300 millirem per year, respectively (see Chapter 3, Table 3-28). Over a 70-year lifetime, individual dose from background radiation would be about 25,000 millirem, which is about 250 times larger than the offsite maximally exposed individual dose listed in Table 4-34. The highest annual dose to a member of the public from repository sources would be about 1.5 millirem or less. This radiation dose, essentially all from naturally occurring radon-222 and decay products, would be about 0.7 percent of the 200-millirem-per-year dose from radon-222 to members of the public in Amargosa Valley from ambient levels of naturally occurring radon (see Chapter 3, Section 3.1.8.2).

The Nevada cancer fatality rate in a population of 100,000 males is about 163 deaths per year (ACS 1998, page 6). Assuming this mortality rate is a baseline that would remain unchanged for the estimated population (in 2000) of about 28,000 within about 80 kilometers (50 miles) of the Yucca Mountain site, there would be about 50 cancer deaths per year from other causes and more than 5,000 cancer deaths over the period of the repository phases. The impact calculations in this EIS indicate that the additional cancer fatalities for the public from short-term activities would be less than 0.4, which would be an increase of about 0.01 percent.

4.1.8 ACCIDENT SCENARIO IMPACTS

This section describes the impacts from potential accident scenarios from performance confirmation, construction, operation and monitoring, and closure activities. The analysis is separated into radiological accidents (Section 4.1.8.1) and nonradiological accidents (Section 4.1.8.2). The analysis of radiological accident consequences used the MACCS2 computer code (Chanin and Young 1998, all). The receptors would be (1) the *maximally exposed individual*, defined as a hypothetical member of the public at the point on the land withdrawal boundary that would receive the largest dose from the assumed accident scenario, (2) the *involved worker,* a worker who would be handling the spent nuclear fuel or high-level radioactive waste when the accident occurred, (3) the *noninvolved worker*, a worker near the accident but not involved in handling the material, and (4) members of the public who reside within approximately 80 kilometers (50 miles) of the proposed repository. All analysis method details are provided in Appendix H.

ACCIDENT TYPES

Radiological accidents are unplanned events that could result in exposure of nearby humans to direct radiation or to radioactive material that would be ingested or inhaled.

Nonradiological accidents are unplanned events that could result in exposure of nearby humans to hazardous or toxic materials released to the environment as a result of the accident.

The impacts to offsite individuals from repository accidents would be small, with calculated doses as high as 0.013 rem to the maximally exposed offsite individual. Doses to a maximally exposed noninvolved worker would be higher, bounded by the worst-case accident scenarios at 31 rem.

4.1.8.1 Radiological Accidents

The first step in the radiological accident analysis was to examine the initiating events that could lead to facility accidents. These events could be external or internal. External initiators originate outside a facility and affect its ability to confine radioactive material. They include human-caused events such as aircraft crashes, external fires and explosions, and natural phenomena such as seismic disturbances and extreme weather conditions. Internal initiators occur inside a facility and include human errors, equipment failures, or combinations of the two. DOE analyzed initiating events applicable to repository operations to define subsequent sequences of events that could result in releases of radioactive material or radiation exposure. For each event in these accident sequences, the analysis estimated and combined probabilities to produce an estimate of the overall accident probability for the sequence. In addition, the analysis used bounding (plausible upper limit) accident scenarios to represent the impacts from groups of similar accidents. Finally, it evaluated the consequences of the postulated accident scenarios by estimating the potential radiation dose and radiological impacts.

The analysis used accident analyses previously performed by others for repository operation whenever possible to identify potential accidents. DOE reviewed these analyses for their applicability to the repository before using them (see Appendix H). The spectrum of accident scenarios evaluated in the analysis is based on the current conceptual design of the facility. Final facility design details are not available; the final designs could affect both the frequency and consequences of postulated accident s. For areas without final facility design criteria, DOE made assumptions to ensure that the analysis did not underestimate impacts.

The radionuclide source term for various accident scenarios could involve several different types of radioactive materials. These would include commercial spent nuclear fuel from both boiling- and pressurized-water commercial reactors (see Appendix A, Section A.2.1), DOE spent nuclear fuel (see Appendix A, Section A.2.2), DOE high-level radioactive waste incorporated in a glass matrix (see Appendix A, Section A.2.3), and weapons-grade plutonium either immobilized in high-level radioactive waste glass matrix or as mixed-oxide fuel (see Appendix A, Section A.2.4). Appendix H contains information on the radionuclide inventories in these materials. The analysis also examined accident scenarios involving the release of low-level waste generated and handled at the repository, primarily in the Waste Treatment Building.

The analysis used the radionuclide inventories from Appendix A for a typical fuel element to estimate the material that could be involved in an accident. It used the MACCS2 computer program, developed under the guidance of the Nuclear Regulatory Commission, to estimate potential radiation doses to exposed individuals (onsite and offsite) and population groups from postulated accidental releases of radionuclides. Appendix H contains additional information on the MACCS2 program and the models and assumptions incorporated in it.

The analysis considered radiological consequences of the postulated accidents for the following individuals and populations:

- *Involved worker.* A facility worker directly involved in activities at the location where the postulated accident could occur
- *Maximally exposed noninvolved worker (collocated worker).* A worker not directly involved with material unloading, transfer, and emplacement activities, assumed to be 100 meters (330 feet) downwind of the facility where the release occurs
- *Maximally exposed offsite individual.* A hypothetical member of the public at the nearest point to the facility at the site boundary. The analysis determined that the land withdrawal boundary location with the highest potential exposure from an accidental release of radioactive material would be about 11 kilometers (about 7 miles) from the accident location (at the western boundary of the land withdrawal area analyzed). The maximally exposed individual for a single-point release of material is different than those for a continuous release (see Section 4.1.2) because the frequency of wind in each direction enters the continuous release calculation of the maximally exposed individual.
- *Offsite population.* Members of the public within 80 kilometers (50 miles) of the repository site (see Chapter 3)

Sixteen accident scenarios were analyzed in detail. These scenarios bound the consequences of credible accidents at the repository. They include accidents in the Cask/Handling Area, the Canister Transfer System, the Assembly Transfer System, the Disposal Container Handling Area, and the Waste Treatment Building. The scenarios consider drops and collisions involving shipping casks, fuel canisters, bare fuel assemblies, low-level radioactive waste drums, and the waste package transporter.

Table 4-35 lists the results of the radiological accident consequence analysis under median, or 50th-percentile meteorological conditions. Table 4-36 lists similar information based on unfavorable meteorological conditions (95th-percentile, or those conditions that would not be exceeded more than 5 percent of the time) that tend to maximize potential radiological impacts. Impacts to the noninvolved worker would result from the inhalation of airborne radionuclides and external radiation from the passing plume. Impacts to the maximally exposed offsite individual and the offsite population would result from

Table 4-35. Radiological consequences of repository operations accident scenarios for median (50th-percentile) meteorological conditions.

		Maximally exposed offsite individual		Population		Noninvolved worker		Involved worker	
Accident[a,b,c]	Frequency (per year)[a]	Dose (rem)	LCFi[d]	Dose (person-rem)	LCFp[d]	Dose (rem)	LCFi	Dose (rem)	LCFi
1. 6.9-meter drop of shipping cask in CTHA-61 BWR assemblies-no filtration	4.5×10^{-4}	1.9×10^{-3}	1.0×10^{-6}	5.5×10^{-2}	2.7×10^{-5}	9.4×10^{-1}	3.8×10^{-4}	76	3.0×10^{-2}
2. 7.1-meter drop of shipping cask in CTHA-26 PWR assemblies-no filtration	6.1×10^{-4}	2.3×10^{-3}	1.2×10^{-6}	6.6×10^{-2}	3.3×10^{-5}	1.1	4.4×10^{-4}	90	3.6×10^{-2}
3. 4.1-meter drop of shipping cask in CTHA-61 BWR assemblies- no filtration	1.4×10^{-3}	1.3×10^{-3}	6.5×10^{-7}	3.9×10^{-2}	2.0×10^{-5}	5.7×10^{-1}	2.3×10^{-4}	46	1.8×10^{-2}
4. 4.1-meter drop of shipping cask in CTHA-26 PWR assemblies-no filtration	1.9×10^{-3}	1.4×10^{-3}	7.0×10^{-7}	4.6×10^{-2}	2.3×10^{-5}	6.6×10^{-1}	2.6×10^{-4}	53	2.1×10^{-2}
5. 6.3-meter drop of MCO in CTS-10 N-Reactor fuel canisters-filtration	4.5×10^{-4}	3.7×10^{-7}	1.9×10^{-10}	1.1×10^{-5}	5.3×10^{-9}	1.1×10^{-4}	4.4×10^{-8}	(e)	(e)
6. 6.3-meter drop of MCO in CTS-10 N-reactor fuel canisters-no filtration	2.2×10^{-7}	1.2×10^{-3}	6.0×10^{-7}	3.4×10^{-2}	1.7×10^{-5}	3.6×10^{-1}	1.4×10^{-4}	(e)	(e)
7. 5-meter drop of transfer basket in ATS-8 PWR assemblies-filtration	1.1×10^{-2}	6.6×10^{-7}	3.3×10^{-10}	4.0×10^{-4}	2.0×10^{-7}	1.7×10^{-4}	6.8×10^{-8}	(e)	(e)
8. 5-meter drop of transfer basket in ATS-8 PWR assemblies-no filtration	2.8×10^{-7}	5.6×10^{-4}	2.8×10^{-7}	1.7×10^{-2}	8.6×10^{-6}	1.6×10^{-1}	6.4×10^{-5}	(e)	(e)
9. 7.6-meter drop of transfer basket in ATS-16 BWR assemblies-filtration	7.4×10^{-3}	5.1×10^{-7}	2.6×10^{-10}	2.9×10^{-4}	1.5×10^{-7}	1.3×10^{-4}	5.2×10^{-8}	(e)	(e)
10. 7.6-meter drop of transfer basket in ATS-16 BWR fuel assemblies-no filtration	1.9×10^{-7}	6.1×10^{-4}	3.1×10^{-7}	1.6×10^{-2}	8.2×10^{-6}	1.8×10^{-1}	7.2×10^{-5}	(e)	(e)
11. 6-meter drop of disposal container in DCHS-21 PWR assemblies-filtration	1.8×10^{-3}	1.8×10^{-6}	9.0×10^{-10}	1.0×10^{-3}	5.2×10^{-7}	5.0×10^{-4}	2.0×10^{-7}	(e)	(e)
12. 6-meter drop of disposal container in DCHS-21 PWR fuel assemblies-no filtration	8.6×10^{-7}	1.7×10^{-3}	8.5×10^{-7}	5.1×10^{-2}	2.5×10^{-5}	5.1×10^{-1}	2.0×10^{-4}	(e)	(e)
13. Transporter runaway and derailment in access tunnel-21 PWR assemblies-filtration-16-meter drop height equivalent	1.2×10^{-7}	4.3×10^{-3}	2.2×10^{-6}	1.1×10^{-1}	5.4×10^{-5}	1.5	6.0×10^{-4}	(f)	(f)
14. Earthquake - 375 PWR assemblies	2.0×10^{-5}	9.1×10^{-3}	4.6×10^{-6}	3.6×10^{-1}	1.8×10^{-4}	8.3	3.3×10^{-3}	(f)	(f)
15. Earthquake w/fire in WTB	2.0×10^{-5}	1.8×10^{-5}	9.0×10^{-9}	6.3×10^{-4}	3.2×10^{-7}	5.2×10^{-3}	2.1×10^{-6}	(f)	(f)
16. LLW drum rupture in WTB	0.59	6.1×10^{-10}	3.1×10^{-13}	2.1×10^{-8}	1.1×10^{-11}	1.4×10^{-7}	5.6×10^{-11}	7.0×10^{-5}	2.8×10^{-8}

a. Source: Appendix H.

b. CTHA = Cask Transfer/Handling Area, CTS = Canister Transfer System, ATS = Assembly Transfer System, DCHS = Disposal Container Handling System, WTB = Waste Treatment Building.

c. To convert meters to feet, multiply by 3.2808.

d. LCFi is the likelihood of a latent cancer fatality for an individual who receives the calculated dose. LCFp is the number of cancers probable in the exposed population from the collective population dose (person-rem). These values were computed based on a conversion of dose in rem to latent cancers as recommended by the International Council on Radiation Protection as discussed in this section.

e. For these cases, the involved workers are not expected to be vulnerable to exposure during an accident because operations are done remotely. Thus, involved worker impacts were not evaluated.

f. For these events, involved workers would likely be severely injured or killed by the event; thus, no radiological impacts were evaluated. For the seismic event, as many as 39 people could be injured or killed in the Waste Handling Building, and as many as 36 in the Waste Treatment Building based on current staffing projections (TRW 1998i, pages 17 and 18).

Table 4-36. Radiological consequences of repository operations accident scenarios for unfavorable (95th-percentile) meteorological conditions.

		Maximally exposed offsite individual		Population		Noninvolved worker		Involved worker	
Accident[a,b,c]	Frequency (per year)[a]	Dose (rem)	LCFi[d]	Dose (person-rem)	LCFp[d]	Dose (rem)	LCFi	Dose (rem)	LCFi
1. 6.9-meter drop of shipping cask in CTHA-61 BWR assemblies-no filtration	4.5×10^{-4}	7.2×10^{-3}	3.5×10^{-6}	1.7	8.6×10^{-4}	5.1	2.0×10^{-3}	76	3.0×10^{-2}
2. 7.1-meter drop of shipping cask in CTHA-26 PWR assemblies-no filtration	6.1×10^{-4}	8.0×10^{-3}	4.0×10^{-6}	2.1	1.1×10^{-3}	5.9	2.4×10^{-3}	90	3.6×10^{-2}
3. 4.1-meter drop of shipping cask in CTHA-61 BWR assemblies-no filtration	1.4×10^{-3}	4.3×10^{-3}	2.2×10^{-6}	1.3	6.5×10^{-4}	3.1	1.2×10^{-3}	46	1.8×10^{-2}
4. 4.1-meter drop of shipping cask in CTHA-26 PWR assemblies-no filtration	1.9×10^{-3}	5.2×10^{-3}	2.6×10^{-6}	1.5	7.8×10^{-4}	3.5	1.4×10^{-3}	53	2.1×10^{-2}
5. 6.3-meter drop of MCO in CTS-10 N-Reactor fuel canisters-filtration	4.5×10^{-4}	1.2×10^{-6}	6.0×10^{-10}	2.6×10^{-4}	1.3×10^{-7}	3.3×10^{-4}	1.3×10^{-7}	(e)	(e)
6. 6.3-meter drop of MCO in CTS-10 N-reactor fuel canisters-no filtration	2.2×10^{-7}	4.3×10^{-3}	2.2×10^{-6}	8.6×10^{-1}	4.3×10^{-4}	1.1	4.4×10^{-4}	(e)	(e)
7. 5-meter drop of transfer basket in ATS-8 PWR assemblies-filtration	1.1×10^{-2}	2.5×10^{-6}	1.3×10^{-9}	3.3×10^{-2}	1.6×10^{-5}	4.6×10^{-4}	1.8×10^{-7}	(e)	(e)
8. 5-meter drop of transfer basket in ATS-8 PWR assemblies-no filtration	2.8×10^{-7}	2.1×10^{-3}	1.1×10^{-6}	5.6×10^{-1}	2.8×10^{-4}	4.6×10^{-1}	1.8×10^{-4}	(e)	(e)
9. 7.6-meter drop of transfer basket in ATS-16 BWR assemblies-filtration	7.4×10^{-3}	2.1×10^{-6}	1.1×10^{-9}	2.4×10^{-2}	1.2×10^{-5}	3.8×10^{-4}	1.5×10^{-7}	(e)	(e)
10. 7.6-meter drop of transfer basket in ATS-16 BWR fuel assemblies-no filtration	1.9×10^{-7}	2.2×10^{-3}	1.1×10^{-6}	5.1×10^{-1}	2.6×10^{-4}	5.1×10^{-1}	2.0×10^{-4}	(e)	(e)
11. 6-meter drop of disposal container in DCHS-21 PWR assemblies-filtration	1.8×10^{-3}	7.3×10^{-6}	3.7×10^{-9}	8.6×10^{-2}	4.3×10^{-5}	1.3×10^{-3}	5.2×10^{-7}	(e)	(e)
12. 6-meter drop of disposal container in DCHS-21 PWR fuel assemblies-no filtration	8.6×10^{-7}	6.1×10^{-3}	3.1×10^{-6}	1.6	8.0×10^{-4}	1.3	5.2×10^{-4}	(e)	(e)
13. Transporter runaway and derailment in access tunnel-21 PWR assemblies-filtration-16-meter drop height equivalent	1.2×10^{-7}	1.3×10^{-2}	6.5×10^{-6}	3.2	1.6×10^{-3}	3.9	1.6×10^{-3}	(f)	(f)
14. Earthquake - 375 PWR assemblies	2.0×10^{-5}	3.2×10^{-2}	1.6×10^{-5}	14	7.2×10^{-3}	7.0	2.8×10^{-2}	(f)	(f)
15. Earthquake w/fire in WTB	2.0×10^{-4}	5.8×10^{-5}	2.9×10^{-8}	2.1	1.1×10^{-5}	5.2×10^{-3}	2.1×10^{-6}	(f)	(f)
16. LLW drum rupture in WTB	0.59	1.9×10^{-9}	9.5×10^{-13}	7.5×10^{-7}	3.7×10^{-10}	1.4×10^{-7}	5.6×10^{-11}	7.0×10^{-5}	2.8×10^{-8}

a. Source: Appendix H.

b. CTHA = Cask Transfer/Handling Area, CTS = Canister Transfer System, ATS = Assembly Transfer System, DCHS = Disposal Container Handling System, WTB = Waste Treatment Building.

c. To convert meters to feet, multiply by 3.2808.

d. LCFi is the likelihood of a latent cancer fatality for an individual who receives the calculated dose. LCFp is the number of cancers probable in the exposed population from the collective population dose (person-rem). These values were computed based on a conversion of dose in rem to latent cancers as recommended by the International Council on Radiation Protection, as discussed in this section.

e. For these cases, the involved workers are not expected to be vulnerable to exposure during an accident since operations are done remotely. Thus, involved worker impacts were not evaluated.

f. For these events, involved workers would likely be severely injured or killed by the event; thus, no radiological impacts were evaluated. For the seismic event, as many as 39 people could be injured or killed in the Waste Handling Building, and as many as 36 in the Waste Treatment Building based on current staffing projections (TRW 1998i, pages 17 and 18).

these exposure pathways and from long-term external exposure to radionuclides deposited on soil during plume passage, subsequent ingestion of radionuclides in locally grown food, and inhalation of resuspended particulates. The analysis did not consider interdiction by DOE or other government agencies to limit long-term radiation doses because none of these doses would be above the Environmental Protection Agency's Protective Action Guides. Interdiction would be likely to occur if the calculated accident doses exceeded these guides.

The most severe accident scenario (earthquake, Table 4-36, number 14) for the 95-percent weather conditions would result in an estimated 0.0072 additional latent cancer fatality for the same affected population. The more conservative summation of all potential accidents in Table 4-36 results in less than 0.02 additional latent cancer fatality for the exposed population. Thus, the estimated number of latent cancer fatalities for the individual receptors from accidents would be very small.

The results described in this section assumed that all commercial spent nuclear fuel would arrive at the repository either uncanistered or in canisters not suitable for disposal. In this base case scenario, all of the fuel would have to be handled as bare fuel assemblies in the Waste Handling Building and placed in disposal containers for disposal, as described above. As noted in Chapter 2, this EIS evaluates other packaging scenarios that include commercial spent nuclear fuel that would arrive at the repository in canisters suitable for disposal without being opened. The base case scenario, which assumes that all fuel would have to be handled as bare fuel assemblies, thus provides a bounding assessment of accident impacts for the packaging scenarios considered in Chapter 2 because accident scenarios involving damage to bare fuel assemblies during handling operations represent the bounding repository accident scenarios. The uncanistered fuel, as indicated in Tables 4-35 and 4-36, represents the more meaningful accident risk because of the additional handling operations required and the higher impacts associated with accidents involving bare assemblies. As a consequence, the base case evaluated in this section provides a bounding assessment of accident impacts in relation to the packaging scenarios.

The analysis evaluated accident scenario impacts during retrieval, and concluded that the transporter runaway and derailment accident scenarios evaluated for emplacement operation would bound other accident scenarios during retrieval operations that are credible. This conclusion is supported by the results of accident evaluations for above-ground dry storage at utility sites, as discussed in Appendix H.

4.1.8.2 Nonradiological Accidents

A potential release of hazardous or toxic materials during postulated operational accidents involving spent nuclear fuel or high-level radioactive waste at the repository would be very unlikely. Because of the large quantities of radioactive material, radiological considerations would outweigh nonradiological concerns. The repository would not accept hazardous waste as defined by the Resource Conservation and Recovery Act. Some potentially hazardous metals such as arsenic or mercury could be present in the high-level radioactive waste. However, they would be in a vitrified glass matrix that would make the exposure of workers or members of the public from operational accidents highly unlikely. Appendix A contains more information on the inventory of potentially hazardous materials.

Some potentially nonradioactive hazardous or toxic substances would be present in limited quantities at the repository as part of operational requirements. Such substances would include liquid chemicals such as cleaning solvents, sodium hydroxide, sulfuric acid, and various solid chemicals (see Section 4.1.3.2). These substances are in common use at other DOE sites. Section 4.1.7 describes potential impacts to workers from normal industrial hazards in the workplace (which includes industrial accidents). The statistics used in the analysis were derived from DOE accident experience at other sites. Impacts to members of the public would be unlikely because the chemicals would be mostly liquid and solid so that any release would be confined locally. (For example, chlorine at the site used for water treatment would be in powder form, so a gaseous release of chlorine would not be possible. Propane gas would not be stored at the site.)

Section 4.1.12.2 describes the quantities of solid hazardous waste generated during repository operations. The construction and closure phases would not generate liquid hazardous waste. The generation, storage, and shipment off the site of solid and liquid hazardous waste generated during operations would represent minimal incremental risk from accidents. Impacts to workers from industrial accidents in the workplace are part of the statistics presented in Appendix F, Section F.2.

4.1.8.3 Sabotage

The accident analysis separately considered sabotage as a potential initiating event. This event would be unlikely to contribute to impacts from the repository. The repository would not represent an attractive target to potential saboteurs due to its remote location and the low population density in the area. Furthermore, security measures DOE would use to protect the waste material from intrusion and sabotage (TRW 1999a, pages 63 to 65) would make such attempts unlikely to succeed. At all times the waste material would be either in robust shipping or disposal containers or inside the Waste Handling Building, which would have thick concrete walls. On the basis of these considerations, DOE concluded that sabotage events would be unlikely at the repository.

4.1.9 NOISE IMPACTS

This section describes possible noise impacts to the public (nuisance noise) and workers (occupational noise) from performance confirmation, construction, operation and monitoring, and closure activities. Repository areas that could generate elevated noise levels include the North Portal, South Portal, Emplacement Shaft, and Development Shaft Operations Areas. The following discussion identifies potential impacts that primarily would affect workers during routine operations. Overall, however, the potential for noise impacts to the public would be very small due to the distances of residences from these areas. Section 4.1.4.2 discusses noise impacts on wildlife.

4.1.9.1 Noise Impacts from Performance Confirmation

As part of site characterization, DOE has evaluated existing noise conditions in the Yucca Mountain region. The noise associated with site characterization activities, which has included that from construction, equipment, drilling equipment, and occasional blasting, has not resulted in large impacts. Because performance confirmation activities would be similar to those for site characterization, large impacts would be likely.

4.1.9.2 Noise Impacts from Construction, Operation and Monitoring, and Closure

Sources of noise in the analyzed land withdrawal area during the construction phase would include activities at the North Portal, South Portal, and Ventilation Shaft Operations Areas involving heavy equipment (bulldozers, graders, loaders, pavers, etc.), cranes, ventilation fans, and diesel generators. Sources of noise during the operation and monitoring phase would include transformer noise, compressors, ventilation fans, air conditioners, and a concrete batch plant. Ventilation fans would have silencers that would keep noise levels below 85 dBA (see Chapter 3, Section 3.1.9 for an explanation of noise measurements) at a distance of 3 meters (10 feet) (TRW 1997c, page 107). The Occupational Safety and Health Administration has identified that the maximum permissible continuous noise level that workers may be exposed to without controls is 90 dBA [29 CFR 1910.95(b)(2)].

The distance from the North Portal Operations Area to the nearest point on the boundary of the analyzed land withdrawal area analyzed would be about 11 kilometers (7 miles) due west. The distance from the South Portal Operations Area to the nearest point on the land withdrawal area boundary would also be about 11 kilometers due west. The point on the boundary closest to a Ventilation Shaft Operations Area would be about 7 kilometers (4 miles) (DOE 1997k, all).

To establish the propagation distance of repository-generated noise for analysis purposes, DOE used an estimated maximum sound level [132 decibels, A-weighted (dBA) for heavy construction equipment, although heavy trucks generate sound levels of between 70 and 80 dBA at 15 meters (50 feet)]. An analysis determined the distance at which that noise would be at the lower limit of human hearing (20 dBA). The calculated distance was 6 kilometers (3.7 miles). Thus, noise impacts would be unlikely at the analyzed land withdrawal area boundary.

Because the distance between repository noise sources and a hypothetical receptor at the analyzed land area withdrawal boundary would be large enough to reduce the noise to background levels and because there would be no residential or community receptors at the withdrawal area boundary [the nearest housing is in Lathrop Wells, about 22 kilometers (14 miles) from the repository site], DOE expects no large noise impacts to the public from repository construction and operations.

Workers at the repository site could be exposed to elevated levels of noise. Small impacts such as speech interference between workers and annoyance to workers would occur. However, worker exposures during all repository phases would be controlled such that impacts (such as loss of hearing) would be unlikely. Engineering controls would be the primary method of noise control. Hearing protection would be required, as needed, as a supplement to engineering controls.

Noise impacts associated with closure would be similar to those associated with construction and operations. Therefore, DOE expects no large noise impacts to the public and workers.

4.1.10 AESTHETIC IMPACTS

This section describes potential aesthetic impacts from performance confirmation, construction, operation and monitoring, and closure activities. These activities would not cause adverse impacts to aesthetic or visual resources in the region. The analysis of such impacts considered the natural and manmade physical features that give a particular landscape its character and value as an environmental factor. The analysis gave specific consideration to scenic quality, visual sensitivity, and distance from observation points.

Yucca Mountain has visual characteristics fairly common to the region (a scenic quality rating of C), and the visibility of the repository site from publicly accessible locations is low or nonexistent. The largest structure would be the Waste Handling Building at the North Portal Operations Area, which would be about 37 meters (120 feet) tall with a taller exhaust stack. Other buildings and structures would be smaller and at elevations equal to or lower than that of the Waste Handling Building. No building or structure would exceed the elevation of the southern ridge of Yucca Mountain [1,400 meters (4,600 feet)]. Therefore, no part of the repository would be visible to the public from the west. The intervening Striped Hills and the low elevation of the southern end of Yucca Mountain and Busted Butte would obscure the view of repository facilities from the south near Lathrop Wells and the Amargosa Valley, approximately 28 kilometers (17 miles) away. There is no public access to the north or east of the site to enable viewing of the facilities. DOE would provide lighting for operation areas at the repository. This lighting could be visible from public access points.

Closure activities, such as dismantling facilities and reclaiming the site, probably would improve the visual quality of the landscape. Adverse impacts to the visual quality due to closure would be unlikely.

4.1.11 IMPACTS TO UTILITIES, ENERGY, MATERIALS, AND SITE SERVICES

This section discusses potential impacts to residential water, energy, materials, and site services from performance confirmation, construction, operation and monitoring, and closure activities. The scope of the analysis included electric power use, fossil-fuel consumption, consumption of construction materials, and onsite services such as emergency medical support, fire protection, and security and law enforcement. The analysis compared needs to available capacity. The region of influence would include the local, regional, and national supply infrastructure that would have to satisfy the needs. The analysis used engineering estimates of requirements for construction materials, utilities, and energy.

Construction activities would occur during both the construction and the operation and monitoring phases. Table 4-37 lists electric energy and fossil-fuel use during the different phases. Table 4-38 lists construction material use. Both tables list comparative values for all thermal load and packaging scenarios. DOE prorated impacts to site services, if any, with those to the commodity areas to produce an estimate of overall impacts.

Overall, DOE does not expect meaningful impacts to residential water, energy, materials, and site services from the Proposed Action. DOE would, however, have to enhance the electric power delivery system to the Yucca Mountain site.

4.1.11.1 Impacts to Utilities, Energy, Materials, and Site Services from Performance Confirmation

DOE would obtain utilities, energy, and materials for performance confirmation activities from existing sources and suppliers. Water would come from existing wells. Power would come from regional suppliers to the existing Nevada Test Site transmission system. Based on site characterization activities, performance confirmation activities would not cause meaningful impacts to regional utility, energy, and material sources. In addition, DOE would continue to use such existing site services as emergency medical support, fire protection, and security and law enforcement (as described in Chapter 3, Section 3.1.11.3) during performance confirmation.

4.1.11.2 Impacts to Utilities, Energy, Materials, and Site Services from Construction, Operation and Monitoring, and Closure

Residential Water

Population growth associated with the Proposed Action could affect regional water resources. Based on the information in Section 4.1.6, in 2030 the Proposed Action would result in a maximum population increase of about 3,700 in Clark and Nye Counties. About 80 percent of these people would live in Clark County and about 20 percent in Nye County. Whether domestic water needs were satisfied predominantly from surface-water sources, as is the case for most of Clark County, or from groundwater sources, as for most of Nye County, these relatively small increases in population would have very minor impacts on existing water demands.

The maximum project-related population increase for Clark County would amount to about 0.3 percent of the 1997 population (see Chapter 3, Section 3.1.7.1). This increase would be a smaller portion of the county’s population in 2030 and, correspondingly, the associated increase in water demand in the county as a result of the proposed project would be very small. The population of Indian Springs in Clark

Table 4-37. Electricity and fossil-fuel use for the Proposed Action.[a]

Phase[b]	Time (years)	High thermal load			Intermediate thermal load			Low thermal load		
		UC[c]	DISP[d]	DPC[e]	UC	DISP	DPC	UC	DISP	DPC
Peak electrical power demand (megawatts)										
Construction	2005-2010	24	24	24	24	24	24	24	24	24
Operation and monitoring	2010-2110									
Development	2010-2032	19	19	19	19	19	19	19	19	19
Emplacement	2010-2033	22	18	19	22	18	19	22	18	19
Total development and emplacement	*2010-2033*	*41*	*38*	*38*	*41*	*38*	*38*	*41*	*38*	*38*
Decontamination	2034-2037	14	10	11	14	10	11	14	10	11
Monitoring	2034-2110	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
	2034-2060	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
	2034-2310	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Closure	2110+6-15	9.2	8.9	8.9	9.2	8.9	8.9	9.2	8.9	8.9
Electricity use (1,000 megawatt-hours)										
Construction	2005-2010	180	180	180	230	230	230	240	240	240
Operation and monitoring	2010-2110									
Development	2010-2032	650	650	650	890	890	890	2,200	2,200	2,200
Emplacement	2010-2033	2,600	2,100	2,100	2,600	2,100	2,100	2,600	2,100	2,200
Decontamination	2034-2037	250	190	200	250	190	200	250	190	200
Monitoring	2034-2110	2,000	2,000	2,000	2,400	2,400	2,400	3,500	3,500	3,500
	2034-2060	680	680	680	810	810	810	1,200	1,200	1,200
	2034-2310	7,200	7,200	7,200	8,600	8,600	8,600	13,000	13,000	13,000
Total 100-year phase	*2010-2110*	*5,500*	*4,900*	*5,000*	*6,100*	*5,600*	*5,600*	*8,600*	*8,000*	*8,100*
Closure	2110+6-15	250	240	240	370	370	370	560	560	560
Fossil-fuel use (million liters)[f]										
Construction	2005-2010	8.1	7.1	7.3	12	11	12	14	13	13
Operation and monitoring	2010-2110									
Development	2010-2032	19	19	19	20	20	20	83	83	85
Emplacement	2010-2033	230	180	190	230	180	190	230	180	190
Decontamination	2034-2037	33	26	27	33	26	27	33	26	27
Monitoring	2034-2110	11	11	11	15	15	15	15	15	15
	2034-2060	3.9	3.9	3.9	5.0	5.0	5.0	5.0	5.0	5.0
	2034-2310	41	41	41	53	53	53	53	53	53
Total 100-year phase	*2010-2110*	*290*	*240*	*240*	*290*	*250*	*250*	*360*	*310*	*310*
Closure	2110+6-15	5.1	4.5	4.6	9.4	8.8	8.9	15	14	15

a. Sources: TRW (1999a, Section 6); TRW (1999b, Section 6); TRW (1999c, pages 6-17 to 6-24).

b. Approximate periods for each phase would be construction, 5 years; operation and monitoring, 100 years; closure, 6-15 years.

c. UC = uncanistered packaging scenario.

d. DISP = disposable canister packaging scenario.

e. DPC = dual-purpose canister packaging scenario.

f. To convert liters to gallons, multiply by 0.26418.

Table 4-38. Construction material use for the Proposed Action.[a]

Phase[b]	Time (years)	High thermal load			Intermediate thermal load			Low thermal load		
		UC[c]	DISP[d]	DPC[e]	UC	DISP	DPC	UC	DISP	DPC
Concrete (1,000 cubic meters)[f]										
Construction	2005-2010	330	330	330	390	380	380	390	390	390
Operation and monitoring	2010-2110									
Development	2010-2032	420	420	420	480	480	480	1,700	1,700	1,700
Emplacement	2010-2033	27	27	27	27	27	27	66	66	66
Operation and monitoring total	*2010-2110*	*450*	*450*	*450*	*510*	*510*	*510*	*1,800*	*1,800*	*1,800*
Closure	2110+6-15	2	2	2	2	2	2	4	4	4
Project total		*780*	*780*	*780*	*900*	*890*	*890*	*2,200*	*2,200*	*2,200*
Steel (1,000 metric tons)[g]										
Construction	2005-2010	70	68	67	81	81	81	83	81	80
Operation and monitoring	2010-2034									
Development	2010-2032	90	90	90	140	140	140	610	610	610
Emplacement	2010-2033	42	42	42	42	42	42	110	110	110
Operation and monitoring total	*2010-2110*	*130*	*130*	*130*	*180*	*180*	*180*	*720*	*720*	*720*
Closure	2110+6-15	0.71	0.71	0.71	0.92	0.92	0.92	2	2	2
Project total		*200*	*200*	*200*	*260*	*260*	*260*	*800*	*800*	*800*
Copper (1,000 metric tons)										
Construction	2005-2010	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Operation and monitoring	2010-2110									
Development	2010-2032	0.1	0.1	0.1	0.1	0.1	0.1	0.9	0.9	0.9
Project total		*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*1.0*	*1.0*	*1.0*

a. Sources: TRW (1999a, Section 6); TRW (1999b, Section 6); TRW (1999c, pages 6-15 to 6-21).

b. Approximate periods for each phase would be construction, 5 years; operation and monitoring, 100 years; closure, 6-15 years.

c. UC = uncanistered packaging scenario.

d. DISP = disposable canister packaging scenario.

e. DPC = dual-purpose canister packaging scenario.

f. To convert cubic meters to cubic yards, multiply by 1.3079.

g. To convert metric tons to tons, multiply by 1.1023

County would increase by a projected maximum of about 110 as a result of the Proposed Action. This number represents about 10 percent of the 1997 Indian Springs population and, based on a Las Vegas Valley average demand for domestic water of 720 liters (190 gallons) per day per person (SNWA 1999, all), would require a quantity of water that is about 6 percent of the community's quasimunicipal groundwater withdrawal in 1997 [0.51 million cubic meters (410 acre-feet)] (NDCNR 1998, all). DOE expects the population of Indian Springs to be larger by 2030 and on a percentage basis, the contribution (and associated water demand) from project-related growth would be smaller than current numbers. However, this small community would be more likely to be affected by projected growth than other areas in Clark County.

In Nye County, estimates of domestic water demand for 1995 are about 750 liters (200 gallons) per day per person (Horton 1997, Table 10). At this demand, the project-related increase in Nye County population would result in an additional water demand of about 0.20 million cubic meters (160 acre-feet) of water per year. This represents about 0.2 percent of the water use in Nye County in 1995. As indicated in Section 4.1.6, most (about 92 percent) of the project-related growth in Nye County would occur in Pahrump. This would equate to adding about 0.18 million cubic meters (150 acre-feet) to Pahrump's annual water demand, which represents about 0.6 percent of the 1995 Pahrump water withdrawal of 30 million cubic meters (24,000 acre-feet). By 2030, when the peak population increases would occur, the project-related increase in water demand would be an even smaller percentage of the total Nye County and Pahrump water need. The increase in domestic water demand in Nye County as a result of the proposed project would be very small.

Residential Sewer

Sewer utilities could be affected by population growth associated with the Proposed Action. In Clark County, where most of the population growth would take place, the fact that the maximum project-related population increase would amount to about 0.3 percent of the 1997 population indicates that impacts to the populous areas of the county (that is, the Las Vegas Valley) would be very small. In Indian Springs, where project-related growth would be a more substantial portion of the community population, small treatment facilities designed for a specific area or individual household septic tank systems would accommodate wastewater treatment needs. In either case, the added population would not be likely to cause overloading to a sewer utility.

Growth in Nye Country from the Proposed Action would be likely to occur primarily in the Pahrump area. There is no reason to believe that project-related population increases would overload a sewer utility. Again, small, limited-service treatment facilities or individual septic tank and drainage field systems would provide the primary wastewater treatment capacities.

Electric Power

During the construction phase (2005 to 2010), the demand for electricity would increase as DOE operated two or three tunnel boring machines and other electrically powered equipment. The tunnel boring machines would account for more than half of the demand for electricity during the construction phase. The estimated peak demand for electrical power during the construction phase would be about 24 megawatts with use varying between about 180,000 and 240,000 megawatt-hours, depending on the thermal load scenario and the packaging scenario. Excavation activities for all three thermal load scenarios would use two or three tunnel boring machines. However, the operations time would increase for the low thermal load scenario because of the increased tunnel lengths.

As discussed in Chapter 3, Section 3.1.11.2, the current electric power supply line has a peak capacity of only 10 megawatts. DOE, therefore, is evaluating modifications and upgrades to the site electrical system, as discussed below.

During the early stages of the operation and monitoring phase (2010 to 2033), the development of emplacement drifts would continue in parallel with emplacement activities. During this period, the peak electric power demand would be between 38 and 41 megawatts, depending on the thermal load scenario and the packaging scenario.

Following the completion of excavation activities in about 2032, the demand for electric power would drop to about 20 megawatts and would continue to drop, following the completion of emplacement and decontamination activities in about 2037, to less than 15 megawatts for monitoring and maintenance activities. The closure phase would last from 6 to 15 years, depending on the thermal load scenario. The peak electric power demand would be less than 10 megawatts for any of the three thermal load scenarios during closure.

The repository demand for electricity would be well within the expected regional capacity for power generation. Nevada Power Company, for example, experienced a growth in peak demand of nearly 30 percent from 1993 to 1997 and has demonstrated the ability to meet customer demand in this high-growth environment through effective planning (*Las Vegas Review-Journal* 1998, all). Nevada Power's current planning indicates that it intends to maintain a reserve capacity of 12 percent. In 2010, at the beginning of the operation and monitoring phase, Nevada Power projects a net peak load of 5,950 megawatts and is planning a reserve of 714 megawatts (NPC 1997, Figures 2 and 4). The maximum 41-megawatt demand that the repository would require would be less than 1 percent of the projected peak demand in 2010, and less than 6 percent of the planned reserve. Thus, DOE expects that regional capacity planning would accommodate the future repository demand.

Repository Electric Power Supply Options

As discussed above, the estimated repository electric power demand would exceed the current electric supply capacity to the site after construction began in 2005. DOE would have to increase the electric power supply to the site to accommodate the initial demand of about 24 megawatts during the construction phase and to support the estimated peak demand of as much as 41 megawatts during the operation and monitoring phase. A range of options focusing on a modification or upgrade of the existing transmission and distribution system is under consideration to meet the repository electricity demand (TRW 1998e, all). DOE eliminated consideration of onsite generation of electricity in conjunction with the onsite plant that would generate steam for heating because the steam plant would be much smaller than a plant needed for power generation, and increasing the capacity of the steam plant would not be cost-effective with the availability of low-priced power in the southern Nevada region. Limited onsite generation capacity would use diesel-powered generators for emergency equipment.

As discussed in Chapter 3, Section 3.1.11.2, the repository site receives electricity through a feeder line from the Canyon Substation, which is rated at 69 kilovolts and has a capacity of 10 megawatts. The minimum modification would be to upgrade this line to 40 to 50 megawatts, modify the Nevada Test Site power loop to support repository operations in conjunction with other Test Site activities, and upgrade utility feeder lines to the Nevada Test Site. The existing Nevada Test Site power loop has a rated capacity of about 72 megawatts, but preliminary analysis of loop performance with the projected repository load (as much as 41 megawatts) indicated that unacceptable voltage reductions could occur at some Test Site locations. The minimum modification to the power loop to reduce the potential for unacceptable voltage reductions would be to install capacitors in the loop. Other options to obtain satisfactory performance for the power loop would include upgrading sections of the loop and the utility-owned feeder lines to the loop. Additional options, which would be variations of this approach, would include providing upgraded power lines directly from the utilities to the repository site.

As discussed in Chapter 3, Section 3.1.11.2, two commercial utility companies supply electricity to the Nevada Test Site feeder lines that power the Test Site power loop. Nevada Power Company owns and operates a 138-kilovolt line from the Las Vegas area to the Mercury Switching Station on the Test Site. Valley Electric Association owns and operates 138- and 230-kilovolt lines from the Las Vegas area to Pahrump and a 138-kilovolt line from Pahrump to the Jackass Flats substation on the Test Site near Lathrop Wells. The options DOE is evaluating include upgrading either or both of these lines. The options also include connecting both utility feeder lines directly to the repository with new 138- or 230-kilovolt lines to either the North or South Portal to obtain independent redundant power capability. DOE has considered adding Sierra Pacific Power Corporation as a supplier by constructing a new power line from the Tonopah/Anaconda area to Lathrop Wells through Beatty with a direct tie to the South Portal at the repository. All system modifications would include appropriate modifications to transformers and switchgear. The approach in all cases would be to use existing power corridors where possible to limit environmental impacts and to reduce the need for additional rights-of-way. Depending on the option chosen, additional National Environmental Policy Act analysis could be required.

Fossil Fuels

Fossil fuels used during the construction phase (2005 to 2010) would include diesel fuel and fuel oil. Diesel fuel would be used primarily to operate surface construction equipment and equipment to maintain the excavated rock pile. Fuel oil would fire a steam plant at the North Portal, which would provide building and process heat for the North Portal Operations Area. In addition, fuel oil would provide water heating and building heat to the South Portal and heat for curing precast concrete components. During construction the estimated use of diesel fuel and fuel oil would be 7.1 million to 14 million liters (1.9 million to 4 million gallons). The highest use would be associated with the combination of the low thermal load scenario and the uncanistered packaging scenario. The regional supply capacity of gasoline and diesel fuel is about 3.8 billion liters (1 billion gallons) per year for the State of Nevada, based on motor fuel use (BTS 1999a, all). About half of the State total is consumed in the three-county region of influence (Clark, Lincoln, and Nye Counties) with the highest consumption in Clark County, so yearly repository use during the construction phase would be less than 1 percent of the current regional consumption.

Fossil-fuel use during the operation and monitoring phase would be for onsite vehicles and for heating. It would range between about 240 million and 360 million liters (about 63 million and 95 million gallons) depending on the thermal load scenario and the packaging scenario. The annual use would be highest for emplacement and development operations (2010 to 2033) and would decrease substantially for monitoring and maintenance activities (2034 to 2110). The projected use of liquid fossil fuels would be within the regional supply capacity and should not cause meaningful impacts. As discussed above, motor fuel use in the State of Nevada in 1996 was about 3.8 billion liters (1 billion gallons) (BTS 1999a, all), which provides the baseline for the regional supply capacity. The highest annual use during the operations and monitoring phase would be less than 5 percent of the 1996 capacity in Clark, Lincoln, and Nye Counties.

During the closure phase, fossil-fuel use would be between 4.5 million and 15 million liters (1.2 million and 4 million gallons), depending on the thermal load scenario. Use during the closure phase would be similar to that for the construction phase.

Construction Material

The primary materials needed to construct the repository would be concrete, steel, and copper. Concrete, which consists of cement and aggregate, would be used for tunnel liners in the subsurface and for the construction of the surface facilities. Excavated rock would be used for the aggregate, and cement would be purchased regionally. During the construction phase the amount of concrete required would range from about 330,000 to 390,000 cubic meters (about 430,000 to 510,000 cubic yards), depending on the thermal load scenario and the packaging scenario. For this phase, as much as about 83,000 metric tons (92,000 tons) of steel would be required for a variety of uses including rebar, piping, vent ducts, and track, and 100 metric tons (110 tons) of copper for electrical cables. Because the subsurface configuration of the repository would differ substantially for the high, intermediate, and low thermal load scenarios, the relative amount of material used during the initial 5-year construction period might not be indicative of the amount required to complete the subsurface through the end of development. For example, the amount of steel used during the construction phase for each of the intermediate thermal load cases would be about the same as the amount for the corresponding low thermal load case, but the total amount of steel used for each intermediate case through the completion of development would be about one-quarter of the amount that would be used for the corresponding low thermal load case.

During the operation and monitoring phase, an additional 1.8 million cubic meters (2.4 million cubic yards) of concrete would be required for the low thermal load scenario and 450,000 cubic meters (590,000 cubic yards) would be required for the high thermal load scenario. The corresponding requirement for steel would be between about 720,000 and 130,000 metric tons (about 790,000 and 140,000 tons), and for copper it would be about 100 metric tons (110 tons).

For the low thermal load scenario, which would require the most concrete, the average yearly concrete demand for continued subsurface development during the operation and monitoring phase would be about 82,000 cubic meters (about 110,000 cubic yards). This quantity of concrete represents less than 3 percent of the cement consumed in Nevada in 1998 (Sherwood 1998, all).

Because the markets for steel and copper are worldwide in scope, DOE expects little or no impact from increased demand for steel and copper in the region.

The closure phase would require an estimated maximum of 4,000 cubic meters (5,200 cubic yards) of concrete for the low thermal load option. An estimated 2,000 metric tons (2,200 tons) of steel would be required for the low thermal load scenario and about 710 metric tons (780 tons) for the high thermal load scenario.

Site Services

During the construction phase, DOE would rely on the existing support infrastructure described in Chapter 3, Section 3.1.11.3, during an emergency at the repository. DOE would maintain these capabilities until the project could provide its own services on the site.

The primary onsite response would occur through the onsite Fire Station, Medical Center, and Health Physics facilities after their construction at the North Portal was complete. The Fire Station would maintain fire and rescue vehicles, equipment, and trained professionals to respond to fires, including radiological, mining, industrial, and accident events at the surface and subsurface. The Medical Center would be adjacent to the Fire Station, and would maintain a full-time doctor and nurse and medical supplies to treat emergency injuries and illnesses. These facilities would have the capability to provide complete response to most onsite emergencies. DOE would coordinate the operation of these facilities with facilities at the Nevada Test Site and in the surrounding area to increase response capability, if necessary.

A site security and safeguards system would include the surveillance and safeguards functions required to protect the repository from unauthorized intrusion and sabotage. The system would include the site security barriers, gates, and badging and automated surveillance systems operated by trained security officers. Support for repository security would be available from the Nevada Test Site security force and the Nye County Sheriff's Department, if needed.

The emergency response system would provide responses to accident conditions at or near the repository site. The system would maintain emergency and rescue equipment, communications, facilities, and trained professionals to respond to fire, radiological, mining, industrial, and general accidents above or below ground.

The planned onsite emergency facilities should be able to respond to and mitigate most onsite incidents, including underground incidents, without outside support. Therefore, no meaningful impact to the emergency facilities of surrounding communities or counties would be likely.

4.1.12 MANAGEMENT OF REPOSITORY-GENERATED WASTE AND HAZARDOUS MATERIALS

This section describes the management of the radioactive and nonradioactive waste that DOE would generate as a result of performance confirmation, construction, operation and monitoring, and closure activities. The evaluation of waste management impacts considered the quantities of nonhazardous industrial, sanitary, hazardous, mixed, and radioactive wastes that repository-related activities would generate. The evaluation assessed these quantities against current public and private capacity to treat and dispose of wastes. The overall impact of managing the Yucca Mountain repository waste streams would not differ among the thermal load scenarios and packaging scenarios. DOE would build onsite facilities to accommodate construction and demolition debris, sanitary and industrial solid wastes, sanitary sewage, and industrial wastewater. The Proposed Action would not cause meaningful impacts at offsite facilities for low-level radioactive and hazardous waste disposal. DOE would use less than 3 percent of the existing offsite capacity for low-level radioactive waste disposal and a very small fraction of the existing hazardous waste disposal capacity. In addition, the Department would build an onsite landfill. Although such activities are not currently planned, the use of existing Nevada Test Site landfills for the disposal of construction and demolition debris and sanitary and industrial solid waste would require the continuation of the operation of these facilities past their estimated lives of 70 and 100 years (DOE 1995f, pages 8 and 9) and probably would require the expansion of their capacities. Further review under the National Environmental Policy Act might be required to expand the capacity of the landfills at the Nevada Test Site.

4.1.12.1 Waste and Materials Impacts from Performance Confirmation

DOE expects performance confirmation activities to generate waste similar to and in about the same quantities as that generated during characterization activities with the exception that low-level radioactive waste would be generated in minimal qualities (TRW 1999a, page 17). Based on 1997 waste generation reports, performance confirmation activities should produce about 3,200 cubic meters (110,000 cubic feet) of nonhazardous construction debris and sanitary and industrial solid waste (Sygitowicz 1998, pages 2 and 4) and about 170 kilograms (380 pounds) (volume measurements were not available) of hazardous waste (Harris 1998, pages 3-6) that would require disposal. In addition, other waste would be recycled rather than disposed. Wastewater would be generated from runoff, subsurface activities, restrooms, and change rooms.

DOE would use current (as described in Chapter 3, Section 3.1.12) or similar methods to handle the waste streams generated by its performance confirmation activities. It would also use offsite landfills to dispose of solid waste and construction debris; accumulate and consolidate hazardous waste and transport it off the site for treatment and disposal; treat and reuse wastewater; and treat and dispose of

WASTE TYPES

Construction/demolition debris: Discarded solid wastes resulting from the construction, remodeling, repair, and demolition of structures, road building, and land clearing that are inert or unlikely to create an environmental hazard or threaten the health of the general public. Such debris from repository construction would include such materials as soil, rock, masonry materials, and lumber.

Industrial wastewater: Liquid wastes from industrial processes that do not include sanitary sewage. Repository industrial wastewater would include water used for dust suppression and process water from building heating, ventilation, and air conditioning systems.

Low-level radioactive waste: Radioactive waste that is not classified as high-level radioactive waste, transuranic waste, byproduct material containing uranium or thorium from processed ore, or naturally occurring radioactive material. The repository low-level radioactive waste would include such wastes as personal protective clothing, air filters, solids from the liquid low-level radioactive waste treatment process, radiological control and survey waste, and possibly used canisters (dual-purpose).

Sanitary sewage: Domestic wastewater from toilets, sinks, showers, kitchens, and floor drains from restrooms, change rooms, and food preparation and storage areas.

Sanitary and industrial solid waste: Solid waste that is neither hazardous nor radioactive. Sanitary waste streams include paper, glass, and discarded office material. State of Nevada waste regulations identify this waste stream as *household waste*.

Hazardous waste: Waste designated as hazardous by the Environmental Protection Agency or State of Nevada regulations. Hazardous waste, defined under the Resource Conservation and Recovery Act, is waste that poses a potential hazard to human health or the environment when improperly treated, stored, or disposed of. Hazardous wastes appear on special Environmental Protection Agency lists or possess at least one of the following characteristics: ignitability, corrosivity, toxicity, or reactivity. Hazardous waste streams from the repository could include certain used rags and wipes contaminated with solvents.

sanitary sewage. Based on site characterization experience, performance confirmation activities would cause no meaningful impacts to the regional waste disposal capacity.

4.1.12.2 Waste and Materials Impacts from Construction, Operation and Monitoring, and Closure

The construction phase (2005 to 2010) would generate nonhazardous, nonradioactive wastes and some hazardous waste from the use of such materials as resins, paints, and solvents. Nonhazardous, nonradioactive wastes would include sanitary and industrial solid wastes, construction debris, industrial wastewater, and sanitary sewage. Table 4-39 lists the estimated quantities of waste that the construction phase would generate. These estimates are based on construction experience, water use estimates, and Yucca Mountain Site Characterization Project experience with wastewater generation from dust suppression.

DOE could use existing Nevada Test Site landfills to dispose of nonrecyclable construction debris and sanitary and industrial solid waste. However, as part of the Proposed Action, DOE would construct a State-permitted landfill on the Yucca Mountain site to dispose of nonrecyclable construction debris and

Table 4-39. Estimated waste quantities from construction.[a]

	High thermal load			Intermediate thermal load			Low thermal load		
Waste type	UC[b]	DISP[c]	DPC[d]	UC	DISP	DPC	UC	DISP	DPC
Construction debris (cubic meters)[e]	3,000	2,400	2,400	3,000	2,400	2,400	3,000	2,400	2,400
Hazardous (cubic meters)	990	690	740	990	690	740	990	690	740
Sanitary and industrial solid (cubic meters)	10,000	8,500	8,700	10,000	8,500	8,700	10,000	8,500	8,700
Sanitary sewage (million liters)[f]	160	150	150	160	160	160	160	160	160
Industrial wastewater (million liters)	42	42	42	51	51	51	51	51	51

a. Sources: TRW (1999a, page 66); TRW (1999b, pages 6-8 and 6-9).
b. UC = uncanistered packaging scenario.
c. DISP = disposable canister packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. To convert cubic meters to cubic feet, multiply by 35.314.
f. To convert liters to gallons, multiply by 0.26418.

sanitary and industrial solid waste. The capacity of this landfill would be large enough to dispose of the projected volumes of this debris and waste for the entire Proposed Action. As listed in Table 4-39, DOE estimates a maximum of 3,000 cubic meters (110,000 cubic feet) of construction debris. If the Department chose not to build a landfill at the repository site, it could ship construction debris to the Test Site's Area 10C landfill, which has a disposal capacity of 990,000 cubic meters (35 million cubic feet) (DOE 1996f, page 4-37). The disposal of construction debris generated during the construction phase would consume less than one-half of 1 percent of the disposal capacity in this landfill. DOE could also ship repository-generated sanitary and industrial solid waste to the Test Site for disposal in the Area 23 landfill, which has a capacity of 450,000 cubic meters (16 million cubic feet) (DOE 1996f, page 4-37). The disposal of the maximum of 10,000 cubic meters (350,000 cubic feet) of sanitary and industrial solid waste generated during the construction phase at the Area 23 landfill would use about 2 percent of the disposal capacity.

Table 4-40 lists the estimated total waste quantities for repository activities associated with emplacement and development (2010 to 2033). Major waste-generating activities would include the receipt and packaging of spent nuclear fuel and high-level radioactive waste and continued development of subsurface emplacement areas. The thermal load scenarios would cause differences in nonradioactive waste quantities from subsurface activities due to the different workforce sizes and main drift lengths. The three packaging scenarios would affect the volumes of hazardous and low-level radioactive wastes generated at the surface facilities as a result of differences in handling the spent nuclear fuel and high-level radioactive waste. In addition, waste would be generated in personnel areas such as change rooms, restrooms, and offices. The dual-purpose canister packaging scenario could require the disposal of an additional estimated 44,000 cubic meters (1.6 million cubic feet) of low-level radioactive waste (not listed in Table 4-40) with an estimated weight of 240,000 metric tons (270,000 tons) (Koppenaal 1998a, all; TRW 1999a, page 75). DOE could decide to recycle the canisters if doing so would be more protective of the environment and more cost effective than direct disposal. Recycling would require melting and recasting of the canister metal to enable other uses.

DOE would package hazardous waste and ship it off the site for treatment and disposal. The Department could continue to dispose of such waste in conjunction with the Nevada Test Site, which has contracts with commercial facilities, or could contract separately with the same or another commercial facility. As listed in Table 4-39, DOE estimates the generation of no more than 990 cubic meters (35,000 cubic feet)

Table 4-40. Estimated waste quantities from emplacement and development activities (2010 to 2033).[a]

	High thermal load			Intermediate thermal load			Low thermal load		
Waste type	UC[b]	DISP[c]	DPC[d]	UC	DISP	DPC	UC	DISP	DPC
Hazardous (cubic meters)[e]	5,800	2,300	2,200	5,800	2,300	2,200	5,800	2,300	2,200
Sanitary and industrial solid (cubic meters)	50,000	41,000	42,000	50,000	41,000	42,000	70,000	61,000	62,000
Sanitary sewage (million liters)[f]	1,400	1,100	1,200	1,400	1,100	1,100	1,400	1,200	1,200
Industrial wastewater (million liters)	900	780	780	930	810	810	1,400	1,300	1,300
Low-level radioactive (cubic meters, after treatment)	67,000	18,000	26,000	67,000	18,000	26,000	67,000	18,000	26,000

a. Sources: TRW (1999a, pages 75 and 76); TRW (1999b, pages 6-17, 6-18, and 6-23).
b. UC = uncanistered.
c. DISP = disposable canister.
d. DPC = dual-purpose canister.
e. To convert cubic meters to cubic feet, multiply by 35.314.
f. To convert liters to gallons, multiply by 0.26418.

of hazardous waste during the construction phase. This maximum volume would result from the construction of facilities to accommodate the uncanistered packaging scenario. The Environmental Protection Agency's National Capacity Assessment Report (EPA 1996b, pages 32, 33, 36, 46, 47, and 50) indicates that the estimated 1993 to 2013 capacity for incineration of solids and liquids at permitted treatment, storage, and disposal facilities in the western states (including Nevada and other states to which repository waste could be shipped for treatment and disposal) is about seven times more than the demand for these services. The landfill capacity would be about 50 times the demand. Therefore, the impact to capacity from the treatment and disposal of hazardous waste from the construction phase would be very small.

DOE would treat and dispose of sanitary sewage and industrial wastewater at onsite facilities. Sanitary sewage from the North Portal Operations Area would go to an existing septic system. The Department would install another septic system to dispose of sanitary sewage from the South Portal Operations Area. The industrial wastewater from surface facilities would flow to an evaporation pond at the North Portal Operations Area and wastewater from the subsurface would flow to an evaporation pond at the South Portal Operations Area. Sludge would accumulate in the North Portal Operations Area evaporation pond so slowly that DOE would not need to remove it before the closure of the pond (TRW 1998g, pages 65 to 67). The accumulated sludge at the South Portal Operations Area evaporation pond, which would consist of mined rock, Portland Cement, and fine aggregate, would be removed as needed and added to the excavated rock pile (Koppenaal 1998b, page 3).

During the operation and monitoring phase (2010 to 2110), the receipt and packaging of spent nuclear fuel and high-level radioactive waste, the operation of support facilities, and the continued development of subsurface emplacement areas would generate radioactive and nonradioactive wastes and wastewaters and some hazardous waste. DOE does not expect to generate mixed waste. However, repository facilities would also have the capability to package and temporarily store mixed waste that operations could generate in unusual circumstances. In addition, the medical clinic would generate a small amount of medical waste that would be disposed of in accordance with applicable Federal and State of Nevada requirements.

Monitoring and maintenance activities after the completion of emplacement (2034 to 2110) would also generate wastes, but in much smaller quantities. The first few years after the completion of emplacement would generate greater quantities of waste due to the decontamination and decommissioning of surface nuclear facilities. DOE estimates as much as 520 cubic meters (18,000 cubic feet) of low-level radioactive waste and as much as 260 cubic meters (9,200 cubic feet) of hazardous waste from this activity (TRW 1999a, page 78), depending on the packaging scenario.

Monitoring and maintenance activities over 26 years would generate a maximum of about 9,900 cubic meters (350,000 cubic feet) of sanitary and industrial solid waste and about 230 million liters (60 million gallons) of sanitary sewage. Ongoing monitoring and maintenance activities for 76 years would generate a maximum of about 20,000 cubic meters (710,000 cubic feet) of sanitary and industrial solid waste and about 450 million liters (120 million gallons) of sanitary sewage. Ongoing monitoring and maintenance activities for 276 years (closure 300 years after the start of emplacement) would generate a maximum of about 61,000 cubic meters (about 2.2 million cubic feet) of sanitary and industrial solid waste and about 1.3 billion liters (340 million gallons) of sanitary sewage (TRW 1999a, page 85; TRW 1999b, pages 6-28 and 6-29).

During the operation and monitoring phase DOE would dispose of sanitary sewage and industrial wastewater in the onsite wastewater systems and sanitary and industrial solid waste in the onsite landfill or at the Nevada Test Site. The sanitary sewage disposal system would be able to handle the estimated daily sewage flows, and the industrial wastewater facilities would be able to handle the estimated annual wastewater flows. DOE would use the onsite landfill to dispose of sanitary and industrial solid waste, or it could use the existing Nevada Test Site landfill in Area 23 to dispose of such waste. The Area 23 landfill has an estimated 100-year capacity for the disposal of waste generated at the Test Site (DOE 1995f, page 9); the addition of repository-generated waste during the operation and monitoring phase would necessitate its expansion.

DOE would treat low-level radioactive waste in the Waste Treatment Building (see Section 2.1.2.1). After treatment, DOE would need to dispose of an estimated maximum 68,000 cubic meters (2.4 million cubic feet) of low-level radioactive waste generated during emplacement activities and the decontamination of surface nuclear facilities (TRW 1999a, pages 72 and 78). This waste would be disposed of at the Nevada Test Site. The Test Site accepts low-level radioactive waste for disposal from other DOE sites. It has an estimated disposal capacity of 3.15 million cubic meters (110 million cubic feet) (DOE 1998l, page 2-19) (see Section 3.1.12). The impact to the total capacity at the Nevada Test Site from the disposal of repository low-level radioactive waste would be 2.2 percent.

During the operation and monitoring phase repository-generated hazardous waste would be shipped off the site for treatment and disposal in a permitted facility. DOE would need to dispose of an estimated maximum of 6,100 cubic meters (220,000 cubic feet) of hazardous waste generated by emplacement activities and the decontamination of surface facilities (TRW 1999a, pages 72 and 78). The estimated maximum annual rate of hazardous waste treatment or disposal would be 260 cubic meters (9,200 cubic feet) (TRW 1999a, page 78). At present, a number of commercial facilities are available for hazardous waste treatment and disposal, and DOE expects similar facilities to be available until the closure of the repository. The National Capacity Assessment Report (EPA 1996b, pages 32, 33, 36, 46, 47, and 50) indicates that the estimated 20-year available capacity for incineration of solids and liquids at permitted treatment, storage, and disposal facilities in the western states is about seven times more than the demand for these services. The estimated landfill capacity is about 50 times the demand. Therefore, the impact to capacity from the treatment and disposal of repository-generated hazardous waste during the operation and monitoring phase would be very small.

If unusual activities generated mixed waste, DOE would package such waste for offsite treatment and disposal. The estimated maximum annual quantity would be about 1 cubic meter (35 cubic feet) (TRW 1999a, page 74), which would have a very small impact on the receiving facility. At present, there is commercial capacity (for example, at Envirocare of Utah, with which the Department has a contract for the treatment and disposal of mixed waste). DOE is also pursuing a permit for a mixed waste disposal facility at the Nevada Test Site that would accept mixed waste from other DOE sites for disposal (DOE 1996f, page 4-36). This facility has a planned annual capacity of 13,000 cubic meters (460,000 cubic feet) (DOE 1997b, Volume 1, page 6-6).

Closure activities, such as the final decontamination and demolition of the repository structures and the restoration of the site, would generate waste and recyclable materials. Table 4-41 lists estimated waste quantities for the closure phase. The ranges of quantities result from more waste generated from more years to complete closure with the low thermal load scenario and differences in surface facilities for the packaging scenarios.

Table 4-41. Estimated waste quantities from closure.[a]

Waste type	Quantity
Demolition debris (cubic meters)[b]	100,000 - 150,000
Hazardous (cubic meters)	440 - 630
Sanitary and industrial (cubic meters)	4,400 - 10,000
Sanitary sewage (million liters)[c]	83 - 200
Industrial wastewater (million liters)	42 - 105
Low-level radioactive (cubic meters, after treatment)	2,100 - 3,500

a. Sources: TRW (1999a, page 81); TRW (1999b, pages 6-38 and 6-39).

b. To convert cubic meters to cubic feet, multiply by 35.314.

c. To convert liters to gallons, multiply by 0.26418.

DOE would dispose of demolition debris and sanitary and industrial solid waste in the onsite landfill (or at the Nevada Test Site), and sanitary sewage and industrial wastewater in the onsite septic systems and industrial wastewater system. After disposing of the waste and wastewater, DOE would close the landfill and evaporation ponds in a manner that met applicable requirements.

The Nevada Test Site landfills would have to continue operating past their estimated lives and to expand as needed. The 10C landfill, which accepts demolition debris, has an estimated 70-year operational life; the Area 23 landfill, which is used for sanitary and industrial solid waste disposal, has a 100-year estimated life (DOE 1995f, pages 8 and 9).

DOE would continue to dispose of hazardous and low-level radioactive wastes off the site. The Department would ship hazardous waste to an offsite vendor with the appropriate permits and available treatment and disposal capacity and would ship low-level radioactive waste to a Nevada Test Site disposal facility. The National Capacity Assessment Report (EPA 1996b, pages 32, 33, 36, 46, 47, and 50) shows that the available capacity for hazardous waste treatment and disposal in the western states would far exceed the demand for many years to come. Therefore, hazardous waste generated during closure activities would be likely to have a very small impact on the capacity for treatment and disposal at commercial facilities. The disposal of low-level radioactive waste generated during repository closure at the Nevada Test Site would affect the disposal capacity about one-tenth of 1 percent.

Table 4-42 lists the waste types that repository activities would generate from construction through closure and the total estimated waste quantities for the nine thermal load scenario and packaging combinations. The table summarizes waste quantities for all phases of the Proposed Action.

If not recycled, dual-purpose canisters would add an estimated 44,000 cubic meters (1.6 million cubic feet) of low-level waste under each of the dual-purpose canister packaging scenarios (Koppenaal 1998a, all; TRW 1999a, page 76).

Table 4-42. Estimated waste quantities for Proposed Action.[a]

Waste type	High thermal load			Intermediate thermal load			Low thermal load		
	UC[b]	DISP[c]	DPC[d]	UC	DISP	DPC	UC	DISP	DPC
Construction and demolition debris (cubic meters)[e]	150,000	100,000	120,000	150,000	100,000	120,000	150,000	100,000	120,000
Hazardous (cubic meters)	7,700	3,500	3,500	7,700	3,500	3,500	7,700	3,500	3,500
Sanitary and industrial solid (cubic meters)	85,000	73,000	74,000	85,000	73,000	74,000	110,000	98,000	99,000
Sanitary sewage (million liters)[f]	2,000	1,800	1,800	2,000	1,800	1,800	2,200	1,900	2,000
Industrial wastewater (million liters)	980	870	870	1,000	900	900	1,600	1,500	1,500
Low-level radioactive (cubic meters after treatment)	71,000	21,000	29,000	71,000	21,000	29,000	71,000	21,000	29,000

a. Sources: TRW (1999a, Section 6); TRW (1999b, Section 6).
b. UC = uncanistered.
c. DISP = disposable canister.
d. DPC = dual-purpose canister.
e. To convert cubic meters to cubic feet, multiply by 35.314.
f. To convert liters to gallons, multiply by 0.2641.

4.1.12.3 Impacts from Hazardous Materials

The operation of the Yucca Mountain Repository would require the use of hazardous materials including paints, solvents, adhesives, sodium hydroxide, dry carbon dioxide, aluminum sulfate, sulfuric acid, and compressed gases. DOE has programs and procedures in place to procure and manage hazardous materials (DOE 1996h, all), ensuring their procurement in the appropriate quantities and storage under the proper conditions. At the repository, DOE would use an automated inventory management program (TRW 1999a, page 62) to control and track inventory.

4.1.12.4 Waste Minimization and Pollution Prevention

DOE would develop a waste minimization and pollution prevention awareness plan similar to the plan it has used during site characterization activities at Yucca Mountain (DOE 1997h, all). The goal of this new plan would be to minimize quantities of generated waste and to prevent pollution. To achieve this goal, DOE would establish requirements for each onsite organization and identify methods and activities to reduce waste quantities and toxicity.

DOE would recycle materials to the extent that it was cost-effective, feasible, and environmentally sound. Table 4-43 lists estimated quantities of materials that DOE would recycle during the life of the repository.

DOE has identified pollution prevention opportunities in the repository conceptual design process. The Waste Treatment Building design includes recycling facilities for the large aqueous low-level radioactive waste stream [690,000 liters (182,000 gallons) per year for the uncanistered packaging scenario] (DOE 1997l, page 23) that would result from decontamination activities. Wastewater recycling would greatly reduce water demand by repository facilities, as well as the amount of wastewater that would otherwise require disposal. In addition, DOE would use practical, state-of-the-art decontamination techniques such as pelletized solid carbon dioxide blasting that would generate less waste than other techniques.

In addition, DOE would use automated maintenance tracking and inventory management programs that would interface with the procurement system (TRW 1999a, page 62). These systems would assist in ensuring the proper maintenance of equipment through a preventive maintenance approach, which could

Table 4-43. Estimated recyclable material quantities.[a]

Material	UC[b]	DISP[c]	DPC[d]
High thermal load			
Recyclables (cubic meters)[e,f]	210,000	170,000	180,000
Steel (metric tons)[g]	37,000	27,000	31,000
Dual-purpose canisters[h] (cubic meters)	NA[i]	NA	44,000
Oils and lubricants (liters)[j]	28,000,000	28,000,000	28,000,000
Intermediate thermal load			
Recyclables (cubic meters)	210,000	170,000	180,000
Steel (metric tons)	37,000	27,000	31,000
Dual-purpose canisters (cubic meters)	NA	NA	44,000
Oils and lubricants (liters)	39,000,000	39,000,000	39,000,000
Low thermal load			
Recyclables (cubic meters)	260,000	230,000	240,000
Steel (metric tons)	37,000	27,000	31,000
Dual-purpose canisters (cubic meters)	NA	NA	44,000
Oils and lubricants (liters)	63,000,000	63,000,000	63,000,000

a. Sources: TRW (1999a, Section 6); TRW (1999b, Section 6).
b. UC = uncanistered packaging scenario.
c. DISP = disposable canister packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Nonhazardous, nonradioactive materials such as paper, plastic, glass, and nonferrous metals.
f. To convert cubic meters to cubic feet, multiply by 35.314.
g. To convert metric tons to tons, multiply by 1.1023.
h. Dual-purpose canisters would be recycled if appropriate, with regard to protection of the environment and cost-effectiveness. Estimated weight is 220,000 metric tons.
i. NA = not applicable.
j. To convert liters to gallons, multiply by 0.26418.

lead to less waste generation. Inventory management would prevent overstocking that could allow chemicals and other items to exceed their shelf lives and become waste.

4.1.13 ENVIRONMENTAL JUSTICE

Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*, directs Federal agencies to identify and address the potential for their activities to cause disproportionately high and adverse impacts to minority or low-income populations. This section uses the results of analyses from other disciplines to determine if disproportionately high and adverse impacts to human health or the environment on minority or low-income populations are likely to occur from repository performance confirmation, construction, operation and monitoring, and closure activities.

4.1.13.1 Methodology and Approach

The environmental justice analysis brings together the results of analyses from different technical disciplines that focus on consequences to certain resources, such as air, land use, socioeconomics, air quality, noise, and cultural resources, that in turn could affect human health or the environment. If any of these analyses were to predict high and adverse impacts to the human population in general, then an environmental justice analysis would determine if those impacts could occur in a disproportionately high and adverse manner to minority or low-income populations. The basis for making this determination is a comparison of the areas of large impacts with maps that indicate high percentages of minority or low-income populations as reported by the Bureau of the Census.

The potential for environmental justice concerns exists if the following could occur:

- *Disproportionately high and adverse human health effects:* Adverse health effects would be risks and rates of exposure that could result in latent cancer fatalities and other fatal or nonfatal adverse impacts to human health. Disproportionately high and adverse human health effects occur when the risk or rate for a minority or low-income population from exposure to a potentially large environmental hazard appreciably exceeds or is likely to appreciably exceed the risk to the general population and, where available, to another appropriate comparison group (CEQ 1997, all).

- *Disproportionately high and adverse environmental impacts to minority or low-income populations:* An adverse environmental impact is one that is unacceptable or above generally accepted norms. A disproportionately high impact is an impact (or the risk of an impact) to a low-income or minority community that significantly exceeds the corresponding impact to the larger community (CEQ 1997, all).

The EIS definition of a minority population is in accordance with the basic racial and ethnic categories reported by the Bureau of the Census. A minority population is one in which the percent of the total population comprised of a racial or ethnic minority is meaningfully greater than the percent of such groups in the total population [for this EIS, a minority population is one in which the percent of the total population comprised of a racial or ethnic minority is 10 percentage points or more higher than the percent of such groups in the total population (CEQ 1997, all)]. Nevada has a minority population of 21 percent (Bureau of the Census 1992a, Tables P8 and P12). For this EIS, therefore, one focus of the environmental justice analysis is the potential for construction, operation and monitoring, and closure of the proposed repository to have disproportionately high and adverse impacts on the populations in census tracts in the region of influence (principally in Clark, Nye, and Lincoln Counties) having a minority population of 31 percent or higher.

Nevada has a low-income population of 10 percent. Using the approach described in the preceding paragraph for minority populations, a low-income population is one in which 20 percent or more of the persons in a census block group live in poverty, as reported by the Bureau of the Census in accordance with Office of Management and Budget requirements (OMB 1999, all). Therefore, the second focus of the environmental justice analysis for this EIS is the potential for construction, operation and monitoring, and closure of the proposed repository to have disproportionately high and adverse impacts on the populations in census block groups having a low-income population of 20 percent or higher.

The environmental justice analysis involves a two-stage assessment of the potential for disproportionately high and adverse impacts on minority and low-income populations:

- First, a review of the activities included in the Proposed Action to determine if they are likely to result in any high and adverse human health impacts

- Second, if the first-stage review identified any high and adverse impacts to human populations in general, an analysis of whether minority or low-income populations would be affected disproportionately

The EIS analyses determined that the impacts that could occur to public health and safety would be small on the population as a whole for all phases of the Proposed Action, and that no subsections of the population, including minority or low-income populations, would receive disproportionate impacts.

4.1.13.2 Performance Confirmation, Construction, Operation and Monitoring, and Closure

Cultural Resources

DOE has implemented a worker education program on the protection of these resources to limit direct impacts to cultural resources, especially inadvertent damage and illicit artifact collecting. If significant data recovery (artifact collection) were required during construction and operation, DOE would initiate additional consultations with Native American groups to determine appropriate involvement. Further, archaeological resources and potential data recovery would be managed and conducted through consultations with the State Historic Preservation Officer or the Advisory Council on Historic Preservation.

Public Health and Safety

DOE has identified potential impacts to public health and safety from repository construction and operation (Section 4.1.7). However, DOE expects such impacts to be small. Because contamination of edible plants and animals would be unlikely from construction, operation and monitoring, and eventual closure of the repository, impacts to persons leading subsistence lifestyles would be unlikely.

Land Use

Direct land-use impacts from the Proposed Action would be low on members of the public because of the existing restriction of site access. There are no communities with high percentages of minority or low-income populations near the proposed repository site.

Socioeconomics

Because of the large population and workforce in the region of influence, socioeconomic impacts from repository construction and operation would be small. During the construction phase and the operation and monitoring phase, the regional workforce would increase less than 0.5 percent above the baseline level (see Section 4.1.6). Changes to the baseline regional population would not be greater than 0.5 percent for the duration of the entire project. Because the Proposed Action would generate minimal impacts to employment and population, potential socioeconomic impacts would be small.

DOE would continue its Native American Interaction Program to help manage cultural resources during construction and operation.

Air Quality

Impacts to air quality from the Proposed Action would be small. Furthermore, DOE would use best management practices for all activities, particularly ground-disturbing activities that could generate fugitive dust and construction activities that could produce vehicle emissions.

Noise

Impacts to sensitive noise receptors from the Proposed Action would not be likely because no sensitive noise receptors live in the Yucca Mountain region. Furthermore, there are no low-income or minority communities adjacent to the site.

4.1.13.3 Environmental Justice Impact Analysis Results

This analysis uses information from Sections 4.1.1 through 4.1.9. Those sections address impacts from all phases of the Proposed Action—construction, operation and monitoring, and closure. As noted above, DOE expects that the impacts of the Proposed Action would be small on the population as a whole. DOE has not identified any subsection of the population, including minority and low-income populations, that would receive disproportionate impacts. Accordingly, DOE has concluded that no disproportionately high and adverse impacts would result from the Proposed Action.

4.1.13.4 A Native American Perspective

In reaching the conclusion that there would be no disproportionately high and adverse impacts on minorities or low-income populations, DOE acknowledges that people from many Native American tribes have used the area proposed for the repository as well as nearby lands (AIWS 1998, page 2-1), that the lands around the site contain cultural, animal, and plant resources important to those tribes, and that the implementation of the Proposed Action would continue restrictions on free access to the repository site. DOE acknowledges that Native American people living in the Yucca Mountain vicinity have concerns about the protection of traditions and the spiritual integrity of the land that extend to the propriety of the Proposed Action.

Native American people living in the Yucca Mountain vicinity hold views and beliefs about the relationship between the proposed repository and the surrounding region that they have expressed in *American Indian Perspectives on the Yucca Mountain Site Characterization Project and the Repository Environmental Impact Statement* (AIWS 1998, all). Concerning the approach to daily life, the authors of that document, who represent the Western Shoshone, Owens Valley Paiute and Shoshone, Southern Paiute, and other Native American organizations, state:

> *…we have the responsibility to protect with care and teach the young the relationship of the existence of a nondestructive life on Mother Earth. This belief is the foundation for our holistic view of the cultural resources, i.e., water, animals, plants, air, geology, sacred sites, traditional cultural properties, and artifacts. Everything is considered to be interrelated and dependent on each other to sustain existence (AIWS 1998, page 2-9).*

The authors discuss the cultural significance of Yucca Mountain lands to Native American people:

> *American Indian people who belong to the CGTO (Consolidated Group of Tribes and Organizations) consider the YMP lands to be as central to their lives today as they have been since the creation of their people. The YMP lands are part of the holy lands of Western Shoshone, Southern Paiute, and Owens Valley Paiute and Shoshone people (AIWS 1998, page 2-20).*

and:

> *The lack of an abundance of artifacts and archaeological remains does not infer that the site was not used historically or presently and considered an integral part of the cultural ecosystem and landscape (AIWS 1998, page 2-10).*

The authors address the continuing denial of access to Yucca Mountain lands:

> *One of the most detrimental consequences to the survival of American Indian culture, religion, and society has been the denial of free access to their traditional lands and resources (AIWS 1998, page 2-20).*

and:

> *No other people have experienced similar cultural survival impacts due to lack of free access to the YMP area (AIWS 1998, page 2-20).*

The authors recognize that past restrictions on access have resulted in generally beneficial and protective effects for cultural resources, sacred sites, and potential traditional cultural properties (AIWS 1998, Section 3.1.1). However, the authors express concerns of Native American people regarding use of the repository:

> *The past, present, and future pollution of these holy lands constitutes both Environmental Justice and equity violations. No other people have had their holy lands impacted by YMP-related activities (AIWS 1998, page 2-20).*

and:

> *Access to culturally significant spiritual places and use of animals, plants, water and lands may cease because Indian people's perception of health and spiritual risks will increase if a repository is constructed (AIWS 1998, page 3-1).*

Even after closure and reclamation, the presence of the repository would represent an irreversible impact to traditional lands and other elements of the natural environment in the view of Native Americans.

Regarding the transportation of spent nuclear fuel and high-level radioactive waste, the authors state:

> *…health risks and environmental effects resulting from the construction and operation of the proposed intermodal transfer facility (ITF) and the transportation of high-level waste and spent nuclear fuel is considered by Indian people to be disproportionately high. This is attributed primarily to the consumption patterns of Indian people who still use these plants and animals for food, medicine, and other related cultural or ceremonial purposes (AIWS 1998, page 2-19).*

and:

> *The anticipated additional noise and interference associated with an ITF* [Intermodal Transfer Facility] *and increased transportation may disrupt important ceremonies that help the plants, animals, and other important cultural resources flourish, or may negatively impact the solitude that is needed for healing or praying (AIWS 1998, page 2-19).*

DOE recognizes that Native American tribal governments have a special and unique legal and political relationship with the Government of the United States, as established by treaty, statute, legal precedent, and the U.S. Constitution. For this reason DOE will consult with tribal governments and will work with representatives of the Consolidated Group of Tribes and Organizations to ensure the consideration of tribal rights and concerns before making decisions or implementing programs that could affect tribes; to continue the protection of Native American cultural resources, sacred sites, and potential traditional cultural properties; and to implement any appropriate mitigation measures.

4.1.14 IMPACTS OF THERMAL LOAD AND PACKAGING SCENARIOS

This section summarizes and compares the short-term environmental impacts for the three thermal load scenarios. These scenarios for the repository are high thermal load (85 MTHM per acre), intermediate thermal load (60 MTHM per acre) and low thermal load (25 MTHM per acre).

Overall the EIS analysis found that differences in environmental impacts for the three thermal load scenarios would be low and that the differences between the scenarios would be small. More specifically:

- All of the short-term impacts from repository activities would be small, both to workers and to the public.

- Long-term impacts to the public for the three thermal load scenarios would be essentially the same for collective dose and for latent cancer fatalities. They would be low (0.005 to 0.02 latent cancer fatality). Over the first 10,000 years, the risk of a latent cancer fatality to the maximally exposed individual would also be low (from 0.000001 to 0.000003) at 20 kilometers (about 12 miles) downgradient from Yucca Mountain. Individual dose rates would be highest for the high thermal load scenario and lowest for the low thermal load scenario.

- Short-term impacts for the surface-water, biological and soil, cultural, aesthetics, noise, and environmental justice resource areas would be small regardless of the thermal load scenario.

Short-term environmental impacts for activities at the repository as a function of packaging scenarios include:

- The greatest impacts for repository-related activities would be associated with the uncanistered packaging scenario with the exception of the generated volumes of solid and industrial wastes. For these wastes, the greatest impacts would result from the dual-purpose and disposable shipping packaging scenarios because these two types of shipping package would eventually become waste.

- Differences in impacts among the packaging scenarios would not be large, generally between 10 and 20 percent.

4.1.15 IMPACTS FROM MANUFACTURING DISPOSAL CONTAINERS AND SHIPPING CASKS

This section discusses the potential environmental impacts from the manufacturing of disposal containers and shipping casks required by the Proposed Action to dispose of spent nuclear fuel and high-level radioactive waste permanently at a monitored geologic repository at Yucca Mountain. This analysis considers transportation overpacks that would provide radiation shielding in the same manner as a shipping cask but that DOE would use only in conjunction with disposable canisters and dual-purpose canisters to be shipping casks without baskets or other internal configurations.

4.1.15.1 Overview

DOE followed the overall approach and analytical methods used for the environmental evaluation and the baseline data directly from the *Department of the Navy Final Environmental Impact Statement for a Container System for the Management of Naval Spent Nuclear Fuel* (USN 1996a, all). DOE’s evaluation focuses on ways in which the manufacture of the disposal containers and shipping casks could affect environmental attributes and resources at a representative manufacturing site. It is not site-specific because more than one manufacturer probably would be required to meet the production schedule requirements for component delivery, and the location of the companies chosen to manufacture disposal containers and shipping casks is not known. The companies and, therefore, the actual manufacturing sites would be determined by competitive bidding.

The analysis used a representative manufacturing site based on five facilities that produce casks, canisters, and related hardware for the management of spent nuclear fuel. The concept of a representative site was used in the Navy EIS (USN 1996a, page 4-1), and the representative site used in this analysis was defined in the same way, using the same five existing manufacturing facilities with the same attributes. The facilities used to define the representative site are in Westminster, Massachusetts; Greensboro, North Carolina; Akron, Ohio; York, Pennsylvania; and Chattanooga, Tennessee (USN

1996a, page 4-17). All of these facilities make components for firms with cask and canister designs approved by the Nuclear Regulatory Commission.

The analysis assumed that the manufacturing facilities and processes being used are similar to the facilities and processes that would produce disposal containers and shipping casks for the Yucca Mountain Repository. Therefore, the analysis considered the manufacturing processes used at these facilities and the total number of disposal containers and shipping casks required to implement each packaging scenario. The analysis assumed that the manufacture of disposal containers and shipping casks would occur at one representative site, but DOE recognizes that it probably would occur at more than one site. The assumption of one manufacturing site is conservative (that is, it tends to overestimate impacts) because it concentrates the potential impacts.

In addition, the analysis of disposal container and cask manufacturing evaluated the use of materials and the potential for impacts to material markets and supplies.

Section 4.1.15.3 describes the disposal containers and shipping casks. Section 4.1.15.4 discusses pertinent information on environmental settings for air quality, health and safety, and socioeconomics. Section 4.1.15.5 describes environmental impacts on air quality, health and safety, socioeconomics, material use, waste generation, and environmental justice.

4.1.15.2 Components and Production Schedule

Table 4-44 lists the quantities of disposal containers and shipping casks analyzed for the packaging scenarios described in Chapter 2. Table 4-44 includes disposal containers for naval spent nuclear fuel that would be emplaced in Yucca Mountain but does not include shipping casks for naval spent nuclear fuel. Shipping casks for naval spent nuclear fuel are owned and managed by the Navy. USN (1996a, all) analyzed environmental impacts for production of naval spent nuclear fuel canisters and shipping casks. Because naval spent nuclear fuel represents less than 4 percent of the inventory to be emplaced in the repository, the production of naval spent nuclear fuel casks would not add much to the impacts described in the following sections.

Table 4-44. Quantities of disposal containers and shipping casks for the Yucca Mountain Repository.[a]

		Packaging scenario[b]		
Component	Description	UC	DISP	DPC
Disposal containers[c]	Containers for disposal of SNF and HLW[d]	10,200	11,400	10,200
Rail shipping casks or overpacks[f]	Storage and shipment of SNF and HLW	0	100	110
Legal-weight truck shipping casks[f]	Storage and shipment of uncanistered fuel	120	10	10

a. The number of containers is an approximation but is based on the best available estimates.
b. UC = uncanistered; DISP = disposable canister; DPC = dual-purpose canister.
c. Source: TRW (1999c, Section 6); values have been rounded.
d. SNF = spent nuclear fuel; HLW = high-level radioactive waste.
e. A larger number of disposal containers is required for disposable canisters because they cannot be packed as densely as other canisters.
f. Cask fleet developed from Ross (1998, all); JAI (1996, all); TRW (1998j, Table 12, pages 17 and 18).

As currently planned, all of the components listed in Table 4-44 would be manufactured over 24 years to support emplacement in the repository. Manufacturing activity would build up during the first 5 years, then would remain nearly constant through the remainder of the 24-year period.

4.1.15.3 Components

Disposal Containers

The disposal container would be the final outside container used to package the spent nuclear fuel and high-level radioactive waste emplaced in the repository. The basic design calls for a cylindrical vessel with an outer layer of A 516 carbon steel that would be 100 millimeters (3.9 inches) thick and an inner liner of corrosion-resistant high-nickel alloy (C-22) that would be 20 millimeters (0.8 inch) thick (TRW 1999c, Section 6.0, page 6-1). The flat end pieces would be 110-millimeter (4.3-inch)-thick carbon steel and 25-millimeter (1-inch)-thick high-nickel alloy. The bottom end pieces would be welded to the cylindrical body at the fabrication shop, and the top end pieces would be welded in place after the placement of spent nuclear fuel or high-level radioactive waste in the container at the repository. About 16 different disposal container designs would be used for different types of spent nuclear fuel and high-level radioactive waste. The designs would vary in length from 3.8 to 6.2 meters (12 to 20 feet) and the outside diameters would range from 1.3 to 2 meters (4.3 to 6.6 feet). In addition, the internal configurations of the containers would be different to accommodate different uncanistered spent nuclear fuel configurations and a variety of spent nuclear fuel and high-level radioactive waste disposable canisters. The mass of an empty disposal container would range from about 21 to 38 metric tons (23 to 42 tons) (TRW 1999c, Section 4.0, pages 4-16 to 4-21).

Casks for Rail and Legal-Weight Truck Shipments

DOE would use two basic kinds of shipping cask designs—rail and truck—to ship spent nuclear fuel and high-level radioactive waste to the repository. The design of a specific cask would be tailored to the type of material it would contain. For example, rail and truck casks that could be used to ship commercial spent nuclear fuel would be constructed of stainless- or carbon-steel plate materials formed into cylinders and assembled to form inner and outer cylinders (USN 1996a, pages 4-3 and 4-4). A depleted uranium or lead liner would be installed between the stainless- or carbon-steel cylinders, and a vessel bottom with lead or depleted uranium between the inner and outer stainless- or carbon-steel plates would be welded to the cylinders. A support structure that could contain neutron-absorbing material would be welded into the inner liner, if required. A polypropylene sheath would be placed around the outside of the cylinder for neutron shielding. After spent nuclear fuel assemblies were inserted into the cask, a cover with lead or depleted uranium shielding would be bolted to the top of the cylinder to close and seal it. Transportation overpacks would be very similar in design and construction to shipping casks but would not have an internal support structure for the spent nuclear fuel because they would be used only for dual-purpose or disposable canisters.

For commercial spent nuclear fuel, casks and overpacks are typically 4.5 to 6 meters (15 to 20 feet) long and about 0.5 to 2 meters (1.6 to 6.6 feet) in diameter. These casks are designed to be horizontal when shipped. Rail casks presently used to ship naval spent nuclear fuel are shorter and are designed to sit upright on railcars. Empty truck casks typically weigh from 21 to 2 metric tons (about 23 to 24 tons). Empty rail casks (or overpacks) for commercial spent nuclear fuel typically weigh from 59 to 91 metric tons (65 tons to a little over 100 tons). The corresponding weights when loaded with spent nuclear fuel range between 22 and 24 metric tons (24 and 26 tons) for truck casks and between 64 and 110 metric tons (70 and 120 tons) for rail casks. For protection during shipment, large removable impact limiters of aluminum honeycomb or other crushable impact-absorbing material would be placed over the ends (JAI 1996, all).

4.1.15.4 Existing Environmental Settings at Manufacturing Facilities

Because there are facilities that could meet the projected manufacturing requirements, the assessment concluded that no new construction would be necessary and that there would be no change in land use for the manufacture of disposal containers and shipping casks. Similarly, cultural, aesthetic, and scenic resources would remain unaffected. Ecological resources, including wetlands, would not be affected because existing facilities could accommodate the manufacture of disposal containers and shipping casks and new or expanded facilities would not be required. Some minor increases in noise, traffic, or utilities would be likely, but none of these increases would result in impacts on the local environment.

Water consumption and effluent discharge during the manufacture of disposal containers and shipping casks would be typical of a heavy manufacturing facility and would represent only a small change, if any, from existing rates. Similarly, effluent discharges would not increase enough to cause difficulty in complying with applicable local, state, and Federal regulatory limits, and would be unlikely to result in a discernible increase in pollutant activity.

Accordingly, the following paragraphs contain information on environmental settings for air quality, health and safety, and socioeconomics. Section 4.1.15.5 evaluates the environmental impacts to these resource areas for a representative site.

Air Quality

The analysis evaluated the ambient air quality status of the representative manufacturing location by examining the air quality of the areas in which the reference manufacturing facilities are located. The principal criteria pollutants for cask manufacturing facilities are ozone, carbon monoxide, and particulate matter (PM_{10}). Areas where ambient air quality standards are not exceeded, or where measurements have not been made, are considered to be in attainment. Areas where the air quality violates Federal or state regulations are in nonattainment and subject to more stringent regulations. Typical existing container and cask manufacturing facilities are in nonattainment areas for ozone and in attainment areas for carbon monoxide and particulate matter.

Because most of the existing typical manufacturing facilities are in nonattainment areas for ozone, the analysis assumed that the representative site would be in nonattainment for ozone and that ozone would be the criteria pollutant of interest. Volatile organic compounds and nitrous oxides are precursors for ozone and are indicators of likely ozone production. For the areas in which the reference manufacturing facilities are located, an average of 3,400 metric tons (approximately 3,800 tons) of volatile organic compounds and 39,000 metric tons (approximately 43,000 tons) of nitrous oxides were released to the environment in 1990, the latest year for which county-level data are available (USN 1996a, page 4-5).

Health and Safety

Data on the number of accidents and fatalities associated with cask and canister fabrication at the representative manufacturing location were based on national incidence rates for the relevant sector of the economy. In 1992, the last year for which statistics are available, the occupational fatality rate for the sector that includes all manufacturing was 3 per 100,000 workers; the occupational illness and injury rate for fabricated plate work manufacturing in 1992 was 6.3 per 100 full-time workers (USN 1996a, page 4-5).

The manufacture of hardware for each of the packaging scenarios would be likely to be in facilities that have had years of experience in rolling, shaping, and welding metal forms, and then fabricating large containment vessels similar to the required disposal containers and shipping casks for nuclear materials. Machining operations at these facilities would involve standard procedures using established metal-working equipment and techniques. Trained personnel familiar with the manufacture of large, multiwall, metal containment vessels would use the equipment necessary to fabricate such items. Because of this experience and training, DOE anticipates that the injury and illness rate would be equal to or lower than the industry rates.

Socioeconomics

Each of the five manufacturing facilities examined in this analysis is in a Metropolitan Statistical Area. The counties comprising each Metropolitan Statistical Area define the affected socioeconomic environment for each facility. The populations of the affected environments associated with the five facilities ranged from about 430,000 to 970,000 in 1992 (USN 1996a, page 4-6). In 1995 output (the value of goods and services produced in the five locations) ranged from $18 billion to $55 billion, income (wages, salaries, and property income) ranged from $9 billion to $26 billion, employment ranged from 245,000 to 670,000 in 1995, and plant employment ranged from 25 to 995 (USN 1996a, page 4-6). Based on averages of this information, the representative manufacturing location has a population of about 640,000 and the facility employs 480. Local output in the area is $30 billion, local income is $15 billion, and local employment is 390,000.

4.1.15.5 Environmental Impacts

As mentioned in Section 4.1.15.4, this evaluation considered only existing manufacturing facilities, so environmental impact analyses are limited to air quality, health and safety, waste generation, and socioeconomics. In addition, this section contains a qualitative discussion of environmental justice.

4.1.15.5.1 *Air Quality*

The analysis used the baseline data and methods developed in USN (1996a, Section 4.3) to estimate air emissions from manufacturing sites for the production of disposal containers and shipping casks. Criteria pollutants and hazardous air pollutants were considered, and predicted emissions were compared with typical regional or county-wide emissions to determine potential impacts of the emissions on local air quality.

Potential emissions were evaluated for a representative manufacturing location using the ambient air quality characteristics of typical manufacturing facilities, as described in Section 4.1.15.4. The analysis assumed that the representative location used for this analysis would be in a nonattainment area for ozone and in attainment areas for carbon monoxide and particulate matter. Therefore, ozone was the only criteria pollutant analyzed. Ozone is not normally released directly to the atmosphere, but is produced in a complex reaction of precursor chemicals (volatile organic compounds and nitrous oxides) and sunlight. This section evaluates the emissions of these precursors.

The reference air emissions associated with the manufacture of disposal containers and shipping casks were developed using the emissions resulting from manufacturing similar components (USN 1996a, page 4-6) and were normalized based on the number of work hours required for the manufacturing process. The analysis prorated these reference emissions on a per-unit basis to calculate annual emissions at the reference manufacturing site, assuming emissions from similar activities would be proportional to the number of work hours in the manufacturing process. To provide reasonable estimates of emissions, the analysis assumed that the volatile organic compounds used as cleaning fluids would evaporate fully into the atmosphere as a result of the cleaning processes used in manufacturing. The estimates of emissions were based on the total number of disposal containers and shipping casks manufactured over 24 years for each packaging scenario.

Table 4-45 lists the estimated annual average and estimated total 24-year emissions from the manufacture of disposal containers and shipping casks at the representative facility for each packaging scenario. Estimated annual average emissions of volatile organic compounds would vary from 0.58 to 0.61 metric ton (approximately 0.64 to 0.67 ton) a year. Nitrous oxides would be the largest emission, varying from 0.75 to 0.78 metric ton (approximately 0.83 to 0.86 ton) a year for the packaging scenarios. Annual

Table 4-45. Ozone-related air emissions (metric tons)[a] at the representative manufacturing location for the different packaging scenarios.

		Packaging scenario[b]		
Compound	Measure	UC	DISP	DPC
Volatile organic compounds	Annual average	0.60	0.61	0.58
	24-year total	15	15	14
	Percent of *de minimis*[c]	6.6%	6.7%	6.4%
Nitrogen oxides	Annual average	0.78	0.78	0.75
	24-year total	19	19	18
	Percent of *de minimis*[c]	8.6%	8.6%	8.2%

a. To convert metric tons to tons, multiply by 1.1023.

b. UC = uncanistered; DISP = disposable canister; DPC = dual-purpose canister.

c. *De minimis* level for an air quality region in extreme nonattainment for ozone is 9.1 metric tons per year of volatile organic compounds or nitrogen oxides (40 CFR 51.853).

average emissions from disposal container and shipping cask manufacturing under any of the scenarios would be less than 0.02 percent of regional emissions of volatile organic compounds and 0.002 percent of regional emissions of nitrous oxides. Emissions from the manufacture of disposal containers and shipping casks would contain a relatively small amount of ozone precursors compared to other sources.

The examination of the packaging scenarios assumed that the emissions of volatile organic compounds and nitrous oxides were new sources; these emissions were compared with emission threshold levels (emission levels below which conformity regulations do not apply). There are different categories of ozone nonattainment areas based on the sources of ozone and amount of air pollution in the region. The different categories have different emission threshold levels (40 CFR 51.853).

For an air quality region to be in extreme nonattainment for ozone (most restrictive levels), the emission threshold level for both volatile organic compounds and nitrous oxides is 9.1 metric tons (10 tons) per year. Table 4-45 also lists the percentage of volatile organic compounds and nitrous oxides from the manufacture of disposal containers and shipping casks in relation to the emission threshold level of an extreme ozone nonattainment area. Air emissions from the manufacture of disposal containers and shipping casks would vary depending on the packaging scenario, with ranges of 6.4 to 6.7 percent and 8.2 to 8.6 percent of the emission threshold levels for volatile organic compounds and nitrous oxides, respectively. In all of the packaging scenarios, component manufacturing would not be likely to fall under the conformity regulations because the predicted emissions of volatile organic compounds and nitrous oxides would be well below (less than 10 percent of) the emission threshold level of 9.1 metric tons per year. However, DOE would ensure the implementation of the appropriate conformity determination processes and written documentation for each designated manufacturing facility.

States with nonattainment areas for ozone could place requirements on many stationary pollution sources to achieve attainment in the future. This could include a variety of controls on emissions of volatile organic compounds and nitrous oxides. Various options such as additional scrubbers, afterburners, or carbon filters would be available to control emissions of these compounds to comply with limitations.

4.1.15.5.2 *Health and Safety*

The analysis used data on the metal fabrication and welding industries from the Bureau of Labor Statistics to compile baseline occupational health and safety information for industries that fabricate steel and steel objects similar to disposal containers and shipping casks (USN 1996a, page 4-8). The expected number of injuries and fatalities were computed by multiplying the number of work years by the injury and fatality rate for each occupation.

Table 4-46. Injuries, illnesses, and fatalities over 24 years at the representative manufacturing location for the packaging scenarios.

	Packaging scenario[a]		
Parameter	UC	DISP	DPC
Injuries and illnesses	275	276	265
Fatalities	0.13	0.13	0.13

a. UC = uncanistered; DISP = disposable canister; DPC = dual-purpose canister.

Table 4-46 lists the expected number of injuries and illnesses and fatalities for each packaging scenario based on the work years required to produce the number of disposal containers and shipping casks needed over 24 years. Injuries and illnesses would range from 265 to 276. Fatalities would be unlikely.

The required number of disposal containers and shipping casks would not place unusual demands on existing manufacturing facilities. Thus, none of the packaging scenarios would be likely to lead to a deterioration of worker safety and a resultant increase in accidents. In addition, nuclear-grade components are typically built to higher standards and with methods that are more proceduralized, both of which lead to improved worker safety.

4.1.15.5.3 *Socioeconomics*

The assessment of socioeconomic impacts from manufacturing activities involved three elements:

- Per-unit cost data for disposal containers (TRW 1999c, Sections 5 and 6) and per-unit cost of shipping casks (TRW 1998j, Table 12, pages 17 and 18)
- Total number of disposal containers and shipping casks to be manufactured (TRW 1999c, Section 6)
- Economic data for the environmental setting for each facility to calculate the direct and secondary economic impacts of disposal container and shipping cask manufacturing on the local economy (BEA 1992, all)
  - Direct effects would occur as manufacturing facilities purchased materials, services, and labor required for manufacturing.
  - Secondary effects would occur as industries and households supplying the industries that were directly affected adjusted their own production and spending behavior in response to increased production and income, thereby generating additional socioeconomic impacts.

Impacts were measured in terms of output (the value of goods and services produced), income (wages, salaries, and property income), and employment (number of jobs).

The socioeconomic analysis of manufacturing used state-level economic multipliers for fabricated metal products (BEA 1992, all). To perform the analysis, DOE obtained the product, income, and employment multipliers for the states where the five existing manufacturing facilities are located. (Multipliers account for the secondary effects on an area’s economy in addition to providing direct effects on its economy). The multipliers were averaged to produce composite multipliers for a representative manufacturing location. The composite multipliers were used to analyze the impacts of each alternative. Table 4-47 lists the state-specific multipliers and the composite multipliers.

The analysis was limited to estimating the direct and secondary impacts of manufacturing activities. No assessment was made of the impacts of manufacturing activities on local jurisdictions. Such an analysis would include the estimation of impacts on county and municipal government and school district revenues and expenditures. Because the production of disposal containers and shipping casks probably

Table 4-47. Economic multipliers for fabricated metal products.[a]

State	Final demand multiplier ($) Products	Final demand multiplier ($) Earnings	Direct effect multiplier (number of jobs)
Massachusetts	1.8927	0.5555	2.2050
North Carolina	1.9145	0.5426	2.1544
Ohio	2.6019	0.7260	3.1064
Pennsylvania	2.5697	0.7194	2.8552
Tennessee	2.1379	0.6107	2.5314
Composite	2.2233	0.6308	2.5705

a. Source: Bureau of the Census (1992h, all).

would occur at existing facilities alongside existing product lines, a substantial population increase due to workers moving into the vicinity of the manufacturing sites in a given year under a packaging scenario would be unlikely. Due to this lack of demographic impacts, meaningful change in the disposition of local government or school district revenues and expenditures would be unlikely. Because substantial population increases would not be likely, the analysis did not consider impacts on other areas of socioeconomic concern, such as housing and public services.

The analysis calculated average annual impacts for the manufacturing period. The impacts of each packaging scenario were compared to the baseline at the representative location in 1995, with results expressed in millions of 1998 dollars. No attempt was made to forecast local economic growth or inflation rates for the representative location because of the non-site-specific nature of the analysis.

Table 4-48 lists the impacts of each packaging scenario on output, income, and employment at the representative manufacturing location. The impacts include the percent of each scenario in relation to overall output, income, and employment in the economy.

Table 4-48. Socioeconomic impacts for packaging scenarios at the representative manufacturing location.

	Average annual output[a]		Average annual income		Average annual employment	
Packaging scenario	$ (millions)	Percent impact[b]	$ (millions)	Percent impact	Person-years	Percent impact
Uncanistered	360	1.2	102	0.68	470	0.12
Dual-purpose canister	365	1.2	104	0.69	450	0.12
Disposable canister	310	1.0	89	0.59	470	0.12

a. Annual output and income impacts are expressed as millions of 1998 dollars.

b. Percent impact refers to the percentage of the baseline data discussed in Section 4.1.14.4 for the representative site.

Local Output

The average annual output impacts of each scenario would range from about $310 million to about $365 million (Table 4-48). Output generated from each scenario would increase total local output from between 1.0 percent and 1.2 percent, on average, over the 24-year manufacturing period.

Local Income

The average annual income impacts of each packaging scenario would range from about $89 million to about $104 million (Table 4-48). Income generated from each scenario would increase total local income by between 0.59 percent and 0.69 percent, on average, over the 24-year manufacturing period.

Local Employment

The average annual employment impacts of each packaging scenario would range from about 450 to about 470 work years (Table 4-48). Employment generated from any of the packaging scenarios would increase total local employment about 0.12 percent, on average, over the 24-year manufacturing period.

4.1.15.5.4 *Impacts on Material Use*

To the extent available, DOE based the calculations of the quantities of materials it would use for the manufacture of each disposal container and shipping cask on engineering specifications for each hardware component. This information was provided by the manufacturers of systems either designed or under licensing review (USN 1996a, Sections 3.0, 4.1.1, and Appendix D; TRW 1999c, all), or from conceptual design specifications for technologies still in the planning stages (JAI 1996, all). Data on per-unit material quantities for each component were combined with information on the number of disposal containers and shipping casks to be manufactured during each packaging scenario. In addition, the analysis assessed the impact of component manufacturing for each scenario on the total U.S. production (or availability in the United States, if not produced in this country) of each relevant input material. The results of the assessment are expressed in terms of percent impacts on total U.S. domestic production of most commodities.

Table 4-49 lists estimated total quantities of materials that DOE would need for each packaging scenario during the 24-year period along with the annual average requirement for each material. For each scenario the largest material requirement by weight would be steel, ranging from about 260,000 to about 280,000 metric tons (280,000 to 310,000 tons).

Table 4-49. Material use (metric tons)[a] for packaging scenarios.

	Basic material use per scenario[b]					
	UC		DISP		DPC	
Material	Total	Annual	Total	Annual	Total	Annual
Aluminum	1,500	63	77	3	1,500	63
Chromium[c]	14,000	590	12,000	500	15,000	620
Copper	36	1	146	6	95	4
Depleted uranium	880	37	1,300	55	120	5
Lead	430	18	1,500	63	3,000	139
Molybdenum[d]	6,000	250	6,600	280	6,000	260
Nickel[e]	29,000	1,200	29,000	1,200	30,000	1,200
Steel	280,000	12,000	260,000	11,000	280,000	12,000

a. To convert metric tons to tons, multiply by 1.1023.

b. UC = uncanistered; DISP = disposable canister; DPC = dual-purpose canister.

c. Chromium estimated as 29 percent of stainless steel and 22 percent of high-nickel alloy.

d. Molybdenum estimated as 13.5 percent of high-nickel alloy.

e. Stainless steel assumed to be 18.5 percent nickel and high-nickel alloy assumed to be 58 percent nickel.

Table 4-50 compares the annual U.S. production capacity to the annual requirements for the materials each scenario would use. With the exception of chromium and nickel, consumption for each scenario for the 24-year manufacturing period would be less than 0.5 percent of the annual U.S. production.

Therefore, the use of aluminum, copper, lead, molybdenum, or steel would not produce a noteworthy increased demand and should not have a meaningful effect on the supply of these materials.

The annual requirement for chromium as a component in stainless-steel and high-nickel alloy ranges from about 0.48 percent to about 0.59 percent of the annual U.S. production. Most chromium, which is

Table 4-50. Annual amount (metric tons)[a] of material required for manufacturing, expressed as a percent of annual U.S. domestic production, for each packaging scenario.

		Packaging scenario[b]					
		UC		DISP		DPC	
Material	Production[c]	Annual	Percent	Annual	Percent	Annual	Percent
Aluminum	5,000,000	63	0.0013	3	0.0001	63	0.0013
Chromium	104,000	590	0.57	500	0.48	620	0.59
Copper	1,900,000	1	0.0001	6	0.0003	4	0.0002
Depleted uranium	14,700[d]	37	0.25	55	0.38	5	0.034
Lead	430,000	18	0.0042	63	0.015	140	0.032
Molybdenum	57,000	250	0.45	280	0.48	260	0.045
Nickel	14,600	1,200	8.3	1,200	8.3	1,200	8.4
Steel	91,500,000	12,000	0.013	11,000	0.012	12,000	0.013

a. To convert metric tons to tons, multiply by 1.1023.

b. UC = uncanistered; DISP = disposable canister; DPC = dual-purpose canister.

c. Source: Bureau of the Census (1997, Table 1155, page 700, and Table 1244, page 756).

d. Source: USN (1996a, page 4-10).

an important constituent of many types of stainless steel, is imported into the United States and is classified as a Federal Strategic and Critical Inventory material. For comparative purposes, the maximum total 24-year program requirement of about 14,000 metric tons (17,000 tons) can be evaluated as a percentage of the 1994 strategic chromium inventory of 1.04 million metric tons (1.15 million tons) (Bureau of the Census 1997, Table 1159, page 702). The total repository program need would be about 1.5 percent of the strategic inventory. With the strategic inventory to support the program demand, chromium use should not cause any market or supply impacts.

Annual nickel use as a component in stainless steel and corrosion-resistant high-nickel alloys appears, relatively, the most important in comparison to U.S. production. The magnitude of the comparison is the result of low U.S. production because the United States imports most of the nickel it uses. Although the annual U.S. production of nickel is only 14,600 metric tons (16,100 tons), the annual U.S. consumption is 158,000 metric tons (174,000 tons) (Bureau of Census 1997, Table 1155, page 700). This annual consumption is supported by a robust world production of 1.04 million metric tons (1.15 million tons) (Bureau of the Census 1997, Table 1158, page 702). The maximum annual program need is a little less than 1 percent of the U.S. consumption and about 0.1 percent of world production. Canada is a major world supplier of nickel. DOE does not anticipate that the maximum program demand would affect the U.S. or world nickel markets.

The annual amount of depleted uranium used over 24 years would range from 0.25 percent to 0.38 percent of the total U.S. annual production. These requirements would be small. Given the limited alternative uses of this material and the large current inventory of surplus depleted uranium hexafluoride owned by DOE, such impacts should be considered to be positive (USN 1996a, page 4-10).
Lead or steel could be substituted for depleted uranium for radiation shielding in some cases. If those materials were used for this purpose, the thickness of the substituted material would increase in inverse proportion to the ratio of the density of the substituted material to the density of depleted uranium. If lead or steel were used, the shielding thickness would increase by about 170 percent or 240 percent, respectively, resulting in a much larger container (USN 1996a, page 4-10).

4.1.15.5.5 *Impacts of Waste Generation*

The component materials used in the manufacture of disposal containers and shipping casks would be carbon steel, high-nickel alloy, and stainless steel, with either depleted uranium or lead used for shielding. The manufacture of shielding would generate hazardous or low-level radioactive waste, depending on the material used. Other organic and inorganic chemical wastes generated by the manufacture of disposal containers and shipping casks and the amounts generated have also been identified.

Based on data in USN (1996a, page 4-13), the analysis estimated annual volumes and quantities of waste produced for each packaging scenario per disposal container and shipping cask manufactured at the representative site. The potential for impacts was evaluated in terms of existing and projected waste handling and disposal procedures and regulations. In addition to relevant state regulatory agencies, the Environmental Protection Agency and the Occupational Safety and Health Administration regulate the manufacturing facilities.

Manufacturing to support the different packaging scenarios would produce liquid and solid wastes at the manufacturing locations. To control the volume and toxicity of these wastes, manufacturers would comply with existing regulations. Pollution prevention and reduction practices would be implemented. The analysis evaluated only waste created as a result of the manufacturing process to produce disposal containers and casks from component materials. It did not consider the waste produced in mining, refining, and processing raw materials into component materials for distribution to the manufacturer. The analysis assumed that the component materials, or equivalent component materials produced from the same raw materials, would be available from supplier stock, which would be available without regard to the status of the Yucca Mountain project.

Liquid Waste

The liquid waste produced during manufacturing would consist of used lubricating and cutting oils from machining operations and the cooling of cutting equipment. This material is currently recycled for reuse. Ultrasonic weld testing would generate some unpotable water-containing glycerin. Water used for cooling and washing operations would be treated for release by filtration and ion exchange, which would remove contaminants and permit discharge of the treated water to the sanitary system.

Table 4-51 lists the estimated amounts of liquid waste generated by the shaping, machining, and welding of the vessels required for each packaging scenario. The annual average amount of liquid waste generated would range from 3.4 to 3.8 metric tons (approximately 3.7 to 4.2 tons) per year. The small quantities of waste produced during manufacturing would not exceed the capacities of the existing equipment for waste stream treatment at the manufacturing facility.

Table 4-51. Annual average waste generated (metric tons)[a] at the representative manufacturing location for packaging scenarios.

	Packaging scenario[b]		
Waste	UC	DISP	DPC
Liquid	3.4	3.8	3.4
Solid	0.47	0.52	0.47

a. To convert metric tons to tons, multiply by 1.1023.

b. UC = uncanistered; DISP = disposable canister; DPC = dual-purpose canister.

Solid Waste

Table 4-51 lists the solid waste that manufacturing operations would generate. The annual average amount of solid waste would range from 0.47 to 0.52 metric ton (approximately 0.52 to 0.57 ton) per year. The primary waste constituents would be steel and components of steel including nickel, manganese, molybdenum, chromium, and copper. These chemicals could be added to existing steel product manufacturing waste streams for treatment and disposal or recycling.

The analysis assumed that depleted uranium to be incorporated in the components would be delivered to the manufacturing facility properly shaped to fit as shielding for a shipping cask. As a result, depleted uranium waste would not be generated or recycled at the representative manufacturing site and would not pose a threat to worker health and safety. Lead used for gamma shielding would be cast between stainless-steel components for the shipping casks. Although the production of a substantial quantity of lead waste under any of the packaging scenarios would be unlikely, such waste would be recycled.

4.1.15.5.6 *Environmental Justice*

The purpose of this environmental justice assessment is to determine if disproportionately high and adverse health or environmental impacts associated with the manufacture of disposal containers and shipping casks would affect minority or low-income populations, as outlined in Executive Order 12898 and the President's accompanying cover memorandum. Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations,* directs Federal agencies to identify and address disproportionately high and adverse human health or environmental effects of their programs and activities on minority and low-income populations. A disproportionately high impact would be an impact (or risk of an impact) in a minority or low-income community that exceeded the corresponding impact on the larger community to a meaningful degree. The analysis discussed below is the analysis used in USN (1996a, Section 4.8), which was adapted to the manufacturing of components for the Yucca Mountain Repository.

The environmental justice assessment considered human health and environmental impacts from the examination of impacts on air quality, waste generation, and health and safety for each scenario. The assessment used demographic data to provide information on the degree to which a scenario would affect minority or low-income populations disproportionately. The evaluation identified as areas of concern those in which disproportionately high and adverse impacts could affect minority or low-income populations.

This evaluation considered the characteristics of the five facilities that manufacture casks or canisters for spent nuclear fuel. For each facility the analysis considered a region defined by an approximately 16-kilometer (10-mile) radius around the site. The percentages of minority and low-income persons comprising the population of the states where the facilities are located were used as a reference.

To explore potential environmental justice concerns, this assessment examined the composition of populations living within approximately 16 kilometers (10 miles) of the five manufacturing facilities to identify the number of minority and low-income individuals in each area. DOE selected this radius because it would capture the most broadly dispersed environmental consequences associated with the manufacturing activities, which would be impacts to air quality. The number of persons in each target group in the defined area was compared to the total population in the area to yield the proportion of minority and low-income persons within approximately 16 kilometers of each facility.

A geographic information system was used to define areas within approximately 16 kilometers (10 miles) of each facility. Linked to 1990 census data, this analytical tool enabled the identification of block groups within 16 kilometers. In cases where the 16-kilometer limit divided block groups, the system calculated the fraction of the total area of each group that was inside the prescribed distance. This fraction provided the basis for estimating the total population in the area as well as the minority and low-income components.

The analysis indicated that in one location the proportion of the minority population in the area associated with the manufacturing facility is higher than the proportion of the minority population in the state. The difference between the percentage of the minority population living inside the 16-kilometer (10-mile) radius and the state is 1.5 percent (USN 1996a, page 4-18). DOE anticipates very small impacts for the total population from manufacturing activities associated with all the scenarios, so there would be no disproportionately high and adverse impacts to the minority population near this facility.

In addition, the percentage of the total population that consists of low-income families living within about 16 kilometers (10 miles) of a manufacturing facility would exceed that of the associated state in one instance. The difference in this case was 0.9 percent (USN 1996a, page 4-18). DOE anticipates very small impacts to individuals and to the total population, and no special circumstances would cause disproportionately high and adverse impacts to the low-income population living near the facility.

The EIS analysis determined that only small human health and environmental impacts would occur from the manufacture of disposal containers and shipping casks. Disproportionately high and adverse impacts to minority or low-income populations similarly would be unlikely from these activities.

4.2 Short-Term Environmental Impacts from the Implementation of a Retrieval Contingency or Receipt Prior to the Start of Emplacement

4.2.1 IMPACTS FROM RETRIEVAL CONTINGENCY

Section 122 of the NWPA requires DOE to maintain the ability to retrieve emplaced waste for at least 50 years after the start of emplacement. Because of this requirement, the EIS includes an analysis of the impacts of retrieval. Although DOE does not anticipate retrieval and it is not part of the Proposed Action, DOE would maintain the ability to retrieve the waste for at least 100 years and possibly for as long as 300 years in the event of a decision to retrieve the waste either to protect the public health and safety or the environment or to recover resources from spent nuclear fuel. This EIS evaluates retrieval as a contingency action and describes potential impacts if it were to occur. The analysis in this EIS assumes that under this contingency DOE would retrieve all the waste and would place it on a surface storage pad pending future decisions about its ultimate disposition. Storage of spent nuclear fuel and high-level radioactive waste on the surface would be in compliance with applicable regulations.

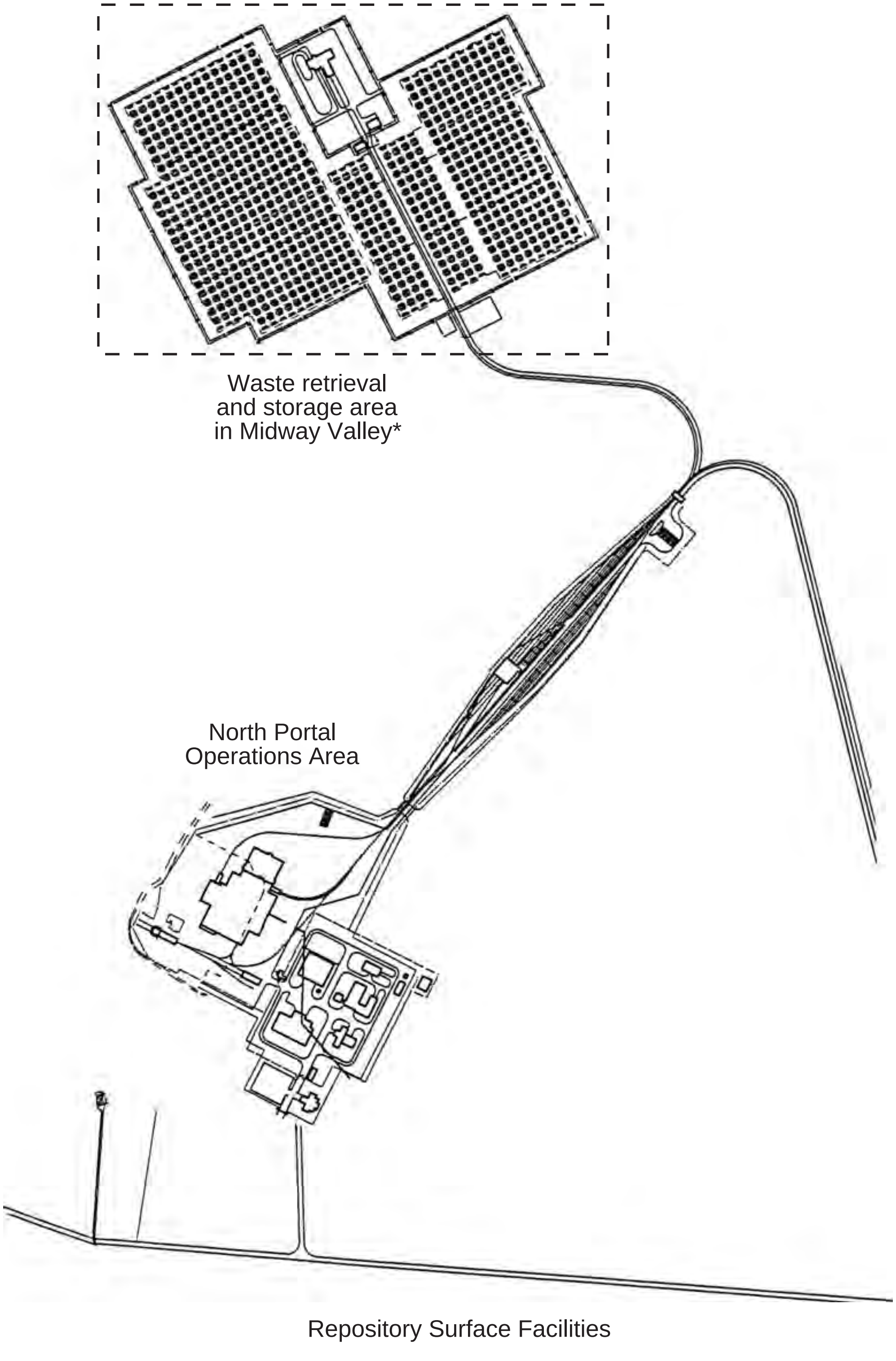
4.2.1.1 Retrieval Activities

If there were a decision to retrieve spent nuclear fuel and high-level radioactive waste from the repository, DOE would move the waste packages from the emplacement drifts to the surface. Operations in the subsurface facilities to remove the waste packages would be the reverse of emplacement operations and would use the same types of equipment (see Section 2.1.1.2).

On the surface, the retrieved waste packages would be loaded on a vehicle for transport to a Waste Retrieval and Storage Area in Midway Valley, about 3.7 kilometers (2.3 miles) from the North Portal Operations Area, to which DOE would build a rail line or roadway. Figure 4-5 shows the relationship between these areas. The Waste Retrieval and Storage Area would include a Waste Retrieval Transfer Building, support facilities, and a number of concrete storage pads. To retrieve and store 70,000 MTHM of spent nuclear fuel and high-level radioactive waste, these facilities would cover about 1 square kilometer (250 acres) (TRW 1999a, Attachment I, page I-8).

DOE based selection of Midway Valley Wash as the site for retrieval activities on the following site selection criteria:

- Proximity to the repository North Portal Operations Area
- Retrieval of the waste in the shortest possible timeframe



*See Figure 3-12 for more specific location of Midway Valley.

Source: TRW (1999a, Attachment I, Figure I-1).

Figure 4-5. Location of the Waste Retrieval and Storage Area in relation to the North Portal Operations Area.

- Adequate space for dry storage of 70,000 MTHM of waste
- No ground displacements due to earthquakes
- Siting outside the probable maximum flood zone
- Minimum costs for construction
- Minimum impacts to the environment

In the Waste Retrieval Transfer Building, the waste packages would be removed and placed in concrete storage modules (one container per module). The concrete module would protect the container and provide shielding. The module and container would then move to a concrete storage pad near the Waste Retrieval Transfer Building, where it would remain awaiting ultimate disposition. Figure 4-6 shows a concrete storage module design concept.

Studies of the strategies and options for retrieval (TRW 1997d, all) indicate it would take about 10 years after a decision to retrieve the emplaced material to plan the operation, procure the necessary equipment, and prepare the Waste Retrieval and Storage Area; about 3 years would involve the construction of facilities and storage areas. To accomplish retrieval would require another 11 years, including additional storage area construction. DOE performed an impact analysis for the retrieval contingency only for the high thermal load scenario. The analysis of impacts for this scenario is sufficient to describe the types and magnitudes of impacts that would occur if DOE implemented the retrieval contingency.

4.2.1.2 Impacts of Retrieval

The following sections present the results of the environmental impact analysis for the retrieval contingency. They consider the construction of the Waste Retrieval and Storage Area, retrieval of the waste packages and their movement to the surface and to the Waste Retrieval and Storage Area, and the loading of the waste packages in concrete storage modules and their placement on concrete storage pads.

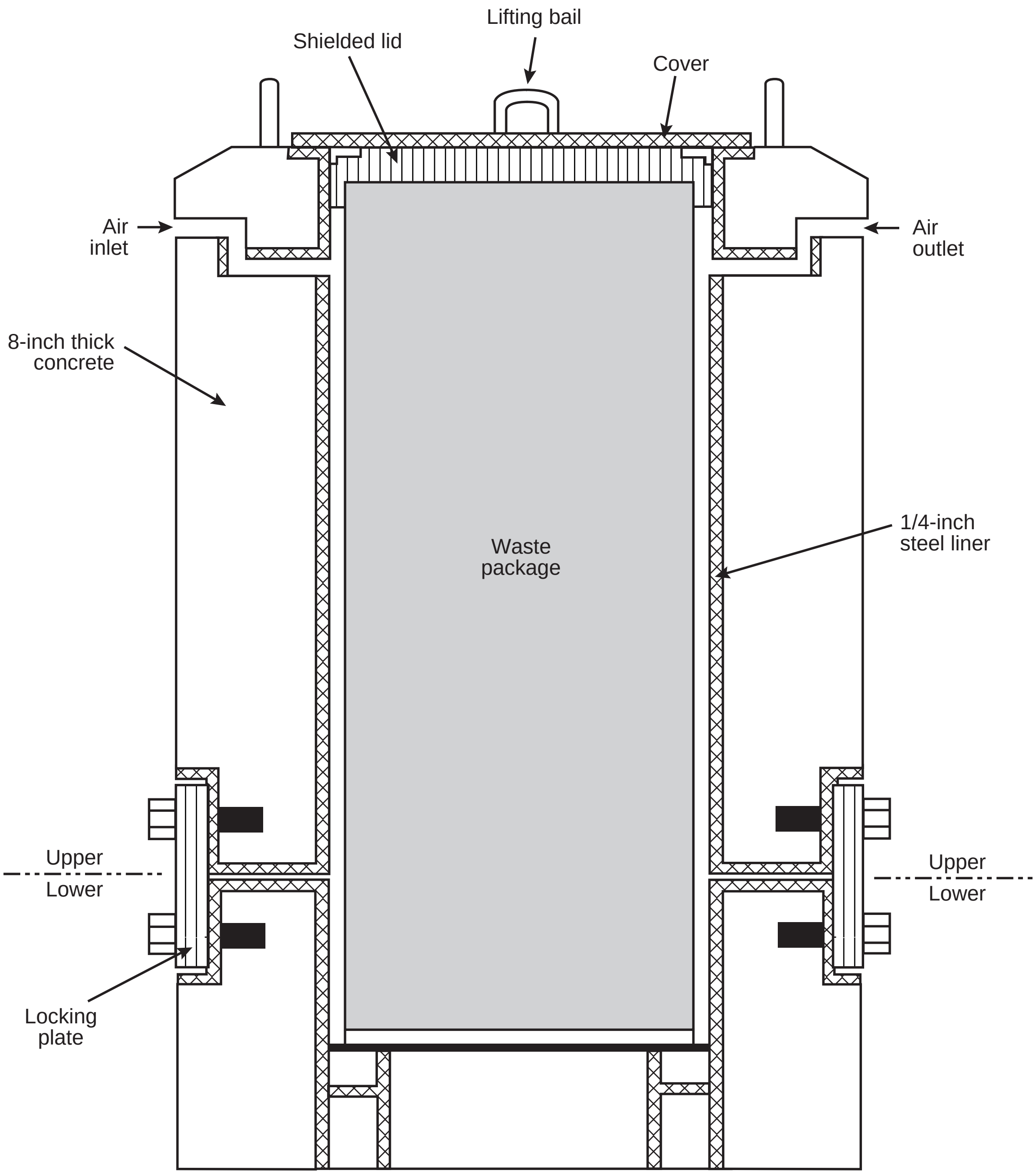
4.2.1.2.1 *Impacts to Land Use and Ownership from Retrieval*

Retrieval would cause no land-use impacts during the construction of the Waste Retrieval and Storage Area. DOE would develop a 1-square-kilometer (250-acre) area approximately 3.7 kilometers (2.3 miles) north of the North Portal Operations Area in Midway Valley (see Figure 4-5) on lands already withdrawn from public use.

4.2.1.2.2 *Impacts to Air Quality from Retrieval*

The construction of the Waste Retrieval and Storage Area and the movement of the spent nuclear fuel and high-level radioactive waste to the surface would result in air quality impacts. The analysis considered both radiological and nonradiological impacts. No radiological air quality impacts would occur during the placement of the storage containers in concrete storage modules, assuming the containers remained intact and free from leaks during handling. However, radon-222 would be released from the active ventilation of the subsurface.

Nonradiological Air Quality Impacts. DOE evaluated nonradiological air quality impacts from the retrieval of materials from the repository for (1) the construction of a Waste Retrieval and Storage Area and (2) the retrieval process. Construction and retrieval activities would result in releases of nitrogen dioxide, sulfur dioxide, carbon monoxide, and PM_{10}. Retrieval activities would not involve subsurface excavation or result in disturbance of the excavated rock pile, so no releases of cristobalite would occur.



Source: TRW (1999a, Figure I-4).

Figure 4-6. Typical concrete storage module design, vertical view.

Construction equipment would release nitrogen dioxide, sulfur dioxide, carbon monoxide, and PM_{10} from fuel consumption and PM_{10} in the form of fugitive dust. The analysis did not take credit for the standard construction dust suppression measures that DOE would implement to lower the projected PM_{10} concentrations. Table 4-52 lists calculated concentrations for criteria pollutant impacts to the public maximally exposed individual and compares these concentrations to regulatory limits. The nitrogen dioxide, sulfur dioxide, carbon monoxide, and PM_{10} concentrations at the location of the maximally exposed individual would be less than 1 percent of the applicable regulatory limits in all cases.

Table 4-52. Criteria pollutant impacts to public maximally exposed individual from retrieval (micrograms per cubic meter).[a,b]

Pollutant	Averaging time	Regulatory limit[c]	Maximum concentration[d]	Percent of regulatory limit
Nitrogen dioxide	Annual	100	0.23	0.23
Sulfur dioxide	Annual	80	0.022	0.028
	24-hour	365	0.18	0.049
	3-hour	1,300	1.4	0.11
Carbon monoxide	8-hour	10,000	2.1	0.020
	1-hour	40,000	13	0.033
Particulates (PM_{10}) ($PM_{2.5}$)	Annual	50 (15)	0.12	0.23
	24-hour	150 (65)	0.83	0.55

a. Appendix G (Section G.1) contains additional information on air quality.

b. All numbers except regulatory limits are rounded to two significant figures.

c. Regulatory limits from 40 CFR 50.4 through 50.11, and Nevada Administrative Code 445B.391 (see Table 3-5).

d. Sum of the highest concentrations at the accessible site boundary regardless of direction.

Radiological Air Quality Impacts. During retrieval activities subsurface ventilation would continue, resulting in releases of naturally occurring radon-222 and its decay products in the ventilation exhaust. Subsurface ventilation would continue for the duration of retrieval, about 14 years (3 years of initial construction, followed by 11 years of retrieval operations). Table 4-53 lists estimated annual and total doses from 14 years of retrieval activities to maximally exposed individuals and potentially affected populations from radon-222 released from subsurface facilities.

4.2.1.2.3 *Impacts to Hydrological Resources from Retrieval*

4.2.1.2.3.1 Surface Water. The retrieval activity that could have surface-water impacts would be the construction of the Waste Retrieval and Storage Area, which would disturb an area of 1 square kilometer (250 acres).

Potential for Runoff Rate Changes. The total disturbed area would include areas cleared to support construction equipment and materials, facilities, and concrete storage pads. If DOE retrieved all the waste, the storage pad area would account for about 0.43 square kilometer (107 acres) of the disturbed land (TRW 1999a, page I-14). Including the areas covered by facilities, roadways, and queuing areas, most of the land disturbance would result in surface areas that would provide almost no infiltration, so precipitation would result in runoff from the Waste Retrieval and Storage Area. As described in Section 4.1.3.2, if precipitation did not generate runoff from surrounding areas, the runoff from the storage area could travel to otherwise empty drainage channels, but would not go far. If precipitation generated runoff everywhere, there would be little difference in the quantity produced in the storage area; it just would occur earlier in the storm. In addition, a comparison of the 1 square kilometer (250 acres) of disturbed land to the estimated 12 square kilometers (3,000 acres) that make up the Midway Valley Wash drainage area (Bullard 1992, Table 5) indicates that changes in runoff and infiltration rates should have little impact on how the entire drainage area responded to precipitation events.

Table 4-53. Estimated radiation doses to maximally exposed individuals and populations from subsurface radon-222 releases during retrieval operations.[a,b]

Impact	Total	Annual
Dose to public		
Maximally exposed individual[c] (millirem)	5.5	0.43
80-kilometer[d] population[e] (person-rem)	28	2.1
Dose to noninvolved (surface) workers		
Maximally exposed noninvolved (surface) worker[f] (millirem)	0.51	0.039
Yucca Mountain noninvolved worker population (person-rem)	0.72	0.23/0.0067[g]
Nevada Test Site noninvolved worker population[h] (person-rem)	0.046	0.0035

a. Appendix G contains detailed information about the air quality analysis.
b. Construction and retrieval activities would last 13 years.
c. About 20 kilometers (12 miles) south of the repository.
d. 80 kilometers = 50 miles.
e. Approximately 28,000 individuals within 80 kilometers of the repository (see Section 3.1.8).
f. Maximally exposed noninvolved worker would be at the South Portal Operations Area.
g. First value is dose for construction workforce; second value is dose for retrieval workforce.
h. DOE workers at the Nevada Test Site [6,600 workers (DOE 1996f, page 5-14) 50 kilometers (30 miles) east-southeast near Mercury, Nevada].

Potential for Altering Natural Drainage. The proposed location for the Waste Retrieval and Storage Area does not cross or intercept well-defined drainage channels with the exception of the northwest corner, which could be close to, or possibly overlay, a short stretch of the upper Midway Valley Wash. Other portions of the facility would be in an area where simple overland flow probably would dominate runoff events. Design layouts of the proposed facility call for the construction of an interceptor trench along the upstream (north) side of the area, extending down either side; this would prevent runoff from entering the storage facility and could be an alteration to existing drainage. If flow in this short stretch of the upper Midway Valley Wash was intercepted, it would be diverted around the facility and then back to the existing course. Siting criteria for this proposed facility state that it will be outside the probable maximum flood zone (TRW 1999a, page I-8). Therefore, a probable maximum flood in this small wash will avoid the facility.

Potential for Flooding. The location for the Waste Retrieval and Storage Area would be outside the probable maximum flood zone, and the interceptor trench on the north side of the facility would accommodate the highest quantities of runoff that could reasonably be present. Therefore, there would be no reasonable potential for flooding to affect the storage facility.

4.2.1.2.3.2 Groundwater. The retrieval activities that could have impacts on groundwater would be the construction of the Waste Retrieval and Storage Area and the retrieval of the emplaced material.

Potential for Infiltration Rate Changes. Most of the disturbed land would be covered by facilities, roadways, queuing areas, and storage pads. These facilities would be relatively impermeable to water, and would cause an additional amount of runoff to drainage channels in comparison to natural conditions. This additional runoff could cause a net increase in the amount of water to infiltrate these natural channels. The additional infiltration would move into the unsaturated zone and represent potential recharge to the aquifer, but it would be a minor amount in comparison to natural infiltration.

Impacts to Groundwater Resources. The estimated annual groundwater demand during retrieval would peak at about 110,000 cubic meters (90 acre-feet) a year (TRW 1999a, page I-22; TRW 1999b, page 6-32). No adverse impacts would be likely from this demand, which would be well within historic use rates.

4.2.1.2.4 *Impacts to Biological Resources and Soils*

The retrieval activity that could affect biological resources and soils would be the construction of the Waste Retrieval and Storage Area.

4.2.1.2.4.1 Impacts to Biological Resources from Retrieval

Impacts to Vegetation. The construction of retrieval facilities would disturb vegetation in an area that is presently undisturbed. The predominant land cover types in Midway Valley are blackbrush and Mojave mixed scrub, both of which are extensively distributed regionally and in the State of Nevada.

Impacts to Wildlife. Impacts to wildlife from the retrieval contingency would be similar to those described for the construction and operation of the repository. They would consist of limited habitat loss and the deaths of individuals of some species as a result of construction activities and vehicle traffic, and would be in addition to those associated with repository construction and operation.

Impacts to Special Status Species. Impacts to special status species from the retrieval contingency would be similar, and in addition to, those described for repository construction. They would consist of loss of a small portion of locally available habitat for the desert tortoise and the deaths of individual tortoises due to construction activities and vehicle traffic.

Impacts to Wetlands. No wetlands would be affected by activities associated with retrieval.

4.2.1.2.4.2 Impacts to Soils from Retrieval. Concrete pads, facilities, and roadways at the Waste Retrieval and Storage Area would eventually cover most of the disturbed land, but a sizable portion would remain as disturbed soil.

Soil Loss. Erosion concerns during the construction of the retrieval facilities would be the same as those described for the construction of the repository facilities (see Section 4.1.4.4). The types of soils encountered would be similar to, if not the same as, those encountered during the construction at the North and South Portal Operations Areas. As during other project activities, DOE would use dust suppression measures to reduce the disturbed land's erodibility.

After the construction of the retrieval facilities, much of the area would no longer be exposed to erosion forces because structures would cover the soil. However, the uncovered disturbed areas would be more susceptible to erosion than the surrounding natural areas. This would be the case until the disturbed land had time to reach equilibrium, including the reestablishment of vegetation. Erosion, if it occurred, probably would involve small amounts of soil from small areas. The amount of soil that could move downwind or downgradient should not present unusual concerns.

Recovery. DOE would reclaim disturbed lands when they were no longer needed for retrieval operations.

4.2.1.2.5 *Impacts to Cultural Resources from Retrieval*

The activity that could affect cultural resources would be the construction of the Waste Retrieval and Storage Area. The following sections discuss archaeological and historic resources and Native American interests in relation to retrieval.

Archaeological and Historic Resources. The results of earlier archaeological fieldwork indicate that there are no National Register-eligible archaeological resources on land recommended for the Waste Retrieval and Storage Area or near the proposed rail or road construction. Therefore, construction activities associated with retrieval probably would not result in direct impacts to National Register-eligible archaeological resources. As during repository construction and operation, increased activities and numbers of workers could increase the potential for indirect impacts to archaeological sites near the construction work.

Native American Interests. A Waste Retrieval and Storage Area in Midway Valley would be 500 meters (1,600 feet) west of the Yucca Wash local use area and Alice Hill. As described in AIWS (1998, all), these areas have cultural importance to Native Americans. There could be some direct or indirect impacts to these areas, depending on the specific locations of Native American significance boundaries.

4.2.1.2.6 *Impacts to Socioeconomics from Retrieval*

Waste retrieval activities would increase the repository workforce above that for ongoing monitoring and maintenance activities. A maximum annual employment of about 1,600 workers (TRW 1999a, page I-22; TRW 1999b, page 6-32) would be required during retrieval operations and concurrent storage pad construction. Retrieval would be a short-term operation, lasting about 14 years. The repository workforce would decrease to a small maintenance staff after completion of retrieval. Employment during retrieval would be less than the peak during the operation and monitoring phase and, therefore, would be unlikely to generate meaningful changes to the region of influence labor force or economic measures. Regional impacts from retrieval operations would probably be small.

4.2.1.2.7 *Occupational and Public Health and Safety Impacts from Retrieval*

The analysis of health and safety impacts to workers divided the retrieval period into two subperiods, as follows:

- A construction subperiod during which DOE would build (1) the surface facilities necessary to handle retrieved waste packages and enclose them in concrete storage units in preparation for their placement on concrete storage pads, and (2) the concrete storage pads (see Section 4.2.1.1). No radioactive materials would be involved in the construction subperiod, so health and safety impacts would be limited to those associated with industrial hazards in the workplace. DOE expects this subperiod to last from 2 to 3 years, although construction of the concrete storage pads probably would continue as needed during most of the operations subperiod. No health and safety impacts to the public would be likely during the initial 2- to 3-year construction subperiod.

- An operations subperiod during which DOE would retrieve the waste packages and move them to the Waste Retrieval Transfer Building. Surface facility workers would unload the waste package from the transfer vehicle and place it on a concrete base. The waste package would be enclosed in a concrete storage unit that, with the waste package inside, would be placed on the concrete storage pad. This subperiod would last about 11 years. The analysis estimated the health and safety impacts from both industrial hazards and from radiological hazards for the operations subperiod for both surface and subsurface workers. Radiological impacts to the public could occur during the operations subperiod when radon-222 and its decay products would be released to the environment in the exhaust stream from the subsurface ventilation system.

The methods used to estimate health and safety impacts to workers and the public were the same as those used to estimate such impacts for the Proposed Action (see Appendix F, Section F.2.1). Additional information pertinent to health and safety impact analysis for retrieval is contained in Appendix F, Section F.4. Section F.4.3 contains detailed information on health and safety impacts which supports the impact summary tables in this section.

Construction Subperiod

As noted above, the only health and safety impacts for this subperiod would be those from industrial hazards during normal workplace activities. Table 4-54 summarizes these impacts. Projected fatality would be about 0.05 and projected lost workday cases would be about 40.

Table 4-54. Industrial hazards health and safety impacts for surface facility workers for retrieval construction subperiod.[a]

Worker group and impact category	Impact
Involved workers	
Total recordable cases	69
Lost workdays	33
Fatalities	0.03
Noninvolved workers	
Total recordable cases	14
Lost workdays	7
Fatalities	0.01
All workers (totals)	
Total recordable cases	83
Lost workdays	40
Fatalities	0.04

a. Sources: Impact rates from Table F-46 and full-time equivalent work years from Table F-45.

Operations Subperiod

Industrial Hazard Impacts to Workers. Table 4-55 lists estimated impacts from industrial hazards for both surface and subsurface workers for the operations subperiod. Because the impact estimates would not vary greatly with the thermal load scenario, the table lists only one set of impact values (for the low thermal load). Impacts would be small and about twice those for the construction subperiod.

Table 4-55. Industrial hazards health and safety impacts for retrieval operations subperiod.[a]

Worker group and impact category	Impact
Involved workers	
Total recordable cases	35
Lost workday cases	15
Fatalities	0.03
Noninvolved workers	
Total recordable cases	35
Lost workday cases	17
Fatalities	0.04
All workers (totals)	
Total recordable cases	70
Lost workday cases	32
Fatalities	0.07

a. Sources: Tables F-48 and F-49.

Radiological Health Impacts to Workers. Table 4-56 lists radiological health impacts for both surface and subsurface workers for the retrieval contingency as well as the total radiological impact. Appendix F contains additional details on the radiological exposure components for the subsurface worker exposure. Impacts would be small, with the latent cancer fatality likelihood for the maximally exposed individual being about 0.003. The calculated latent cancer fatality incidence to workers for retrieval would be 0.19.

Radiological Health Impacts to the Public. See Table 4-53 for estimated radiological impacts to the public from releases of radon-222 and its decay products through the subsurface ventilation system exhaust.

Table 4-57 lists estimated radiological health impacts to the public over the operations subperiod. The calculated radiological health impacts to members of the public from a retrieval operation would be small. The calculated likelihood of a latent cancer fatality for the maximally exposed individual would be about 2.8×10^{-6}. The calculated latent cancer fatality incidence would be about 0.014.

Table 4-56. Radiological health impacts from retrieval operations.[a,b]

Worker group and impact category	Surface facility workers	Subsurface facility workers	Total/High
Involved workers			
Maximally exposed individual dose[c]	4,400	6,950	6,950[d]
Latent cancer fatality probability	0.002	0.003	0.003[d]
Collective dose (person-rem)	75	380	455
Latent cancer fatality incidence	0.03	0.15	0.18
Noninvolved workers			
Maximally exposed individual dose	280	1,290	1,370[d]
Latent cancer fatality probability	0.0001	0.0005	0.0005[d]
Collective dose (person-rem)	6	22	28
Latent cancer fatality incidence	0.002	0.009	0.01
All workers (totals)[e]			
Collective dose (person-rem)	81	400	480
Latent cancer fatality incidence	0.03	0.16	0.19

a. Sources: Appendix F, Tables F-51 and F-52.
b. There would be no radiological health impacts to the public during the construction subperiod.
c. For 11-year period of operation (millirem).
d. Values are not totals, but the largest of the compounds.
e. Totals might differ from sums of values due to rounding.

Table 4-57. Radiological health impacts to the public for retrieval operations period.[a,b]

Worker group and impact category	Impact
Individual	
Maximally exposed individual (millirem)	5.5
Latent cancer fatality probability	2.8×10^{-6}
Population	
Collective dose (person-rem)	28
Latent cancer fatality incidence	0.014

a. Source: Table 4-49.
b. There would be no radiological health impacts to the public during the construction subperiod.

Radiological Health Impacts to the Public. The potential for exposure of members of the public to radiological materials released as a result of retrieval operations would exist only during the operations subperiod. These impacts are summarized in Table 4-57. The predicted incidence of latent cancer fatality would be about 0.1.

Summary of Impacts

Industrial Health and Safety Impacts to Workers for Retrieval. Table 4-58 summarizes the industrial health and safety impacts to workers from the retrieval construction and operations subperiods. Estimated fatalities would be low, about 0.1, with about 72 lost workday cases.

Radiological Impacts to Workers. Radiological impacts to workers from retrieval would occur primarily during the operations subperiod, as summarized in Table 4-56.

Table 4-58. Overall industrial hazards health and safety impacts for retrieval.[a]

Worker group and impact category	Impact
Involved workers	
Total recordable cases	100
Lost workday cases	48
Fatalities	0.07
Noninvolved workers	
Total recordable cases	48
Lost workday cases	24
Fatalities	0.04
All workers (totals)	
Total recordable cases	150
Lost workday cases	72
Fatalities	0.11

a. Sources: Tables 4-58 and 4-59

4.2.1.2.8 *Impacts from Accidents During Retrieval*

During retrieval operations, activities at the repository would be essentially the reverse of waste package emplacement, except operations in the Waste Handling Building would not be necessary because the waste packages would not be opened. The handling accident scenario applicable for these operations would be bounded by the transporter runaway accident scenario evaluated in Section 4.1.8. The waste packages would be retrieved remotely from the emplacement drifts, transported to the surface, and transferred to a Waste Retrieval and Storage Area (DOE 1997m, all). This area would include a Waste Retrieval Transfer Building where the waste packages would be unloaded from the transporter, transferred to a vertical concrete storage unit, and moved to a concrete storage pad.

Because the retrieval operations would be essentially the same as the emplacement operations (in reverse), the accident scenarios involving the waste package during operations would bound the retrieval operation. The bounding accident scenario during emplacement would be a transporter runaway and derailment accident in a main drift (see Appendix H, Section H.2.1.4). For above-ground storage accidents, the accident analysis for the continued storage analysis would apply. Recent analyses have found that the only credible accident with meaningful consequences would be an aircraft crash into one of the above-ground storage facilities. However, the aircraft penetration potential would not be sufficient to breach the thickness of the waste package (Davis 1998, all).

The analysis assumed that above-ground storage following retrieval would be licensed in compliance with Nuclear Regulatory Commission requirements (10 CFR Part 72). These requirements specify that storage modules must be able to withstand credible accident-initiating events.

4.2.1.2.9 *Aesthetic Impacts from Retrieval*

Retrieval activities would not be likely to produce adverse impacts on the visual quality of the landscape surrounding Yucca Mountain. Retrieval would essentially be the reverse of emplacement and would use the same types of equipment. Impacts from emplacement would be small. The only difference from the emplacement activities would be the construction of a Waste Retrieval and Storage Area in Midway Valley north of the North Portal Operations Area with a connecting transportation corridor. These activities would occur in the repository area and in Class C scenic quality lands away from the public view and, therefore, would have no impact on the existing visual character of the landscape.

4.2.1.2.10 *Noise Impacts from Retrieval*

The analysis in Section 4.1.9 shows that there would be no appreciable noise impacts for the construction, operation and monitoring, and closure phases of repository operations. Noise impacts associated with retrieval would be less than those associated with repository operations because of the reduced scope of activities and the smaller number of workers required. Worker traffic noise levels would also be less because fewer workers would commute to the site. Thus, noise impacts from retrieval operations would be small.

4.2.1.2.11 *Impacts to Utilities, Energy, Materials, and Site Services from Retrieval*

The following sections discuss utility, energy, materials, and site service impacts.

Utilities and Energy. The estimated electric power demand for retrieval would be less than 10 megawatts. This demand would be well within the capacity that would be available at the repository.

The fossil-fuel use estimated for retrieval activities would approach 25 million liters (6.6 million gallons). This consumption level is less than 0.1 percent of the annual consumption in the State of Nevada.

Materials. For the Waste Retrieval and Storage Area, DOE would build a concrete pad and retrieval support facilities. Construction would require about 540,000 cubic meters (410,000 cubic yards) of concrete and 42,000 metric tons (46,000 tons) of steel, which would not affect the regional supply capacity. About 10,000 concrete storage modules would be required. The concrete would be obtained from offsite sources or the onsite batch plant would be used. The storage modules would be relatively simple concrete vessels with a 0.64-centimeter (0.25-inch) steel liner. About 110,000 cubic meters (140,000 cubic yards) of concrete would be required to build 10,000 modules, which probably would be manufactured commercially. Material usage impacts would be small. The impacts of shipping about 10,000 concrete storage modules to the site would be comparable to those for shipping about 10,000 storage containers to the site (see Section 6.2.5).

Site Services. The onsite emergency response capability and the security, medical, and fire protection units that would support operations would be available to support retrieval, so no additional impacts would be likely.

Table 4-59 summarizes impacts to utilities, energy, and materials.

Table 4-59. Utilities, energy, and materials for retrieval.[a,b,c]

	Electric		Fossil fuel	Construction materials	
Location	Peak (MW)[d,e]	Use (1,000 MWh)[f]	Liquid fuels (million liters)[g]	Concrete (1,000 cubic meters)[h]	Steel (1,000 metric tons)[i]
Surface	1.2	82	20	540	42
Subsurface	7.7	270 - 520	2.5	0	0
Totals	**8.9**	**350 - 600**	**22.5**	**540**	**42**

a. Sources: TRW (1999a, pages I-22 to I-24); TRW (1999b, page 6-35).
b. All entries except peak electric power are cumulative totals for the entire period.
c. Approximate retrieval period would be 11 years.
d. Peak electric power is the peak demand that would occur during the period.
e. MW = megawatts.
f. MWh = megawatt-hours.
g. To convert liters to gallons, multiply by 0.26418.
h. To convert cubic meters to cubic yards, multiply by 1.3079.
i. To convert metric tons to tons, multiply by 1.1023.

4.2.1.2.12 *Impacts to Waste Management from Retrieval*

The construction of the Waste Retrieval and Storage Area would generate an estimated 12,000 cubic meters (420,000 cubic feet) of construction debris, 2,400 cubic meters (85,000 cubic feet) of sanitary and industrial solid waste, and 450 cubic meters (16,000 cubic feet) of hazardous waste (TRW 1999a, page I-22). Based on operations generation rates (TRW 1999a, page 76; TRW 1999b, page 6-34), the retrieval of the storage containers would generate an estimated 5,100 cubic meters (180,000 cubic feet) of sanitary and industrial solid waste. Throughout the construction of the retrieval facilities and retrieval operations, the workforce would generate sanitary sewage. After the spent nuclear fuel and high-level radioactive waste were placed in the concrete storage modules and on the concrete storage pads, waste generation would continue due to the presence of a workforce. Surveillance and monitoring activities would generate sanitary and industrial solid and low-level radioactive waste.

Construction debris and sanitary and industrial solid waste would be disposed of at onsite facilities or at the Nevada Test Site. Sanitary sewage would be disposed of at onsite facilities. Low-level radioactive waste would be disposed of at the Nevada Test Site or another government or commercial facility in accordance with applicable Federal and state requirements. Hazardous waste would be shipped off the site for treatment and disposal at a permitted commercial facility. The National Capacity Assessment

Report (EPA 1996b, pages 32, 33, 36, 46, 47, and 50) shows that the available capacity for hazardous waste treatment and disposal in the western states would far exceed the demand for many years to come. Therefore, hazardous waste possibly generated during retrieval activities would have a very small impact on the capacity for treatment and disposal at commercial facilities.

4.2.1.2.13 *Impacts to Environmental Justice from Retrieval*

Workers at the Yucca Mountain site would be representative of the population mix in the surrounding areas of Nevada. Hence, there would be no disproportionate impacts to minority or low-income populations in the Yucca Mountain region or to the workers during retrieval operations. In addition, because disproportionate impacts to minority or low-income populations from repository construction and operation would be unlikely, none would be likely from retrieval.

4.2.2 IMPACTS FROM RECEIPT PRIOR TO THE START OF EMPLACEMENT

Repository operations would begin after DOE received a license from the Nuclear Regulatory Commission to receive and possess spent nuclear fuel and high-level radioactive waste. For this EIS, DOE assumed that the receipt and emplacement of spent nuclear fuel and high-level radioactive waste would begin in 2010 and that emplacement would occur over a 24-year period ending in 2033 (70,000 MTHM at approximately 3,000 MTHM per year). The EIS considers the potential for the transport of spent nuclear fuel or high-level radioactive waste to the Yucca Mountain site several years before the waste was actually emplaced in the repository. DOE recognizes that regulatory changes would have to occur for the receipt of spent nuclear fuel and high-level radioactive waste before the start of emplacement, and would have to build a facility similar to that described as part of the retrieval contingency (Section 4.2.1.1) for the receipt of these materials pending their emplacement.

Such a facility would consist of a series of concrete pads in the Midway Valley Wash area (the same area described for the retrieval contingency). The facility would be capable of storing as much as 10,000 MTHM of spent nuclear fuel and high-level radioactive waste in concrete storage modules.

The types of impacts resulting from the construction and operation of a Waste Staging Facility would be similar to those from the implementation of a retrieval contingency, described in Section 4.2.1. The impacts would include land disturbance, emission of particulate and gaseous pollutants, and radiation doses from the handling of spent nuclear fuel and high-level radioactive waste. However, because the amounts of these materials would be smaller than those analyzed for the retrieval contingency, the overall impacts from the Waste Staging Facility would be smaller than those described in Section 4.2.1.

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5

Environmental Consequences of Long-Term Repository Performance

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5. ENVIRONMENTAL CONSEQUENCES OF LONG-TERM REPOSITORY PERFORMANCE

This chapter describes potential human health impacts from radioactive and nonradioactive materials released to the environment during the first 10,000 years after closure of a repository at Yucca Mountain. The impact calculations assumed that the current population in the Yucca Mountain region would remain constant, as discussed in Section 5.2.4.1. The chapter also describes the peak radiation dose during the first 1 million years after closure. Closure of a repository would include the following events, which are analyzed in Chapter 4:

- Sealing of the underground emplacement drifts
- Backfilling and sealing of other underground openings
- Removal of the surface facilities
- Construction of surface monuments to discourage human intrusion
- Creation of institutional controls, including land records and monuments, to identify the location of the repository

In addition, this chapter discusses estimates of potential biological impacts from radiological and chemical groundwater contamination; potential environmental impacts of such contamination and potential biological impacts from the long-term production of heat by decay of the radioactive materials that would be disposed of in a repository at Yucca Mountain; and potential environmental justice impacts. These would be the only other potential impacts likely from the long-term postclosure system. There would be no repository activities; no changes in land use, employment of workers, water use or water quality other than from the transport of radionuclides; and no use of energy or other resources, or generation or handling of waste after closure of a repository. Therefore, analysis of impacts to land use, noise, socioeconomics, cultural resources, surface-water resources, aesthetics, utilities, or services after closure is not required. As part of closure activities, the U.S. Department of Energy (DOE) would return the land to its original contour and erect appropriate monuments marking the repository, which would result in some minor impacts on aesthetics depending on the exact design of the monuments (currently undetermined). Impacts from closure are discussed in Chapter 4. After the completion of closure, risk of sabotage or intruder access would be highly unlikely. Chapter 4 (Section 4.1.8.3) discusses the potential for sabotage prior to closure. Section 5.7.1 discusses potential impacts from an intruder after closure.

DOE performed this analysis of potential impacts after repository closure for three thermal load scenarios. The selected thermal load would be attained by varying the spacing between emplacement drifts and between waste packages in the drifts. The high thermal load of 85 metric tons of heavy metal (MTHM) per acre would emplace radioactive materials over the smallest repository area. The intermediate thermal load of 60 MTHM per acre would emplace radioactive materials over a larger repository area. The low thermal load of 25 MTHM per acre would emplace the radioactive materials over the largest repository area.

This assessment considered the following three transport pathways (means by which contamination could reach the biosphere) from spent nuclear fuel and high-level radioactive waste to reach human populations and cause health consequences:

- Groundwater
- Surface water
- Atmosphere

The principal pathway would result from rainwater migrating down through the unsaturated zone into the repository, dissolving some of the material in the repository, and carrying contaminants from the dissolved material downward through the unsaturated zone and through the groundwater system to locations where human exposure could occur. A surface-water pathway would arise only from groundwater that reached the surface at a discharge location, so the assessment considered surface-water consequences along with groundwater consequences. An airborne pathway could result from radioactive carbon-14 from spent nuclear fuel that migrated to the surface in the form of carbon dioxide gas that mixed with the atmosphere. Spent nuclear fuel contains other gases such as various xenon isotopes and krypton-85, but their very short half-lives would preclude their presence by the time of closure. Radon generated by uranium decay would not be a problem in the Yucca Mountain vicinity because closed residential structures would be unlikely on Yucca Mountain (see Section 5.2.4.1).

The assessment estimated potential human health impacts from the groundwater transport pathway at four locations in the Yucca Mountain groundwater hydrology region of influence: water wells 5, 20, and 30 kilometers (3, 12, and 19 miles) from the repository and the nearest surface-water discharge point [about 80 kilometers (50 miles) from the repository]. These consequences are in terms of radiological dose and the probability of a resulting latent cancer fatality. A latent cancer fatality is a death from cancer resulting from, and occurring sometime after, exposure to ionizing radiation or other carcinogens.

DOE assessed the processes by which waste could be released from a repository at Yucca Mountain and transported to the environment. The analysis used computer programs developed to assess the release and movement of radionuclides and hazardous materials in the environment. Some of the programs analyzed the behavior of engineered components such as the waste package, while others analyzed natural processes such as the movement of groundwater. The programs are based on the best available geologic, topographic, and hydrologic data and current knowledge of the behavior of the materials proposed for the system. The assessment used data from the Yucca Mountain site characterization activities, material tests, and expert opinions as input parameters to estimate human health consequences. Many parameters used in the analysis cannot be exactly measured or known; only a range of values can be known. The analysis accounted for this type of uncertainty; thus, the results are ranges of health consequences.

The long-term performance assessment considered human health impacts during the first 10,000 years after repository closure and the peak dose during the first 1 million years after repository closure. Estimates of potential human health impacts from the undisturbed evolution of a repository included the effects of such natural processes as corrosion of waste packages, dissolution of waste forms, and changing climate. In addition, the assessment examined the effects of such disturbances as exploratory drilling, seismicity, or volcanic events.

DOE has developed the information about the potential environmental impacts that could result from either the Proposed Action or the No-Action Alternative to inform the Secretary of Energy's determination whether to recommend Yucca Mountain as the site of this Nation's first monitored geologic repository for spent nuclear fuel and high-level radioactive waste.

5.1 Inventory for Performance Assessment Calculations

DOE proposes to dispose of between 10,000 and 11,000 waste packages containing as much as 70,000 MTHM of spent nuclear fuel and high-level radioactive waste in a repository at Yucca Mountain. There are several different types of disposal containers for commercial spent nuclear fuel and different container designs for DOE spent nuclear fuel and high-level radioactive waste. The exact number of waste packages, therefore, would depend on various options in the proposed design. This long-term consequence assessment identified the inventory by the source categories of waste material to be disposed of (commercial spent nuclear fuel, DOE spent nuclear fuel, weapons-usable plutonium, and high-level radioactive waste). For purposes of modeling, the inventory for each of the categories was averaged into an appropriate number of packages, each with identical contents. The average of the modeled inventories resulted in a total of nearly 12,000 idealized packages (slightly higher than the actual number of waste packages that would be emplaced) in three basic types, as described in the sections below. Figure 5-1 shows the averaging process.

INVENTORY OF RADIOACTIVE MATERIALS

There are more than 200 radionuclides in the waste inventory (see Appendix A). To perform impact calculations efficiently, this evaluation used a reduced number of radionuclides (see Appendix I). Those radionuclides eliminated from further consideration had at least one of the following characteristics:

- Radionuclides with short half-lives (generally less than several hundred years) that are not decay products of long-lived radionuclides (for example, krypton-85, xenon isotopes, and cesium-137)
- Radionuclides with high chemical sorption or low solubility that will decay before arriving at a human exposure point (for example, americium-241 and nickel-59)
- Radionuclides with low biosphere dose conversion factors that convert concentration to dose [relatively high radionuclide concentrations in groundwater would be required to produce a given dose compared to other radionuclides (for example, zirconium-93)]

TERMS RELATED TO RADIOACTIVE MATERIALS

A **curie** is a unit of radioactivity equal to the amount of a radioactive isotope that decays at a rate of 37 trillion disintegrations per second.

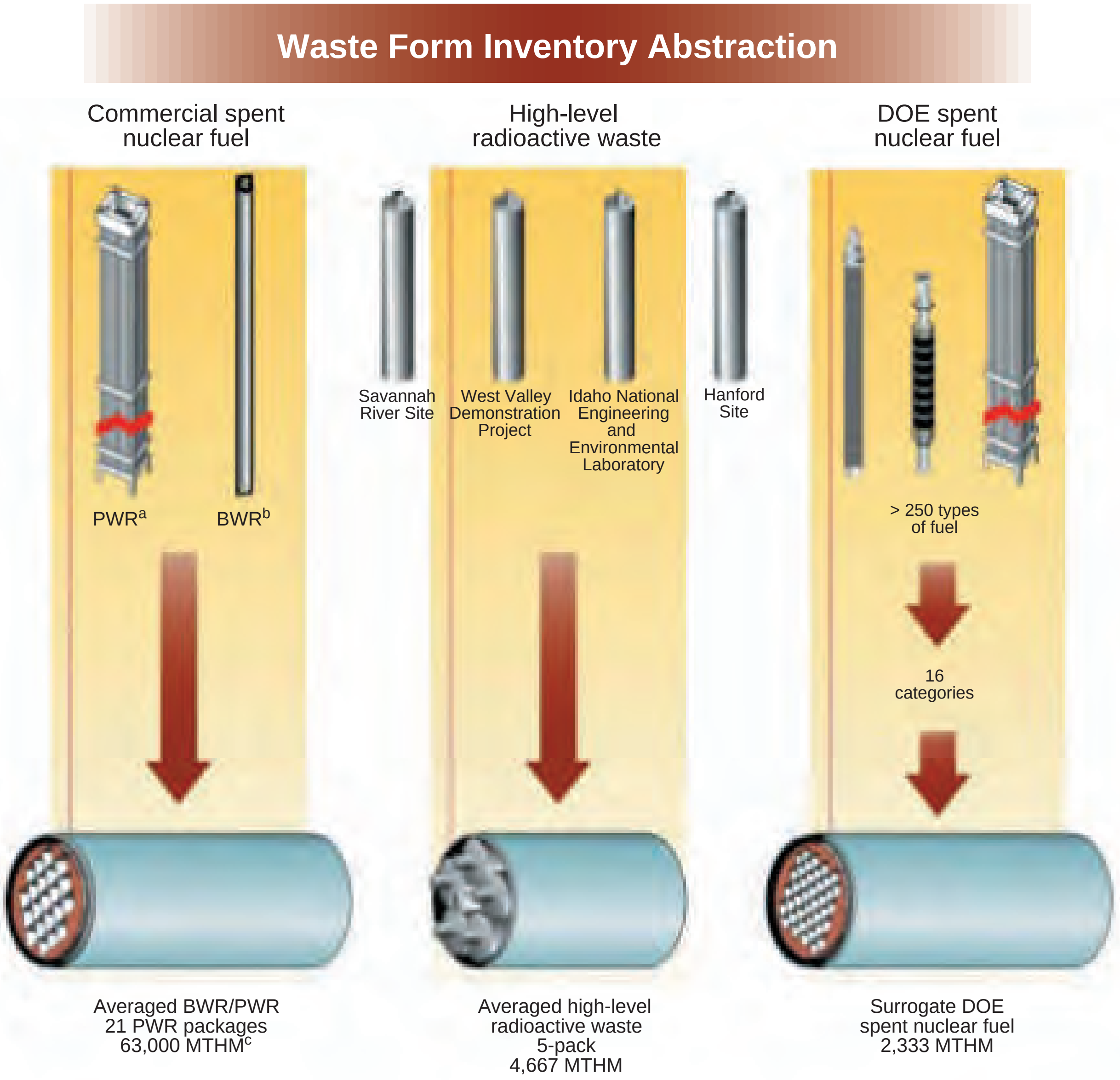
A **half-life** is the period during which radioactive decay causes half a given amount of a radionuclide to change to some other radionuclide or stable element.

During **decay**, the atom loses particles such as neutrons, electrons, or protons, and transforms to a different atomic mass or, in some cases, to a different atomic number and, ultimately, to a different element possessing different properties.

The large amounts of uranium in the repository would produce large quantities of radon as a decay product. The longest-lived radon isotope is radon-222, with a half-life of 4 days (CRC 1997, page 4-24); however, the large amount of uranium would result in a steady level of radon over time. The only potential transport and exposure pathway for radon would be the atmosphere because radon would not travel far enough in water to reach a receptor before decaying. The analysis did not consider radon for a gas pathway because it is a health problem only when trapped in closed structures (that is, it decays rapidly to nongaseous elements), and there should be no closed structures at the top of the mountain (see Section 5.2.4.1). Based on these considerations and previous performance analysis results at Yucca Mountain (TRW 1995b, all), DOE selected nine dominant radionuclides for analysis. Appendix I and previous performance analysis results at Yucca Mountain (Barnard et al. 1992, all; TRW 1995b, all) and the Viability Assessment (DOE 1998a, Volume 3, pages 3-95 to 3-99) contain more details on the inventory selection for the long-term performance models.

Table 5-1 lists the averaged radionuclide inventory in a waste package at the time of emplacement for the nine selected radionuclides for the following three sources:

- Commercial spent nuclear fuel
- DOE spent nuclear fuel
- High-level radioactive waste (including weapons-usable plutonium)



a. PWR = pressurized-water reactor.
b. BWR = boiling-water reactor.
c. MTHM = metric tons of heavy metal.

Note: For purposes of illustration, waste packages are shown without lids.

Source: Modified from DOE (1998a, Volume 3, page 3-98).

Figure 5-1. Inventory averaging (abstraction) process.

Table 5-1. Average radionuclide inventory (curies unless otherwise noted) per waste package for performance assessment calculations.[a]

Isotope	Half-life (years)	Commercial SNF[b] (7,760 idealized packages)	DOE SNF (2,546 idealized packages)	HLW[c] (1,663 idealized packages)
Carbon-14	5.7×10^3	12	0.31	0
Iodine-129	1.6×10^7	0.29	0.0057	0.000042
Neptunium-237	2.1×10^6	11	0.15	0.74
Protactinium-231	3.3×10^4	5.1[d]	0.66[d]	0.036[d]
Plutonium-239	2.4×10^4	3,100	160	24
Plutonium-242	3.9×10^5	17	0.11	0.02
Selenium-79	6.5×10^4	3.7	0.089	0.29
Technetium-99	2.1×10^5	120	2.6	30
Uranium-234	2.5×10^5	21	0.54	0.9

a. Source: DOE (1998a, Volume 3, Table 3-14, page 3-96).
b. SNF = spent nuclear fuel.
c. HLW = high-level radioactive waste.
d. Grams per waste package.

Some of the values in Table 5-1 are adjusted for ingrowth of radionuclides as products of decay of other radionuclides and are not an exact match with the inventory data in Appendix A. For example, americium-241, with a half-life of about 432 years, decays to neptunium-237. Because the waste packages are designed to last much longer than this (thousands of years), most of the americium-241 would decay to neptunium-237 before a waste package could fail. The analysis increased the inventory of neptunium-237 in the commercial spent nuclear fuel waste packages by 58 percent to account for this radioactive decay. A total of 11,969 idealized packages was used in the analysis.

DOE used a screening analysis to identify those chemically toxic materials that would require more detailed analysis (see Appendix I). The analysis started with a proposed inventory of all materials in the repository at the time of closure. This inventory included construction materials, waste package materials, and the contents of the waste packages. For each material, the screening process considered total inventory, solubility of the material in water, and chemical toxicity. The analysis found that earthen and concrete materials had no potential toxicity. The only known organic materials would be additives to the concrete (binders and conditioners) that either are inherently nontoxic or could break down completely in response to exposure to high radiation fields (TRW 1999b, pages 4-56 to 4-65) for 100 years or more before closure.

The first step in the screening process was to eliminate all nontoxic materials. In the second step, more materials were eliminated because their total quantity would be very low and dilution in the repository environment would reduce their concentration to below toxic levels before they entered the saturated groundwater system. Other materials would have low concentrations because of their very low solubilities. Low quantities or low concentrations accounted for the elimination of most hazardous materials in the spent nuclear fuel and high-level radioactive waste. The final step in the screening process was to eliminate materials that would not be transported to a surface drainage point or well in sufficient concentrations to pose a human health hazard.

Based on the screening analysis, DOE selected chromium, molybdenum, and uranium for detailed assessments of their potential human health impacts. Sections 5.6.1 through 5.6.3 describe these impacts. Chromium and molybdenum were retained for further analysis because they would be present in large quantities and remain in very soluble toxic forms. Uranium was retained because it would be present in very large quantities, is quite soluble, and is toxic as a heavy metal. The nickel-chromium alloy (Alloy-22) portion of the disposal container nominally would be 21.25 percent chromium (ASTM 1994, all). In addition, there would be approximately 4.3 kilograms (9.5 pounds) of chromium in a pressurized-water reactor fuel assembly and 1.9 kilograms (4.2 pounds) in a boiling-water reactor fuel assembly (see Appendix A). About 70 percent of the chromium in the repository would be in Alloy-22 disposal containers; the remainder would be in the fuel assemblies. All of the molybdenum would be in the Alloy-22, which nominally is about 13.5 percent molybdenum. DOE estimated the uranium inventory by using the repository capacity (in MTHM) to consider chemical toxicity. This is a very conservative approach because some of the heavy metal in spent nuclear fuel is plutonium and thorium, and the high-level radioactive waste has very small quantities of uranium because it is the byproduct of uranium and plutonium separations. The MTHM basis of high-level radioactive waste is the heavy metal content of the fuel from which the material was derived during the separation process. Plutonium was not included in the assessment of chemical toxicity because (in contrast to uranium) its radiotoxicity exceeds its chemical toxicity. Table 5-2 lists the total potential inventory of chromium, molybdenum, and uranium in the repository.

Table 5-2. Total inventory of chemically toxic materials in the repository.[a]

Element	Metric tons[b]
Chromium	14,000
Molybdenum	6,200
Uranium	70,000

a. Source: Appendix I, Table I-10.

b. To convert metric tons to tons, multiply by 1.1023; numbers are rounded to two significant figures.

5.2 System Overview

Radioactive materials in the repository would be placed about 300 meters (980 feet) beneath the surface (DOE 1998a, Volume 3, page 3-3). In physical form, the emplaced materials would be almost entirely in the form of solids with a very small fraction of the total radioactive inventory in the form of trapped gases (see Section 5.5). With the exception of a small amount of radioactive gas in the fuel rods, the primary means for the radioactive and chemically toxic materials to contact the biosphere would be along groundwater pathways. The materials could pose a threat to humans if the following sequence of events occurred:

- The waste packages and their contents were exposed to water
- Radionuclides or chemically toxic materials in the package materials or wastes became dissolved or mobilized in the water
- The radionuclides or chemically toxic materials were transported in water to an aquifer, and the water carrying radionuclides or chemically toxic materials was withdrawn from the aquifer through a well or at a surface-water discharge point and used directly by humans for drinking or in the human food chain (such as through irrigation or watering livestock)

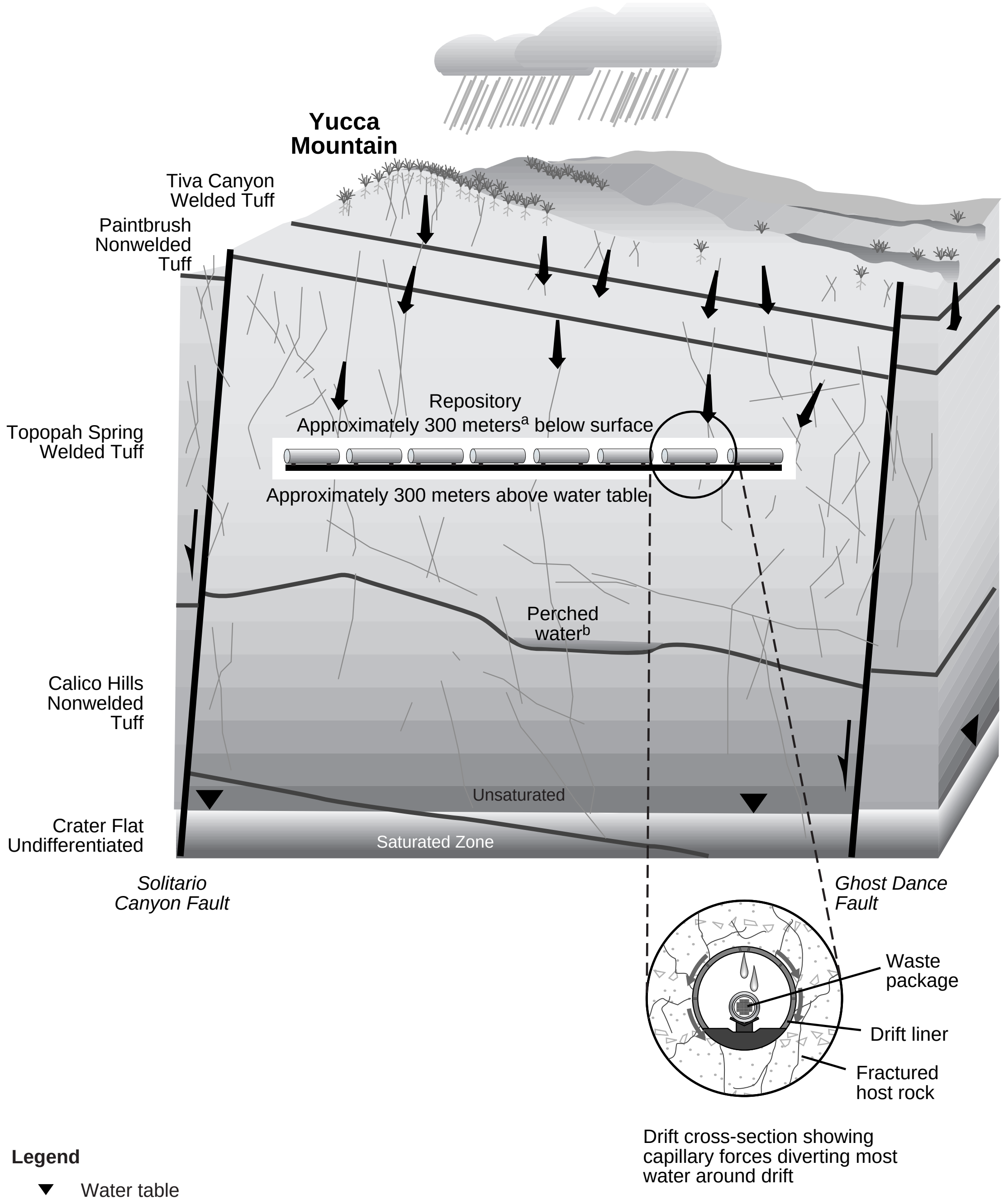
WASTE PACKAGE

A *waste package* consists of the waste form and any containers (disposal container, barriers, and other canisters), spacing structure or baskets, shielding integral to the container, packing in the container, and other absorbent materials immediately surrounding an individual disposal container, placed inside the container, or attached to its outer surface. The waste package begins its existence when the outer lid welds are complete and accepted and the welded unit is ready for emplacement in the repository.

Thus, the access to and flow of contaminated water are the most important considerations in determining potential health hazards.

5.2.1 COMPONENTS OF THE NATURAL SYSTEM

Figure 5-2 is a simplified schematic of a repository at Yucca Mountain. It shows the principal features of the natural system that could affect the long-term performance of the repository. Yucca Mountain is in a



a. To convert a meters to feet, multiply by 3.2808.

b. Perched water is a localized pocket of groundwater.

Source: Modified from DOE (1998a, Volume 3, page 3-3).

Figure 5-2. Components of the natural system.

semiarid desert environment where the average annual precipitation is between 100 and 250 millimeters (4 and 10 inches), varying by specific location over the immediate region (DOE 1998a, Volume 1, page 2-29). The water table is an average of 600 meters (2,000 feet) below the surface of the mountain. The proposed repository would be in unsaturated rock approximately midway between the desert environment and the water table.

The water table is the boundary between the unsaturated zone above and the saturated zone below. In the subsurface region above the water table, the rock contains water but the water does not fill all the open spaces in the rock. Because the open spaces are only partially filled, this region is called *the unsaturated zone.* Water in the unsaturated zone tends to move generally downward in response to capillary action and gravity. In contrast, water fills all the open spaces in the rock below the water table, so this region is called the *saturated zone.* Water in the saturated zone tends to flow laterally from higher to lower pressures. Both zones contain several different rock types, as shown in Figure 5-2. The layers of major rock types in the unsaturated zone at the Yucca Mountain site are the Tiva Canyon welded, Paintbrush nonwelded, Topopah Spring welded, Calico Hills nonwelded, and Crater Flat undifferentiated tuffs. Figure 5-2 shows two of the faults at the proposed site—the Ghost Dance fault that occurs within the repository block and the Solitario Canyon Fault that forms the western boundary of the repository block. Faults are slip zones where rock units have become displaced either vertically, laterally, or diagonally, resulting in the rock layers being discontinuous. These slip zones tend to form a thin plane in which there is more open space that acts as a channel for water. Some faults tend to fill with broken rock formed as they slip, so they take on a very different flow property from that of the surrounding rock. The proposed repository would be in the Topopah Spring welded tuff in the unsaturated zone, about 300 meters (980 feet) below the surface and approximately 300 meters above the water table (DOE 1998a, Volume 3, page 3-3).

HYDROGEOLOGIC TERMS

Saturated zone: The area below the water table where all spaces (fractures and rock pores) are completely filled with water.

Unsaturated zone: The area between the surface and the water table where only some of the spaces (fractures and rock pores) are filled with water.

Matrix: The solid, but porous, portion of the rock.

When it rains in the Yucca Mountain vicinity, most of the water runs off and a very limited amount infiltrates the rock on the surface of the mountain. Some of the water that remains on the surface or infiltrates the rock evaporates back into the atmosphere (directly or through plant uptake and evapotranspiration). The very small amount of water that infiltrates the rock and does not evaporate percolates down through the mountain to the saturated zone. Water that flowed through the unsaturated zone into the proposed repository could dissolve some of the waste material, if there was a breach in the package containment, and could carry it through the groundwater system to the accessible environment, where exposure to humans could occur.

5.2.2 COMPONENTS OF THE WASTE PACKAGE

Under the Proposed Action, spent nuclear fuel and high-level radioactive waste would be placed in cylindrical metal *disposal containers*. After being sealed, a disposal container would be called a *waste package*. Each waste package would have a 10-centimeter (4-inch)-thick carbon-steel outer shell, and an inner shell of a 2-centimeter (0.8-inch)-thick nickel-chromium alloy (called *Alloy-22*). The Alloy-22 would corrode 100 to 1,000 times slower than the carbon steel. Commercial spent nuclear fuel, which would comprise 98 percent of the radioactivity in the repository, would be additionally protected by a thin cladding of a zirconium alloy. Approximately 1 percent (by volume) of the commercial spent nuclear fuel would have cladding made of stainless steel rather than zirconium alloy. Commercial spent nuclear fuel would account for 75 percent of the total number of waste packages. Zirconium alloy has a corrosion rate much lower than that of Alloy-22. Water would not reach the fuel until there were openings in the carbon steel, the Alloy-22, and the cladding material. About 3.3 percent of the proposed repository inventory would be DOE spent nuclear fuel that would have a variety of cladding. Cladding was not considered to be a transport barrier for DOE spent nuclear fuel. The high-level radioactive waste form would not have cladding; this material would be in stainless-steel canisters, which for conservatism were not given any value as barriers.

5.2.3 VISUALIZATION OF THE REPOSITORY SYSTEM FOR ANALYSIS OF LONG-TERM PERFORMANCE

In general, the repository system was modeled as a series of processes linked together, one after the other, spatially from top to bottom in the mountain. From a computer modeling standpoint, it is important to break the system into smaller portions that relate to the way information is collected. In reality, an operating repository system would be completely interconnected, and virtually no process would be independent of other processes. However, the complexity of such a system demands some idealization of the system for an analysis to be performed.

In the following presentation, the processes are discussed in relation to the key attributes of the repository safety strategy. The four key attributes are:

- Limited water contacting waste package
- Long waste package lifetime
- Slow release of radionuclides from the waste
- Reduction in the concentration of radionuclides and chemically toxic material during transport from the waste to a point of human exposure

Along with the processes, this chapter discusses the models used to analyze them. The analysis included models associated with abnormal or disruptive events like volcanism, seismicity, and human intrusion. These events, if they occurred, would affect the undisturbed repository. The *Viability Assessment of a Repository at Yucca Mountain* contains details of the model construction and the input and output parameters (DOE 1998a, Volume 3, pages 3-1 to 3-162), and Appendix I, Section I-4 discusses the changes made for this EIS. The following sections summarize the expected behavior of the major components.

5.2.3.1 Limited Water Contacting Waste Package

Changes in climate over time provide a range of conditions that determine how much water could fall onto and infiltrate the ground surface. Based on current scientific understanding, the current climate is estimated to be the driest that the Yucca Mountain vicinity will ever experience. All future climates were assumed to be similar to or wetter than current conditions. The *climate* model provides a forecast of future climates based on information about past patterns of climates (DOE 1998a, Volume 3, pages 3-8 and 3-9). The model represents future climate shifts as a series of instant changes between the current dry climate, a long-term average climate with about twice the precipitation of the dry climate, and a very wet climate with about three times the precipitation of the dry climate. The water from precipitation that is not lost back to the atmosphere by evaporation or transpiration enters the unsaturated zone flow system. Water infiltration is affected by a number of factors related to climate, such as an increase or decrease in vegetation on the ground surface, total precipitation, air temperature, and runoff. The *infiltration* model uses data collected from studies of surface infiltration in the Yucca Mountain region (DOE 1998a, Volume 1, page 2-41). It treats infiltration as variable in the region, with more occurring along the crest of Yucca Mountain than along its base. The results of the climate model affect assumed infiltration rates.

Water generally moves downward in the rock matrix and in rock fractures. The rock mass at Yucca Mountain is composed of volcanic rock that is fractured to varying degrees as a result of contraction during cooling of the original, nearly molten rock and as a result of extensive faulting in the area. Water flowing in the fractures moves much more rapidly than the water moving through the matrix. In some locations, some of the water collects into locally saturated zones in the rock or is diverted laterally by differences in the rock properties. The overall unsaturated flow system is very heterogeneous, and the locations of flow paths, velocities, and volumes of groundwater flowing along these paths are likely to change many times over the life of the repository system. The *unsaturated zone flow* model assumes constant flow over a specific time period (taken from the infiltration model) and generates three-dimensional flow fields for three different infiltration boundary conditions, the three different climates described above, and several values of rock properties (DOE 1998a, Volume 3, pages 3-2 to 3-23). Because this model can assess the movement of materials leached from failed waste packages, the analysis used it to analyze the period after which most of the heat effects would have subsided and assumed there would be no further influence of heat on unsaturated zone flow fields.

The heat generated by the decay of nuclear materials in the repository would cause the temperature of the surrounding rock to rise from the time of emplacement until approximately 15 to 25 years after repository closure (DOE 1998a, Volume 3, page 3-37). The water and gas in the heated rock would be driven away from the proposed repository during this period, referred to in this document as the *thermal pulse*. This would occur under all thermal load scenarios discussed in this EIS. The thermal output of the materials would decrease with time; eventually, the rock would return to its original temperature, and the water and gas would flow back toward the proposed repository. The *mountain-scale thermal hydrology* model uses two-dimensional cross-sections taken from the three-dimensional, site-scale unsaturated zone flow model (see Appendix I, Section I.4). It provides the air mass-fraction and gas-flux near the repository drift to the near-field geochemical process models.

Some conceptual uncertainty exists regarding the influence of heat on water movement in the unsaturated zone. Some analysts (DOE 1998o, all) have suggested there could be a large thermal influence on the movement and chemistry of water after the repository cooled. Specifically, differences in temperature could focus water flow back toward the repository, resulting in much higher seepage rates than this analysis considered in the period after the thermal pulse. Therefore, this view would yield different results than the current drift-seepage models. Such a focus could have a large effect on the movement of radionuclides in the unsaturated zone. DOE is planning to conduct studies to measure the influence of temperature differences on water movement (DOE 1998a, Volume 4, page 3-17).

In addition, there is uncertainty concerning the influence of high temperatures on rock properties. The high temperatures might cause mineral alterations and produce long-term alteration in unsaturated zone water chemistry. However, some sensitivity studies on alternative chemistry scenarios suggest this would not have a large effect on the results (DOE 1998a, Volume 3, pages 4-85 to 4-86). Specifically, the effect of loss of sorptive capacity in the unsaturated zone was examined and would not have a large effect on biosphere dose. DOE is planning to conduct studies of the influence of heat on the chemical environment (DOE 1998a, Volume 4, page 3-22).

After the water returned to the repository walls, it would drip into the repository but only in a relatively few places. The number of seeps that could occur and the amount of water that would be available to drip would be restricted by the low rate at which water flows through Yucca Mountain, which is in a semiarid area. Drips could occur only if the hydrologic properties of the rock mass caused the water to concentrate enough to feed a seep. Over time, the number and locations of seeps would increase or decrease, corresponding to increased or decreased infiltration based on changing climate conditions. The *seepage flow* model calculates the amount of seepage that could occur based on input from the unsaturated zone flow model (DOE 1998a, Volume 3, pages 3-11 and 3-12). The basic conceptual model for seepage suggests that openings in unsaturated rock act as capillary barriers and divert water around them. For seepage to occur in the conceptual model, the rock pores at the drift wall would have to be locally saturated. Drift walls could become locally saturated by either disturbance to the flow field caused by the drift opening or variability in the permeability field that creates channeled flow and local ponding. Of the two reasons, the variability effect is more important. Drift-scale flow calculations made with uniform hydrologic properties suggest that seepage would not occur at expected percolation fluxes. However, calculations that include permeability variations do estimate seepage, with the amount depending on the hydrologic properties and the incoming percolation flux. Ongoing studies suggest that water travels through the unsaturated zone at highly variable rates from less than 100 years to thousands of years (see Chapter 3, Section 3.1.4.2.2).

5.2.3.2 Long Waste Package Lifetime

Because a repository at Yucca Mountain would be located above the water table in the unsaturated zone, the most important process controlling waste package lifetime is whether water would drip from the seeps on the package.

The location of the seeps would depend to some extent on the natural conditions of the rock but also on the alterations caused by construction of a repository. Alterations such as increased fracturing might be caused by mechanical processes related to drilling the drifts or by thermal heating and expansion of the drift wall. The alterations in the seepage could also be caused by chemical alterations occurring as the engineered materials dissolved in water and reprecipitated in the surrounding rock, closing the pores and fractures. The chemistry in the drift would change continually because of the complex interactions among the incoming water, circulating gas, and materials in the drift (for example, concrete from the liner or metals in the waste package). The changes in chemistry would be strongly influenced by heat during the thermal pulse.

The *drift-scale thermal hydrology* model calculates waste package surface temperature and relative humidity in the drift for different waste package types in several regions of the repository and provides these values to the waste package degradation model (DOE 1998a, Volume 3, pages 3-29 to 3-33). This model also calculates average waste form temperature and liquid saturation in the invert in the regions of the repository and provides these values to the waste form degradation and unsaturated zone transport models. Finally, it calculates average drift wall temperature, relative humidity, and liquid saturation for the invert, and provides these values to the near-field geochemistry models.

In the reference design, the radioactive waste placed in the proposed repository would be enclosed in a two-layer waste package. The layers would be of two different materials that would fail at different rates and from different mechanisms as they were exposed to various repository conditions. As described in Section 5.2.2, the outer layer would be carbon steel and the inner layer a high-nickel alloy metal. Where water dripped on the waste packages, the packages would corrode over time. The breaches probably would occur as deep, narrow pits or as broader areas called *patches*. The changing thermal, hydrologic, and chemical conditions in the repository would influence the corrosion rate of the waste packages.

The *near-field geochemistry* model calculates the interaction of water flowing through the drift with the material in the drift (DOE 1998a, Volume 3, pages 3-39 to 3-73). Equilibrium calculations generate a set of chemical composition parameters that the *waste-package degradation* model uses. In addition, the waste-package degradation model uses information from the drift-scale thermal hydrology model and the near-field geochemistry model to determine a corrosion rate that would vary at different areas on a given waste package (patch to patch and pit to pit) and from waste package to waste package. The surface of a conceptual waste package would have 400 separate areas called patches (DOE 1998a, Volume 3, pages 3-73 to 3-90). This model calculates the cumulative number of package failures as a function of time (a *failure* would be the first pit penetration or first patch penetration), the average size of failed patches over time, and the average pit area per package over time. The final calculations include assumed failures (to be conservative) that could be caused by manufacturing defects or mishandling.

The analysis assessed the possible effect of chemically toxic materials. The analysis did not identify any organic materials as being present in enough quantities to be toxic. A screening process eliminated most other materials because they were not of concern for human health effects (see Appendix I, Section I.3.2). Some of the components of the high-nickel alloy (such as chromium and molybdenum) were of sufficient quantity and possible toxicity to warrant an assessment of their transport into the biosphere. The rate of release of these materials was taken directly from the waste-package degradation modeling. These contaminants were modeled in the same way as the radionuclides in the models discussed below.

5.2.3.3 Slow Release of Radionuclides from Waste Package

If seepage water eventually entered a waste package through holes caused by corrosion, it could contact the radioactive material inside. Most of the material would be from commercial reactors, but some would be defense high-level radioactive waste, immobilized waste form incorporating formerly weapons-usable plutonium, and DOE spent nuclear fuel. Because most of the material would be commercial spent nuclear fuel, the long-term performance of the repository system would depend primarily on that material. The next two paragraphs discuss important considerations about commercial spent nuclear fuel.

The water would first contact the very thin layer [about 570 micrometers (0.022 inch) thick] of a zirconium alloy that would cover the surface of most of the fuel elements. This layer, called cladding, would have to be breached by mechanical or chemical processes before the radioactive fuel pellets could be exposed. *Cladding degradation* by chemical or physical processes such as corrosion or creep rupture is specified directly as a fraction of failed cladding over time (DOE 1998a, Volume 3, pages 3-100 to 3-103). This model includes other cladding degradation modes such as mechanical failure. It provides the cladding failure rate to the waste-form degradation and engineered-barrier system transport models.

After the cladding failed, individual fuel elements would start to degrade, making the radionuclides available for transport. The degradation process could involve several stages because the waste forms would sometimes be altered to different chemical phases before they reached a phase that would allow the nuclides to be released from the waste. Also, different radionuclides have different chemical properties, so the reaction rates of the individual nuclides with water would vary greatly. In general, however, modeling results show that once the waste form began to alter, it would take about 1,000 years for the commercial spent nuclear fuel to degrade completely in the case of the reference design repository. The result would be that certain nuclides would be released much earlier than others. The results of the long-term performance analysis show this effect, as different nuclides become the key contributors to dose rate over different time periods.

The *waste-form degradation* model uses degradation-rate formulas developed from experiments for the three different waste forms discussed in Section 5.1. This model provides values for the mass of the waste form exposed and the volume of water in contact with this waste form over time. These outputs are used to calculate the radionuclide release rate to the water inside the waste package. The rate at which a particular radionuclide would be released from the waste form would depend on the solubility of the radionuclide in the seepage water. Low-solubility radionuclides would tend to reach their solubility limit quickly, so the waste form could release them at the rate at which the water carried them away. High-solubility radionuclides would be released at a rate that would depend on the rate at which the water reacted with the waste form. The Viability Assessment (DOE 1998a, Volume 3, page 3-99) contains a more detailed discussion of the waste degradation model. The solubilities and assumed mechanisms in the waste degradation models are based on the best available information, but there are differing opinions, particularly about mechanisms of release and solubility of specific radionuclides such as neptunium-237. These differing opinions deal with:

- The appropriate solubility for neptunium (DOE 1998o, all)
- Mobilization of radionuclides from the spent nuclear fuel through a vapor-phase release mechanism (DOE 1998o, page 7) (the current model assumes only a liquid-phase release mechanism)

The long-term performance modeling results show that neptunium-237 would be an important contributor to long-term health effects.

Either of these variations could result in a different rate of release than the current analysis estimated. Higher neptunium solubility could result in higher release rates because solubility determines the release rate of neptunium in the current model. However, the long package life in the current system (modeling results show only a few packages would fail before 10,000 years) would tend to reduce any effect of differences in release rates prior to 10,000 years after closure, should any of these alternative interpretations prove to be accurate. In the model results, package failure rates versus time dominate the dose rates such that the release rate after package failure would play a minor role in determining total dose over time. In the 1-million-year period after closure, there could be some change in dose rates. The addition of vapor processes to aqueous transport processes could increase estimated dose rates by an undetermined amount. DOE is planning additional studies that will help deal with these issues (DOE 1998a, Volume 4, page 3-19).

To move out of the waste package, the radionuclides either would be carried away from the waste form in flowing water or would move in a thin film of water by diffusion. To escape, the radionuclides would have to exit through a pit or patch in the waste package and move out into the waste emplacement drift. The *radionuclide-mobilization and engineered-barrier system transport* model uses the seepage flux and radionuclide solubility in the groundwater to calculate the amount of each radionuclide that would move into the unsaturated zone (DOE 1998a, Volume 3, pages 3-90 to 3-109). It passes the amount of each radionuclides released directly to the unsaturated zone transport model.

5.2.3.4 Reduction in Concentration of Radionuclides and Chemically Toxic Materials During Transport

After escaping from the waste package, the radionuclides and other nonradioactive materials could advance through materials on the drift floor, which would be mainly concrete, and the corrosion products from the waste package. At this point, the radionuclides could either adhere to some of the materials on the drift floor, continue moving in the water, or become attached to extremely small particles of clay, silica, or iron called “colloids.” Because of their molecular charge and physical size, these colloidal particles would move through the rock mass under the proposed repository somewhat differently than noncolloidal particles.

The radionuclides and chemically toxic materials would move down beneath the proposed repository at different rates based on (1) the chemical characteristics of the contaminants and of the rock they would be passing through and (2) the velocity of the water in which they were contained. The rock underlying the repository is unsaturated, and the water movement behaves as described above. Some water moves rapidly in fractures and some much more slowly in the rock. The transport rate would also depend on the tendency of the individual radionuclide or chemical to interact with the rock through which it would move. Some radionuclides would adhere to some minerals in a process called *sorption* and would be bound in the rock for long periods. Sorption can be irreversible in some instances, leaving the nuclide bound permanently in the rock. In other cases, the radionuclides could desorb at a future time and move through the rock. Other types of radionuclides would move more quickly through the rock with little or no interaction that delayed their transport. The analysis assumed that the nonradioactive toxic chemicals would not sorb and would move at the same rate as the water. This conservative assumption was based on a lack of reliable data on the sorption of these materials on tuff. The three-dimensional *unsaturated zone transport* model calculated the amount of each radionuclide and nonradioactive chemical species that would move from the unsaturated zone into the saturated zone and passed this value to the saturated zone transport model (DOE 1998a, Volume 3, pages 3-109 to 3-129).

When the radionuclides reached the water table, they would be caught in the saturated zone flow system. Beneath Yucca Mountain, the water in the saturated zone flows in a generally southerly direction toward the Amargosa Valley. Nuclide sorption would also occur in the rocks and alluvium along the flow paths in the saturated zone. Because of the differences in chemistry between the unsaturated and saturated zone rock and water, the transportation rates of nuclides involved in sorption would be different for the two zones. As the radionuclides moved in the saturated zone along different paths and through different materials, they would gradually become more dispersed and the concentration of the nuclides in any volume of water would decrease.

The *saturated zone transport* model calculates the movement of radionuclides from the unsaturated zone through an aquifer to a groundwater well or surface discharge location. This model is based on the assumption that water in the saturated zone travels along six paths or stream tubes between Yucca Mountain and the well (DOE 1998a, Volume 3, pages 3-130 to 3-143). This six-stream-tube model does not model dilution in the saturated zone; rather, a dilution factor recommended in an expert elicitation exercise (DOE 1998a, Volume 3, page 3-138) was applied to the results for 20 kilometers (12 miles). The basic recommended dilution factor was supplemented by additional empirical calculations for the distances and repository layouts in this EIS. Appendix I, Section I.4.5.4, of this EIS discusses these additional dilution factors. The model performs these flow and transport simulations for nine radionuclides and three chemically toxic materials using multiple simulations of uncertain saturated zone model parameters.

If the radionuclides were removed from the saturated zone by water pumped from wells, the radioactive material could cause doses to humans in several ways. For example, the well water could irrigate crops that persons or livestock consumed, water stock animals that provided milk or meat products, or provide drinking water. In addition, if the water pumped from irrigation wells evaporated on the ground surface, the nuclides could be left as fine particulate matter that could be picked up by the wind and inhaled by humans. The *biosphere* pathway model (DOE 1998a, Volume 3, pages 3-145 to 3-162) addresses what would happen to radionuclides between the time they were pumped from a well and the time they were ingested by a human being. The model uses a biosphere dose-conversion factor that converts saturated zone radionuclide concentrations to individual radiation dose rates. The dose factor was developed by analyzing the multiple pathways through the biosphere by which radionuclides can affect a person. The biosphere scenario assumed a reference person living in the Amargosa Valley region at various distances from the proposed repository at Yucca Mountain. People living in the community of Amargosa Valley would be the group most likely to be affected by radioactive releases (the critical group) because of their proximity to the proposed repository, and because the Amargosa Valley region is hydraulically downgradient from the proposed repository (Luckey et al. 1996, page 14). The reference person is representative of this group: an adult who lives year-round at this location, uses a well as the primary water source, and otherwise has habits (such as the consumption of local foods) similar to those of the inhabitants of the region. Because changes in human activities over millennia are unpredictable, the analysis assumed that the present-day reference person described future inhabitants.

The chemically toxic materials are not evaluated in the biosphere model because there are no usable dose comparison values. Instead, the concentrations of these materials in the groundwater are reported at the same distances where the radionuclide doses were evaluated. The concentrations are then compared to available regulatory standards such as the Maximum Contaminant Level Goal.

The groundwater analysis described above does not consider an alternative view of possible important groundwater migration mechanisms. In 1989, J. S. Szymanski (then a DOE staff scientist) raised the possibility of inundation of the proposed repository as an issue in a report to DOE (Szymanski 1989, all). This view is discussed in detail in Chapter 3, Section 3.1.4.2.2, and DOE does not agree with the inundation scenario for the reasons discussed in Chapter 3. There has been no analysis to determine the effects; however, if such an event occurred, the long-term impacts would probably increase greatly.

The groundwater path doses are based on specific paths of groundwater flow derived from regional data. There are differing opinions about these flow paths, which are derived from regional hydraulic head data and other measurements (Lehman and Brown 1996, all). This alternative concept of flow interprets local high pressure to be due to features such as faults and concludes with a largely different flow pattern in the 20-kilometer (about 12-mile) radius around the proposed repository. These alternative paths could produce somewhat different results in the saturated zone groundwater travel rates, direction, and dilution factors. Such changes could have some effect on the dose estimates. DOE does not know whether adaptation of the alternative paths would increase or decrease dose or how large an effect there would be. The current design of the proposed repository relies very heavily on the delay of release by providing long-lived waste packages, such that package failures would occur periodically over hundreds of thousands of years. The long lives of the packages tend to control the dose results, especially because the saturated zone delay and mixing has a small effect on the concentrations exiting the proposed repository. Therefore, alternative flow paths would not be likely to have a large effect on doses.

5.2.3.5 Disruptive Events

The key attributes of the system, given in the previous sections, describe the continually ongoing processes expected to occur in and around the proposed repository system. The term used to denote the sequence of anticipated conditions is the "nominal case." In contrast, the "disturbed case" refers to discrete, unanticipated events that disrupt the nominal case system. The disruptive events include the following (with impacts discussed in Section 5.7):

- Formation of a volcano in or near the proposed repository
- Earthquake
- Human intrusion into the proposed repository

Yucca Mountain is in a terrain that has experienced volcanic activity in the geologic past. The rocks in which the repository would be constructed are volcanic in origin. However, scientific studies of

FEATURES, EVENTS, AND PROCESSES

Features are physical parts of the system important to how the system could perform. Examples include the Ghost Dance Fault and the Topopah Spring stratigraphic unit.

Events are occurrences in time that can affect the performance or behavior of the system. Events tend to happen in short periods in comparison to the period of concern, and they tend to occur at unpredictable times. Examples include a volcanic intrusion or a human intrusion by drilling.

Processes are physical and chemical changes that occur over long periods, tend to be 100-percent likely to occur, and are predictable. Examples include corrosion of the metals in the waste package and dissolving of waste form materials after exposure to water.

the timing, volume, and other aspects of volcanism have concluded that volcanic activity in this area has been waning in the recent geologic past and that the probability of volcanic activity as a repository-disturbing event is low. For completeness, part of the long-term performance analysis is an assessment of the consequences of a small cinder cone formed by a dike (a lava flow) that flowed up through or close to the proposed repository drifts.

In contrast, earthquakes have occurred in the Yucca Mountain geologic region of influence, and are likely to occur in the future. The effects of an earthquake that would be important to postclosure repository performance primarily would result from ground motions rather than from direct offset along a fault, because the waste emplacement areas would be away from block-bounding faults, which are the most likely sites for fault offsets. The primary effect of ground shaking would be to hasten rock fall into the drift. Such rock fall would have the potential to damage the waste package and hasten water intrusion into the waste form.

The analysis treated human intrusion as an event in which part of the contents of a waste package would be released to the water table through the borehole of a well drilled directly through the proposed repository. Providing a verifiable forecast of future human activity is very difficult, if not impossible. The impact of such human intrusion was not included directly in the final presentation of results but was compared to the long-term performance results to determine the potential level of influence. In other words, the probability of human intrusion occurring was not modeled; however, the possible consequences were qualitatively evaluated for a few intrusion scenarios.

5.2.3.6 Nuclear Criticality

A nuclear criticality occurs when sufficient quantities of fissionable materials come together in a precise manner and the required conditions exist to start and sustain a nuclear chain reaction. The waste packages would be designed to prevent a criticality from occurring in one of them. In addition, it is very unlikely that a sufficient quantity of fissionable materials could accumulate outside the waste packages in the precise configuration and with the required conditions to create a criticality. If, somehow, an external criticality were to occur, analyses indicate that it would have only minor effects on repository performance. An explosive criticality is not credible (DOE 1998a, Volume 3, pages 4-92 to 4-99).

5.2.3.7 Atmospheric Radiological Consequences

In addition to the groundwater pathway, the long-term performance analysis evaluated the potential consequences of the release of radioactive gases into the environment. An analysis separate from the groundwater modeling described in the previous sections was used to forecast such consequences. The model used results from the waste-package degradation models to evaluate when packages and fuel cladding would fail and therefore release contained radioactive gases. This model provided input to release and transport estimates for the atmospheric pathway. Section 5.5 contains details of this analysis.

5.2.4 UNCERTAINTY

As with any impact estimate, there is a level of uncertainty associated with the forecast, especially when estimating impacts over thousands of years. *Uncertainty* can be defined as the measure of confidence in the forecast related to determining how a system will operate or respond. The amount of uncertainty associated with an impact estimate is a reflection of several factors, including the following four:

- An understanding of the components of a system (such as human and societal, hydrogeologic, or engineered) and how those components interact. The greater the number of components, the more complex the system, or the lesser capability to measure or understand the system or components produces a greater potential for uncertainty. Similarly, fewer studies or more assumptions produce greater potential for uncertainty.

- The time scale over which estimates are made. Longer time scales for forecasts produce greater potential for uncertainty.

- The available computation and modeling tools. More general computation tools or more assumptions produce greater potential for uncertainty.

- The stability and uniformity (or variability) of the components and system being evaluated. Less stability and uniformity (that is, greater variability) produces a greater potential for uncertainty.

DOE recognizes that uncertainties exist from the onset of an analysis; however, forecasts are valuable in the decisionmaking process because they provide insight based on the best information and scientific judgments available. The following section discusses uncertainties in the context of possible effects on the impact estimates reported in this chapter. The discussion is divided to address:

- Uncertainty associated with societal changes and climate
- Uncertainty associated with currently unavailable data
- Uncertainty associated with models and model parameters

5.2.4.1 Uncertainty Associated with Societal Changes, Climate, and Other Long-Term Phenomena

General guidance on predicting the evolution of society has been provided by the National Academy of Sciences. In its report, *Technical Bases for Yucca Mountain Standards* (National Research Council 1995, all), the Committee on Technical Bases for Yucca Mountain Standards concluded that there is no scientific basis for predicting future human behavior. The study recommends policy decisions that specify the use of default (or reference) scenarios to incorporate future human behaviors in compliance assessment calculations. The analysis in this chapter follows the recommended approach, using as defaults societal conditions as they exist today; as such, it is based on the assumption that populations would remain at their present locations and population densities would remain at their current levels. However, this assumption, while appropriate for estimating impacts for comparison with other proposed actions, is not realistic because it is likely that populations will move and change in size. For example, if populations were to move closer to or increase in size in the Yucca Mountain groundwater hydrology region of influence, the radiation dose and resultant impacts could increase. DOE does not have the means to predict such changes quantitatively with great accuracy; therefore, the analysis does not attempt to quantify the resultant effects on overall impacts. In addition, the analysis does not address the potential benefits from future human activities including improved technology for removing radioactive materials from drinking water or the environment or medical advances such as cures for cancer.

Estimates of future climatic conditions are based on what is known about the past, with consideration given to climate impacts caused by human activities. Calcite in Devils Hole, a fissure in the ground approximately 40 kilometers (25 miles) southeast of Yucca Mountain, provides the best dated record of climate changes over the past 500,000 years. The record shows continual variation, often with very rapid jumps, between cold glacial climates (for the Great Basin, these are called pluvial periods) and warm interglacial climates similar to the present. Fluctuations average 100,000 years in length. Because this basic time scale has been corroborated by other measurements (for example, oxygen-isotope variations in marine sediments), it has been selected as the average climate cycle (DOE 1998a, Volume 3, page 3-8). The past climate cycles were then idealized into a regular cycle of pulses, which were repeated throughout the period of the forecast. This method inherently assumes that the future will repeat the past.

However, while current understanding of the causes of climate change allows some confidence in this approach, a considerable amount of conservatism was built into the models to account for possible climate uncertainties. For example, a large range of water fluxes were used to reflect the wide rainfall variations that could occur over thousands and hundreds of thousands of years. The analysis assumed that the current climate is the driest it will ever be at Yucca Mountain.

5.2.4.2 Uncertainty Associated with Currently Unavailable Data

DOE is planning additional work to help reduce the amount of uncertainty associated with currently unavailable data. The supporting models will be updated to address the principal factors that have been made a high priority in the DOE plan (DOE 1998a, Volume 4, page 2-29). These factors include:

- Drift seepage and percolation to depth
- Effects of heat and excavation on flow
- Dripping onto waste packages
- Chemistry of water on the waste packages
- Integrity of the inner corrosion-resistant waste package barrier
- Integrity of the spent nuclear fuel cladding
- Formation and transport of radionuclide-bearing colloids
- Transport in the unsaturated zone

The planned work in these areas is summarized below. More detailed information about this work and other planned work to address principal factors with lower priority is provided in the technical work plan (DOE 1998a, Volume 4, page 3-1 to 3-58).

Data on percolation and seepage at the drift scale will continue to provide insights on the processes that will control the amount of water that might contact waste packages. Planned work will examine percolation over that part of the proposed repository layout accessed by the cross drift and in geologic layers that will include more of the repository horizon. Plans include the following testing and modeling activities:

- *Excavation of two additional niches and preparation of two fracture/matrix test beds in the cross drift.* Seepage and fracture/matrix interaction tests will be performed in the lower Topopah Spring units that comprise the majority of the potential repository horizon. Planned tests include liquid release tests and long-term tracer injection tests.

- *Perform additional geochemical and isotopic analyses to determine where water has flowed in the past.* Concentrations of chemical components in the rock such as chloride, bromide, and sulfate will be measured, and the results will be used to identify fast paths and travel times. Ongoing analyses of the isotopic ages of fracture-lining minerals will provide information on the history of water movement. These studies show how and when water has moved through the unsaturated zone and reveal characteristics of the water, such as the chemical composition and temperature.

- *Perform a controlled study of percolation from the cross drift to the underlying Exploratory Studies Facility main drift.* The cross drift infiltration experiment in the crossover alcove will provide data on percolation rates through fractured welded tuffs under controlled boundary conditions.

- *Monitor moisture conditions in the Exploratory Studies Facility, including the cross drift.* Moisture monitoring activities in Alcoves 1 and 7 of the Exploratory Studies Facility will continue and monitoring in the cross drift will be established, for the study of moisture balance, ventilation effects, and the movement of water used in construction.

- *Update percolation and seepage models.* Percolation processes have been modeled at two scales: mountain and drift. These models will be updated so the modeled hydrostratigraphy is consistent with recent laboratory and field test data. Models for seepage into drifts will also be updated to encompass field test data and the effects of thermally driven-coupled processes.

The effects of heating on seepage are being investigated in a drift-scale thermal test currently being conducted and by laboratory experiments that will support models for predicting the effects of coupled processes over much longer periods.

5.2.4.3 Uncertainty Associated with Models and Model Parameters

The total system performance model used to assess the impacts from groundwater migration includes a very large number of submodels and requires a large amount of input data to estimate the performance of the system. The model must account for important features of the system, likely events, and processes that would contribute to the release and migration of materials. Because of the long periods simulated, the complexity and variability of a natural system, and several other factors, the performance modeling must deal with a large degree of uncertainty. This section discusses the nature of the uncertainties and how they were accounted for in the analysis and their implication to interpretation of impact results. The *Viability Assessment of a Repository at Yucca Mountain* (DOE 1998a, Volume 3, pages 4-63 to 4-71) contains further details concerning this subject.

5.2.4.3.1 *Variability Versus Uncertainty*

A variable feature, event, or process is one that changes over space or time. Examples include the porosity of the rock mass, the temperature in the repository, and the geochemical environment in the repository drifts. If all information was available, such parameters would be best expressed as known mathematical functions of space and time. In contrast, uncertainty relates to a lack of knowledge regarding a feature, event, or process—one whose properties or future outcome cannot be predicted. Four types of uncertainty are typically considered: value uncertainty, conceptual model uncertainty, numerical model uncertainty, and uncertainty regarding future events. The treatment of a feature, event, or process as purely variable or purely uncertain can lead to different modeling results.

Uncertainty and variability are sometimes related. The exact nature of the variability in a natural system cannot be known because all parts of the system cannot be observed. For example, DOE cannot dig up all the rock in Yucca Mountain and determine that the positioning of the rock layers is exactly as suggested by core sample data. Therefore, there is uncertainty about the properties of the rock at specific locations in the mountain because properties change with distance and it is not known how much they change at any given location. If the variability can be appropriately quantified or measured, a model usually can be developed to include this variability. If the variability cannot be physically quantified or estimated, it should be treated as uncertainty (lack of knowledge). However, the ability to model some types of spatial variability can be limited not only by lack of data but also by the capacity of a computer to complete calculations (for example, if one simulation took weeks or months to complete). In these instances, variability must be simplified in such a way as to be conservative (that is, the simulation would overestimate the impact).

Two basic tools were used in the analysis to deal with uncertainty and variability: alternative conceptual models and probability theory. Alternative conceptual models were used to handle uncertainty in the understanding of a key physical-chemical process controlling system behavior. Probability theory was used to understand the impacts of uncertainty in specific model parameters (that is, would results change if the parameter value was different). In particular, uncertain processes often required different conceptual models. For example, different conceptual models of how water in fractures communicates with water in the smaller pores or the matrix of the rock in the unsaturated zone lead to different flow and transport models. Sometimes conceptual models are not mutually exclusive (for example, both matrix and fracture flow might occur), and sometimes they do not exhaustively cover all possibilities (apparently matrix and fracture flow do cover all possibilities). These examples indicate that the use of alternative conceptual models, while often necessary to characterize some types of uncertainty, is not always as exact as desired.

A process of weighting alternative conceptual models (as described below) was used in the long-term performance assessment to account for uncertainties in conceptual models. The *Monte Carlo* sampling technique was used for handling uncertainty in specific model parameters and for alternative conceptual models that were weighted beforehand with specific probabilities. The method involves random sampling of ranges of likely values, or *distributions*, for all uncertain input parameters. Distributions describe the probability of a particular value in the range. A common type of distribution is the familiar “bell-shaped” curve, also known as *normal distribution*. Parameters in the system performance analysis are described by many different types of distributions appropriate for how the values and their probabilities are understood. Numerous realizations of the repository system behavior were calculated, each based on one set of samples of all the inputs. Each total system realization had an associated probability so that there is some perspective on the likelihood of that set of circumstances occurring. The Monte Carlo method yields a range for any chosen performance measure (for example, peak dose rate to an individual in a given period at a given location) along with a probability for each value in the range. In other words, it gives an estimate of repository performance and determines the possible errors based on the estimate. In this chapter, the impact estimates are expressed as the mean of all the realizations and the 95th-percentile value (that is, the value for which 95 percent of the results were smaller).

5.2.4.3.2 *Weighting of Alternative Conceptual Models*

In some cases, modeling alternatives form a continuum, and sampling from the continuum of assumptions fits naturally in the Monte Carlo framework of sampling from probability distributions. In other cases, the assumptions or models are discrete choices. In particular, some processes are so highly uncertain that there are not enough data to justify developing continuous probability distributions over the postulated ranges of behavior. In such cases, a high degree of sampling is unwarranted, and an analysis often models two or three cases that it assumes to encompass (bound) the likely behavior.

There were two possible approaches to incorporating discrete alternative models in the performance assessment: weighting all models into one comprehensive Monte Carlo simulation (lumping), or keeping the discrete models separate and performing multiple Monte Carlo simulations for each discrete model (splitting). In this analysis, a combination of the two approaches was used. The main results in Section 5.4 were developed using the splitting approach because they were based on a limited range of uncertainty. Based on expert judgment (and to some extent the finite time and resources that could be applied to the analysis effort), the analysis used a best estimate of the more likely ranges of model behavior and parameter ranges. Some alternative models were not included in the analysis, and some parameter ranges of the included models were narrowed. The level of uncertainty included in the model was based on the current level of knowledge regarding the various processes controlling system behavior. In several instances, the range of uncertainty was set quite large, in a conservative manner. Because of this narrowed range of models and parameters, the results are *conditional*, meaning that they depend on certain models and parameters being held constant or having their variance restricted. One such condition is the specific design of the repository and the waste packages in the reference design of this EIS. Another important condition is that the cladding on the spent nuclear fuel can be depended on as a barrier.

Other conditional results were used to characterize the effect of certain assumptions. For example, results are given in this chapter for three thermal load scenarios; Section 5.4.4 describes the result when the fuel cladding was not considered as a barrier. Additional splitting was done to consider such events as human intrusion (Section 5.7.1), volcanic disturbances (Section 5.7.2), and seismic disturbances (Section 5.7.3). The consequences of these types of events are not part of results given in Section 5.4, rather they are reported as added impacts with certain probabilities of occurrence.

5.2.4.3.3 *Uncertainty and the Proposed Action*

The analysis for the Proposed Action encompassed many of the underlying uncertainties. It included some of all four types of uncertainty: value or parameter uncertainty, conceptual model uncertainty, numerical model uncertainty, and future-event uncertainty. Therefore, the results represent a "lumping" approach. Uncertainty not lumped into the modeling, which produced the central results in Section 5.4, was addressed discretely in alternative models, alternative features, and alternative events such as human intrusion. These alternatives were "split" from the nominal results, and their effects on performance are described separately.

5.2.4.3.4 *Uncertainty and Sensitivity*

In addition to accounting for the uncertainty, characteristics of the engineered and natural systems (such as the unsaturated and saturated zones of the groundwater system) that would have the most influence on repository performance also need to be understood. This information helps define *uncertainty* in the context of what would most influence the results. This concept is called *sensitivity analysis.* A number of methods are used to explain the results and quantify sensitivities. Total system performance is a function of sensitivity (if a parameter is varied, how much do the performance measures change) and uncertainty (how much variation of a parameter is reasonable). For example, the long-term performance results could be very sensitive to a certain parameter, but the value for the parameter is exactly known. In the uncertainty analysis techniques described below, that parameter would not be regarded as important. However, many parameters in the analyses do have an associated uncertainty and do become highly important to performance. On the other hand, the level of their ranking can depend on the width of the assigned uncertainty range.

Most of the important parameters with possibly limited uncertainty ranges in the model were examined in alternative models. The alternative models either expand the range of the parameters beyond the expected range of uncertainty or change the weighting of the parameter distribution. For example, this type of analysis was performed for alternative models of seepage (DOE 1998a, Volume 3, pages 5-1 to 5-9) and cladding degradation (DOE 1998a, Volume 3, pages 5-32 to 5-35).

System performance could be sensitive to repository design options, but models and parameters for these various options do not have an assigned uncertainty. Therefore, although they can be important, they do not show up as key parameters based on uncertainty analysis. The determination of the parameters or components that are most important depends on the particular performance measure being used. This point was demonstrated in the 1993 Total System Performance Assessment (Andrews, Dale, and McNeish 1994, all; Wilson et al. 1994, all) and the *Total System Performance Assessment–1995* (TRW 1995b, all). For example, these two analyses showed that the important parameters would be different for 10,000-year peak doses than for 1-million-year peak doses.

There are several techniques for analyzing uncertainties, including the use of qualitative scatter plots where the results (for example, dose rate) are plotted against the input parameters and visually inspected for trends. In addition, performance measures can be plotted against various subsystem outputs or surrogate performance measures (for example, waste package lifetime) to determine if that subsystem or performance surrogate would be important to performance. There are several formal mathematical techniques for analyzing the sets of realizations from a Monte Carlo analysis to extract information about the effects of parameters. Such an analysis determined the principal factors affecting the performance of the reference design.

5.2.4.3.5 *Confidence in the Long-Term Performance Estimates*

As described above, the analysis accounted for the many uncertainties involved. Further, an understanding of the sensitivities of principal factors in the system performance was developed. Table 5-3 lists the principal factors as they relate to repository performance, and relates the factors to model confidence and significance of uncertainty (sensitivity). If there is low confidence in the model (high uncertainty) and high significance, planned research will further refine the model and data (DOE 1998a, Volume 4, Section 3). For example, ongoing research emphasizes transport through the unsaturated zone and the integrity of the inner corrosion-resistant waste package barrier.

Table 5-3. Confidence in the long-term performance of the repository system in relation to groundwater contamination.[a]

Desired attributes of the repository and principal factors associated with the reference design	Confidence in the models to reasonably represent the impacts and processes	Significance of uncertainty to the estimate of performance
Limited water contacting waste package		
Precipitation and infiltration of water into the mountain	High	Medium
Percolation to depth	Medium	Medium
Seepage into drifts	Low	High
Effects of heat and excavation on flow	Low	Medium
Dripping onto waste package	Low	Medium
Humidity and temperature at waste package	Very High	Low
Long waste package lifetime		
Chemistry at waste package	Medium	Medium
Integrity of outer waste package barrier	High	Medium
Integrity of inner waste package barrier	Medium	High
Low rate of release of radionuclides from breached waste package		
Seepage into waste package	Medium	Medium
Integrity of spent fuel cladding	Medium	High
Dissolution of uranium oxide and glass waste form	High	Medium
Solubility of neptunium-237	High	Medium
Formation of radionuclide- bearing colloids	Low	Medium
Transport of radionuclides within and out of waste package	Medium	Medium
Radionuclide concentration reduction during transport between the waste package and the environment		
Transport of radionuclides through the unsaturated zone	Low	High
Transport of radionuclides through the saturated zone	Low	Medium
Dilution from pumping in water supply	Very High	Medium
Biosphere transport and uptake	Very High	Low

a. Source: Adapted from DOE (1998a, Volume 4, Table 2-2, page 2-20).

The general approach to long-term performance analysis in this EIS conforms with international practices, as assured through continued participation in the Performance Assessment Advisory Group of the Nuclear Energy Agency of the Organization for Economic Cooperation and Development in Paris. The Performance Assessment Advisory Group has had the Yucca Mountain Site Characterization Project as a contributing and participating member for many years, and the group has fostered the open discussion of current performance assessment approaches across national boundaries and regulatory boundaries. This practice has allowed the critical evaluation of member nations' performance assessment approaches. A document produced by this group compared more than 10 recent performance assessments, in terms of approach and scope, and made recommendations for the general content of a safety evaluation (OECD 1997, all). This information is being considered in the planning, production, and documentation of ongoing performance assessment work.

In addition, the long-term performance analysis approach in this EIS is generally accepted by the external oversight and internal review groups, including the Nuclear Waste Technical Review Board and the Total System Performance Assessment Peer Review Panel. Nevertheless, these two groups have criticized specific elements of the performance assessment work represented in this EIS, and they have made recommendations in several reports for additional work to support the modeling.

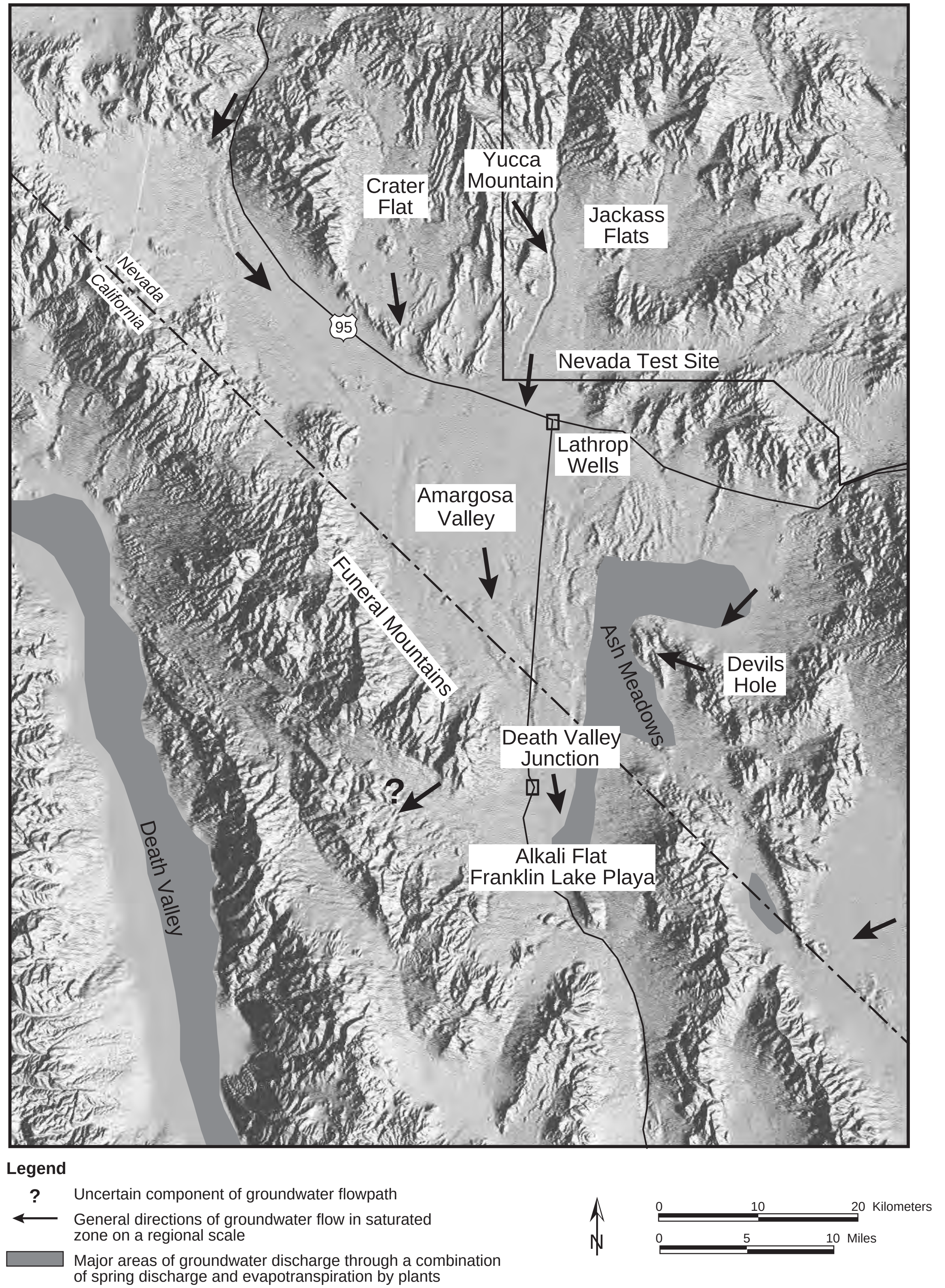
For example, the most recent report of the Total System Performance Assessment Peer Review Panel states that “the overall performance assessment framework and the approach used in developing the TSPA-VA were sound and followed accepted methods,” but also includes approximately 145 pages of observations and suggestions for improvements. All of the suggestions are being addressed in the overall planning for the Site Recommendation of 2001 and, if the site is approved, the License Application of 2002. Volume 4 of the Viability Assessment (DOE 1998a, Volume 4, pages 3-1 to 3-68) discusses this planning. The Panel was particularly critical when stating that the report failed to provide a statement of the “probable behavior of the repository” as requested by Congress. The Panel interpreted that requirement to be an impossibly exacting test. The Panel suggested that the Department should move away from seeking predictive certainty and show safety through bounding arguments and conservative designs, as is done in this EIS. The Department, in the context of preparing a performance evaluation that provides for a “reasonable assurance” of safety, generally agrees with the Panel’s advice.

The EIS performance assessment represents a “snapshot in time” and ongoing work will help refine that snapshot. In the meantime, DOE believes the performance results of this EIS are conservative estimates, and that work currently in progress or planned will increase confidence in the overall modeling approach.

5.3 Locations for Impact Estimates

Yucca Mountain is in southern Nevada, in the transition area between the Mojave Desert and the Great Basin. It is a semiarid region with linear mountain ranges and intervening valleys, with current rainfall averaging between about 100 and 250 millimeters (4 and 10 inches) a year, sparse vegetation, and a low population. Although there is low infiltration of water through the mountain and no people currently live in the analyzed land withdrawal area, radioactive and chemically toxic materials released from the repository could affect persons living closer to the proposed repository in the distant future. This section describes the regions where possible human health impacts could occur.

Figure 5-3 is a map with arrows showing the general direction of groundwater movement from Yucca Mountain. Shading indicates major areas of groundwater discharge through a combination of springs and evapotranspiration by plants. The general path of water that infiltrates through Yucca Mountain is south toward Lathrop Wells, into and through the area around Death Valley Junction in the lower Amargosa Valley. Natural discharge of groundwater from beneath Yucca Mountain probably occurs farther south at Franklin Lake Playa (Czarnecki 1990, pages 1 to 12), and spring discharge in Death Valley is a possibility (D’Agnese et al. 1997, pages 64 and 69). Although groundwater from the Yucca Mountain vicinity flows near or under Ash Meadows in the volcanic tuff or alluvial aquifers, the surface discharge areas at Ash Meadows and Devils Hole are fed from the carbonate aquifer. While these two aquifers are connected, the carbonate aquifer has a hydraulic head that is 36 meters (120 feet) higher than that of the volcanic or alluvial aquifers. Because of this pressure difference, water from the volcanic aquifer does not flow into the carbonate aquifer; rather, the reverse occurs. Therefore, no contamination from Yucca Mountain could discharge to the surface at Ash Meadows or Devils Hole (TRW 1999h, all). Therefore, radionuclides released from a repository at Yucca Mountain would not appear in the surface discharge at



Source: Modified from DOE (1998a, Volume 3, page 3-131).

Figure 5-3. Map of the saturated groundwater flow system.

Ash Meadows or Devils Hole. Because there would be no contamination of this discharge water, there would be no human health impacts. Furthermore, there would be no consequences to the endangered Ash Meadows Amargosa pupfish (*Cyprinodon nevadensis mionectes*) or Devils Hole pupfish (*Cyprinodon diabolis*) at those locations.

Figure 3-21 in Chapter 3 shows the estimated population of 28,000 permanent residents within 80 kilometers (50 miles) of Yucca Mountain in 2000. This map provides the information used to estimate population doses from radionuclides released to the atmosphere from the repository. The atmosphere analysis used an 84-kilometer radius rather than the 80-kilometer (50-mile) radius described in Chapter 3 to include the population of Pahrump.

POPULATION DOSE AND FUTURE POPULATION SIZE

Population dose is a summation of the dose received by individuals in an exposed population (unit of measure is *person-rem).* The population dose depends on the number of people at different locations. If the number of people increases in the future, the population dose estimate would also increase.

People who could be exposed in the future to groundwater-borne contaminants would live to the south of Yucca Mountain in the direction of groundwater flow. At present, there are no permanent residences within 5 kilometers (3 miles) to the south of the proposed repository. Groundwater depth is approximately 100 meters (330 feet) at 5 kilometers from Yucca Mountain. Closer to Yucca Mountain, groundwater is at depths greater than 200 meters (660 feet), which imposes economic constraints on agricultural uses of land (DOE 1998a, Volume 3, page 3-150). Population projections for 2000 indicate that the area within 5 kilometers of the proposed repository would remain unpopulated (see Chapter 3, Figure 3-21) (for further discussion on why 2000 population was used, see Section 5.2.4.1). However, because there are sources of potable groundwater, the analysis performed human health impact calculations for a hypothetical person living 5 kilometers south of the proposed repository who uses well water.

At present, very few people live within 20 kilometers (12 miles) to the south of the repository, but there is some land suitable for farming in that region. For example, about eight permanent residents live in the Lathrop Wells community. Therefore, the analysis performed human health impact calculations, based on human ingestion of groundwater from wells in the area, for a person living 20 kilometers south of the proposed repository. The nearest private property in the direction of groundwater flow from the repository site is at the Nevada Test Site boundary approximately 18 kilometers (11 miles) to the south. Environmental consequences at 18 kilometers would not be expected to differ substantially (about 10 percent) from those estimated at 20 kilometers. The closest population center in the Amargosa Valley is about 30 kilometers (19 miles) away. The analysis calculated human health impacts from well water contamination to persons living at that location. Groundwater carrying dissolved radionuclides from the Yucca Mountain Repository could emerge as surface water at Franklin Lake Playa. The analysis also calculated human health impacts from surface-water discharge to a hypothetical person living near Franklin Lake Playa and identified them as impacts at the 80-kilometer (50-mile) or discharge location.

5.4 Waterborne Radiological Consequences

The following sections report potential radiation dose rates, expressed in millirem per year, to an individual living south of Yucca Mountain and using groundwater (characterized as the maximally exposed individual). The analysis converted the dose rate to the probability of contracting a fatal cancer (referred to as a latent cancer fatality) due to exposure to radioactive materials in the water. In addition, the analysis calculated population doses in person-rem for two different periods: for the 70-year lifetime at the time of the peak dose during the first 10,000 years after repository closure, and integrated over the first 10,000 years after repository closure. The analysis also converted the population dose to the expected number of latent cancer fatalities in the population. DOE based the analysis on the inventories discussed in Section 5.1. However, the analysis included the entire carbon-14 inventory of the commercial spent nuclear fuel as a solid in the groundwater release models. Actually, 2 percent of the carbon-14 exists as a gas in the fuel (see Section 5.5). Thus, the groundwater models slightly overestimate (by 2 percent) the potential impacts from carbon-14.

MAXIMALLY EXPOSED INDIVIDUAL

DOE has used *maximally exposed individual* in environmental impact statements to help describe potential radiological impacts to an individual member of the public. Its use follows established DOE National Environmental Policy Act guidance and precedents.

The broad definition of a maximally exposed individual is a hypothetical person who is exposed to environmental contaminants (for example, radiation) in such a way—by a combination of factors including location, lifestyle, dietary habits, and so on—that this individual would be the most highly exposed member of the public. The definition of maximally exposed individual for evaluating postclosure exposures from the groundwater pathway in this EIS is a subset of this broad definition, defined for a narrower set of exposure conditions. In this EIS, the maximally exposed individual is a hypothetical member of the group of adults that would live in the Amargosa Valley after repository closure (no earlier than 2118), with a characteristic range of lifestyle, food consumption, and groundwater usage patterns. More specifically, this individual would grow half of the foods that the individual would consume on the property, irrigate crops and water livestock using groundwater, and would also use groundwater as a drinking water source and to bathe and wash clothes. The EIS analyzed four maximally exposed individuals to represent impacts from use of groundwater at four distances from the repository: 5, 20, 30, and 80 kilometers (3, 12, 19, and 50 miles). The 80-kilometer distance is Franklin Lake Playa.

5.4.1 CONSEQUENCES FROM THE GROUNDWATER EXPOSURE PATHWAY FOR THE HIGH THERMAL LOAD SCENARIO

Four sets of 100 model simulations were run for the high thermal load scenario, one set for each of the four distances from Yucca Mountain. Each simulation used separate sets of sampled uncertainty parameters and generated a dose-rate profile for the 10,000 years following repository closure. Each simulation produced the maximum dose rate (in millirem per year) over the 10,000 years. Table 5-4 lists the mean and the 95th-percentile values of the set of 100 peak dose rates. The table lists the dose rate to the maximally exposed individual and the resultant probability of a latent cancer fatality for that individual. The distance of the receptor from the repository would have a large influence on the dose and the number of latent cancer fatalities.

RADIATION MEASURES

The **millirem** is the unit of radiological dose reported in this analysis. *Milli* means one one-thousandth. A *rem* (Roentgen Equivalent in Man) is the amount of ionizing radiation required to produce the same biological effect in a person as 1 roentgen of high-penetration X-rays. A **roentgen** is a unit of measure of X-ray or gamma-ray radiation exposure discussed in terms of the amount of energy transferred to a unit mass of air. One roentgen corresponds to the absorption of 87.7 ergs (6.5×10^{-6} foot-pound) per gram of air.

Ninety-five percent of the calculated dose rates for the maximally exposed individual at 5 kilometers (3 miles) would be below 1.3 millirem per year and would have an associated lifetime probability of a latent fatal cancer of 0.000044. For comparison purposes, the background radiation level from environmental sources in the United States is approximately 300 millirem per year (NCRP 1987, page 14), corresponding to an individual lifetime probability of contracting a latent cancer fatality of about 0.001.

Population doses were calculated based on the dose rates in Table 5-4. The population size was based on the population numbers in Figure 3-21 in Chapter 3 of this EIS. For these calculations, the analysis assumed that no one would be exposed at 5 kilometers (3 miles); eight people would be exposed at about 20 kilometers (12 miles); 1,126 people would be exposed at about 30 kilometers (19 miles); and 13 people would be exposed at about 80 kilometers (50 miles). Thus, approximately 1,150 people would be exposed to contaminated groundwater. This stylized population dose analysis assumes that people would continue to live in the locations being used at present. This assumption is consistent with the recommendation made by the National Academy of Sciences (National Research Council 1995, all) because it is impossible to make accurate predictions of future lifestyles and residence locations.

Table 5-4. Consequences for a maximally exposed individual from groundwater releases of radionuclides during 10,000 years after repository closure for the high thermal load scenario.

	Mean consequence[b]		95th-percentile consequence[c]	
MEI[a]	Peak dose rate (millirem/year)[d]	Probability of an LCF[e]	Peak dose rate (millirem/year)[d]	Probability of an LCF
At 5 kilometers[f]	3.2×10^{-1}	1.1×10^{-5}	1.3	4.4×10^{-5}
At 20 kilometers	2.2×10^{-1}	7.6×10^{-6}	5.8×10^{-1}	2.0×10^{-5}
At 30 kilometers	1.2×10^{-1}	4.2×10^{-6}	2.8×10^{-1}	1.0×10^{-5}
At discharge location[g]	3.0×10^{-2}	1.1×10^{-6}	2.9×10^{-3}	1.0×10^{-7}

a. MEI = maximally exposed individual.

b. Based on four sets, one for each distance of 100 simulations of total system performance, each using random samples of uncertain parameters.

c. Represents a value for which 95 out of the 100 simulations yielded a smaller value.

d. All peaks occur at or near 10,000 years, indicating that the dose rate would still be rising at the end of the simulation period.

e. LCF = latent cancer fatality; incremental lifetime (70 years) risk of contracting a fatal cancer for individuals, assuming a risk of 0.0005 latent cancer per rem for members of the public (NCRP 1993a, page 31).

f. To convert kilometers to miles, multiply by 0.62137.

g. 80 kilometers at Franklin Lake Playa.

Table 5-5 lists the population consequences associated with the results given in Table 5-4. The values in Table 5-5 include a scaling factor for water use. The performance assessment transport model calculated the dose rates for the maximally exposed individual assuming dissolved radionuclides would mix only in water that flowed through the unsaturated zone of Yucca Mountain with no further mixing in the saturated zone aquifer. Infiltration through the Yucca Mountain Repository accounts for only about 27,000 cubic meters (22 acre-feet) of water per year (see Appendix I, Section I.4.5.3). This compares to an annual water use in the Amargosa Valley of about 17.3 million cubic meters (14,000 acre-feet) (see Table 3-11). The analysis diluted the concentration of the nuclides in the 27,000 cubic meters of water throughout the 17.3 million cubic meters of water prior to calculating the population dose.

Table 5-5. Population consequences from groundwater releases of radionuclides during 10,000 years after repository closure for the high thermal load scenario.

	Mean consequence[a]		95th-percentile consequence[b]	
Case	Population dose (person-rem)	Population LCF[c]	Population dose (person-rem)	Population LCF
Peak 70-year lifetime	1.5×10^{-2}	7.5×10^{-6}	3.5×10^{-2}	1.8×10^{-5}
Integrated over 10,000 years	3.7×10^{-1}	1.8×10^{-4}	1.2	5.8×10^{-4}

a. Based on four sets, one for each distance, of 100 simulations of total system performance, each using random samples of uncertain parameters.

b. Represents a value for which 95 out of the 100 simulations yielded a smaller value.

c. LCF = latent cancer fatality; expected number of cancer fatalities for populations, assuming a risk of 0.0005 latent cancer per rem for members of the public (NCRP 1993a, page 31).

The consequences listed in Table 5-4 are small because the analysis computed that most of the waste packages would last longer than 10,000 years. The inner layer of the waste package would have a very low corrosion rate, but there is a high degree of uncertainty in the value of the average corrosion rate. Model simulations estimated that some of the waste packages would fail within 10,000 years but some would last for more than 1 million years after repository closure. The analysis accounted for premature failures due to manufacturing defects or mishandling during emplacement. It assumed that these failures (called *juvenile failures*) would occur exactly 1,000 years after repository closure. Based on a study of industrial experience of manufacturing and handling (DOE 1998a, Volume 3, page 3-81), the estimated rate of juvenile failures would be very low. If juvenile failures did not occur, the mean consequences listed in Table 5-4 would decrease by about 2 percent, while the 95th-percentile consequences would be unchanged.

The radionuclides that would contribute the most to individual dose in 10,000 years would be iodine-129, technetium-99, and carbon-14 dissolved in groundwater. For example, the mean consequence at 30 kilometers (19 miles) has iodine-129 contributing 59 percent of the dose rate, technetium-99 contributing 36 percent, and carbon-14 contributing 4 percent. This analysis assumed that 2 percent of the carbon-14 migrated as gas in the form of carbon dioxide (see Section 5.5 for more details). The groundwater modeling conservatively ensures that all of the carbon-14 migrates into the water part.

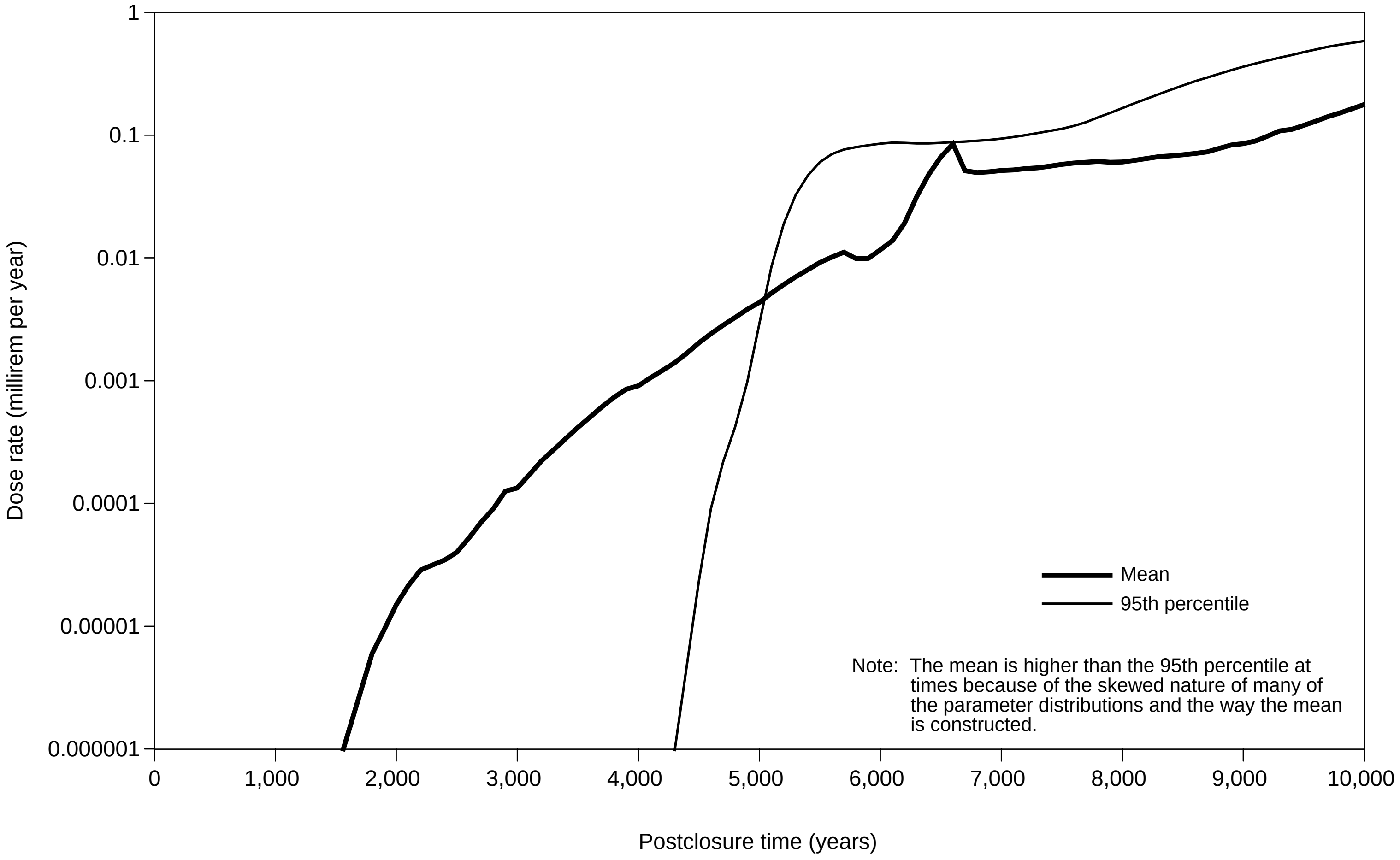
The times that the peak dose rates listed in Table 5-4 would occur are close to 10,000 years and still would be less than 1.0 millirem per year (Figure 5-4). This indicates that the dose rate would be rising at the end of the 10,000-year simulation period. The peak doses before 10,000 years would be due to the relatively quick dissolution and transport of technetium-99, iodine-129, and carbon-14 from failed waste packages. Table 5-6 lists the same type of results as those in Table 5-4, but the timeframe is 1 million years after repository closure. A small fraction of the model simulations for the 80-kilometer (50-mile) distance have an increasing dose rate at the 1-million-year mark. The dose rates that would be increasing after 1 million years were usually among the smallest of the entire set of 100 results. The simulations were ended after 1 million years largely because further radioactive decay would decrease dose rates even for very long-lived radionuclides. The peak dose rate usually coincided with the occurrence of a wetter climate period.

Table 5-6. Maximally exposed individual doses from groundwater releases of radionuclides during 1 million years after repository closure for the high thermal load scenario.

	Mean[b]		95th-percentile[c]	
MEI[a]	Peak dose rate (millirem/year)	Time of peak (years)	Peak dose rate (millirem/year)	Time of peak (years)
At 5 kilometers[d]	1,400	792,000	9,100	320,000
At 20 kilometers	260	336,000	1,400	364,000
At 30 kilometers	150	418,000	820	416,000
At discharge location[e]	50	818,000	190	716,000

a. MEI = maximally exposed individual.
b. Based on four sets, one for each distance, of 100 simulations of total system performance, each using random samples of uncertain parameters.
c. Represents a value for which 95 out of the 100 simulations yielded a smaller value.
d. To convert kilometers to miles, multiply by 0.62137.
e. 80 kilometers at Franklin Lake Playa.

The radionuclides that would contribute the most to the peak dose rate in 1 million years would be neptunium-237 and plutonium-242. The mean dose at 30 kilometers (19 miles) showed neptunium-237 contributing 92 percent of the dose rate, plutonium-242 contributing 5 percent, plutonium-239 contributing 1 percent, and uranium-234 contributing 1 percent. The plutonium isotopes contributing to dose were due to colloidal transport of plutonium, not transport of plutonium as a dissolved element in



Note: The mean is higher than the 95th percentile at times because of the skewed nature of many of the parameter distributions and the way the mean is constructed.

Figure 5-4. 10,000-year history of dose at 20 kilometers (12 miles) from the repository for the high thermal load scenario.

groundwater. In the construct of the mean, the time of occurrence of the peak dose can be very sensitive and might change abruptly to different times. This occurs because the time plot of the mean curve is relatively flat with occasional sudden peaks. Thus, the times of the peaks might not seem to be following a pattern. Since the mean does not represent any actual trial in the 100 simulations, the times of occurrence might not have much meaning. Similar effects will be noted in some of the results for the other thermal loads.

Table 5-7 lists peak radionuclide concentrations (amount of radionuclide in a volume of water) at four human exposure locations for the high thermal load scenario for the first 10,000 years after repository closure. It also lists the gross alpha-particle activity and the drinking water dose (the dose resulting from direct ingestion of the water at the given concentration). The gross alpha concentration is an analytical measurement used in monitoring the radiological quality of drinking water contamination levels. It represents the total amount of radioactivity from radionuclides with radioactivity due to the emission of alpha particles. (An alpha particle is a positively charged particle emitted by certain radioactive material, made up of two neutrons and two protons or the equivalent of a helium nuclei.) The consequences at each distance come from a different set of 100 simulations. As a result, some model predictions show fluctuations in the relative concentration of specific nuclides can occur at different distances. For example, the modeled concentration of carbon-14 for the 95th-percentile consequence would be higher at 30 kilometers (19 miles) than at 20 kilometers (12 miles), although the total modeled dose is about 2 times higher at 20 kilometers than at 30 kilometers (see Table 5-4).

Table 5-7. Peak radionuclide concentrations (picocuries per liter) in water and associated annual drinking water dose at human exposure distances for 10,000 years after repository closure for the high thermal load scenario.

	Mean consequence[a,b]				95th-percentile consequence[c]			
	Distance (kilometers)[d]				Distance (kilometers)			
Radionuclide	5	20	30	80	5	20	30	80
Carbon-14	2.1	1.1	6.4×10^{-1}	1.8×10^{-3}	8.2	1.8	3.1	2.7×10^{-2}
Iodine-129	1.3×10^{-1}	7.0×10^{-2}	4.1×10^{-2}	1.0×10^{-4}	5.7×10^{-1}	1.2×10^{-1}	2.0×10^{-1}	2.0×10^{-3}
Neptunium-237	6.4×10^{-4}	2.3×10^{-8}	6.1×10^{-15}	5.6×10^{-24}	6.5×10^{-4}	1.3×10^{-17}	1.3×10^{-23}	4.2×10^{-24}
Protactinium-231	2.9×10^{-12}	4.7×10^{-26}	4.7×10^{-26}	2.4×10^{-26}	2.0×10^{-24}	2.0×10^{-24}	1.3×10^{-26}	1.3×10^{-26}
Plutonium-239	5.7×10^{-5}	5.6×10^{-9}	4.8×10^{-10}	1.3×10^{-13}	1.8×10^{-9}	2.4×10^{-11}	8.1×10^{-10}	2.1×10^{-17}
Plutonium-242	3.5×10^{-7}	2.9×10^{-11}	3.1×10^{-12}	8.9×10^{-16}	1.0×10^{-11}	7.8×10^{-14}	4.5×10^{-12}	1.5×10^{-19}
Selenium-79	3.8×10^{-1}	8.2×10^{-4}	2.4×10^{-6}	1.4×10^{-21}	1.7×10^{0}	1.4×10^{-18}	6.8×10^{-19}	3.2×10^{-21}
Technetium-99	4.5×10^{1}	3.0×10^{1}	1.0×10^{1}	3.3×10^{-2}	3.9×10^{2}	8.4×10^{1}	1.3×10^{2}	8.3×10^{-1}
Uranium-234	8.8×10^{-5}	9.0×10^{-10}	1.2×10^{-16}	2.9×10^{-23}	8.3×10^{-5}	4.4×10^{-23}	3.7×10^{-23}	3.7×10^{-23}
Gross alpha[e]	7.0×10^{-4}	2.9×10^{-8}	4.8×10^{-10}	1.3×10^{-13}	6.5×10^{-4}	2.4×10^{-11}	8.1×10^{-10}	2.1×10^{-17}
Annual drinking water dose (millirem)	8.1×10^{-2}	4.8×10^{-2}	2.0×10^{-2}	5.9×10^{-5}	5.4×10^{-1}	1.2×10^{-1}	1.8×10^{-1}	1.3×10^{-3}

a. Based on four sets, one for each distance, of 100 simulations of total system performance, each using random samples of uncertain parameters.
b. The concentrations for the mean and 95th-percentile consequences are the concentrations that yielded the mean and 95th-percentile doses reported in Table 5-4.
c. Represents a value for which 95 out of the 100 simulations yielded a smaller value.
d. To convert kilometers to miles, multiply by 0.62137.
e. By regulatory convention, the gross alpha-particle radiation does not include uranium.

The annual drinking water doses in Table 5-7 (and below in Tables 5-11 and 5-15) are based on the assumption that an individual drinks exactly 2 liters (about 0.5 gallon) of water each day. Ingestion dose conversion factors were taken from Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion (Eckerman, Wolbarst, and Richardson 1988, pages 155 to 179). The full-pathway dose rates calculated in this chapter using biosphere dose conversion factors were based on food and water intake values for a reference adult derived from an extensive survey of residents of the Amargosa Valley (DOE 1998a, Volume 3, pages 3-151 to 3-155).

Thus, the drinking water dose reported in Table 5-7 might be different from the portion of the total dose reported in Table 5-4 that is due to water consumption. For both the mean and 95th-percentile consequences, the gross alpha activity would be much lower than the 15 picocuries per liter specified as the attainment limit for drinking water for community water systems [40 CFR Part 141, Subpart B, Section 141.15(b)]. The dose rates from drinking liters (0.5 gallon) of water a day would also be below the 4-millirem-per-year limit for community water systems [40 CFR Part 141, Subpart B, Section 141.16(a)].

5.4.2 CONSEQUENCES FROM THE GROUNDWATER EXPOSURE PATHWAY FOR THE INTERMEDIATE THERMAL LOAD SCENARIO

Under the intermediate thermal load scenario, DOE would place the same inventory of materials in the repository as under the high thermal load scenario. This scenario would differ from the high thermal load scenario by increased spacing between the emplacement drifts. Thus, the radioactive and chemically hazardous material would be spread out over about 4.3 square kilometers (1,100 acres) rather than the approximately 3 square kilometers (740 acres) for the high thermal load scenario.

Table 5-8 lists the mean and 95th-percentile consequences of the set of 100 peak dose rates computed for this scenario. It also lists the dose to the maximally exposed individual and the resultant probability of a latent cancer fatality. The radionuclides contributing the most to the individual dose in 10,000 years would be technetium-99, iodine-129, and carbon-14. Figure 5-5 shows how peak dose increases over the first 10,000 years at the 20-kilometer (12-mile) distance and would remain below 1 millirem per year during this period.

Table 5-8. Consequences for a maximally exposed individual from groundwater releases of radionuclides during 10,000 years after repository closure for the intermediate thermal load scenario.

	Mean consequence[b]		95th-percentile consequence[c]	
MEI[a]	Peak dose rate (millirem/year)[d]	Probability of an LCF[e]	Peak dose rate (millirem/year)[d]	Probability of an LCF
At 5 kilometers[f]	1.4×10^{-1}	4.9×10^{-6}	1.1	3.9×10^{-5}
At 20 kilometers	1.3×10^{-1}	4.5×10^{-6}	5.8×10^{-1}	2.0×10^{-5}
At 30 kilometers	4.6×10^{-2}	1.6×10^{-6}	1.1×10^{-1}	3.9×10^{-6}
At discharge location[g]	2.9×10^{-3}	1.0×10^{-7}	1.9×10^{-3}	6.6×10^{-8}

a. MEI = maximally exposed individual.

b. Based on four sets, one for each distance, of 100 simulations of total system performance, each using random samples of uncertain parameters.

c. Represents a value for which 95 out of the 100 simulations yielded a smaller value.

d. All peaks occur at or near 10,000 years, indicating that the dose rate would still be rising at the end of the simulation period.

e. LCF = latent cancer fatality; incremental lifetime (70 years) risk of contracting a fatal cancer for individuals, assuming a risk of 0.0005 latent cancer per rem for members of the public (NCRP 1993a, page 31).

f. To convert kilometers to miles, multiply by 0.62137.

g. 80 kilometers at Franklin Lake Playa.

Table 5-9 lists the population consequences for the intermediate thermal load scenario. The scaling factor for changing the dose rate for the maximally exposed individual into a dose rate for a member of the population was computed by diluting the approximately 31,000 cubic meters (25 acre-feet) of water infiltrating through the Yucca Mountain Repository (see Appendix I, Section I.4.5.3) by the annual water use in the Amargosa Valley of about 17.3 million cubic meters (14,000 acre-feet).

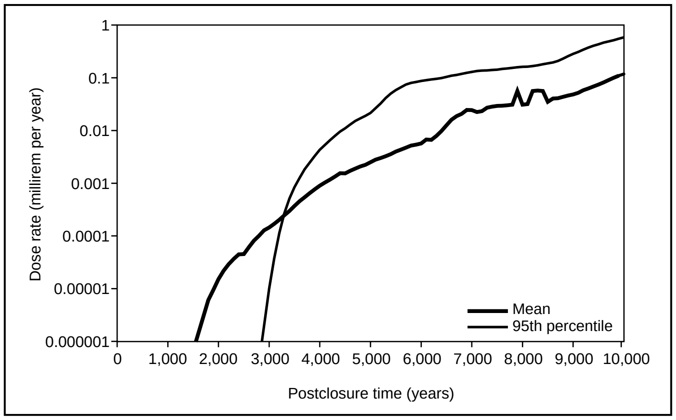


Figure 5-5. 10,000-year history of dose at 20 kilometers (12 miles) from the repository for the intermediate thermal load scenario.

Table 5-9. Population consequences from groundwater releases of radionuclides during 10,000 years after repository closure for the intermediate thermal load scenario.

	Mean consequence[a]		95th-percentile consequence[b]	
Case	Population dose (person-rem)	Population LCF[c]	Population dose (person-rem)	Population LCF
Peak 70-year lifetime	6.6×10^{-3}	3.3×10^{-6}	1.7×10^{-2}	8.3×10^{-6}
Integrated over 10,000 years	1.3×10^{-1}	6.7×10^{-5}	3.6×10^{-1}	1.8×10^{-4}

a. Based on four sets, one for each distance, of 100 simulations of total system performance, each using random samples of uncertain parameters.

b. Represents a value for which 95 out of the 100 simulations yielded a smaller value.

c. LCF = latent cancer fatality; expected number of cancer fatalities for populations, assuming a risk of 0.0005 latent cancer per rem for members of the public (NCRP 1993a, page 31).

Table 5-10 lists results for peak consequences for the 1-million-year period. The radionuclides that would contribute the most to the peak dose rate would be neptunium-237 and plutonium-242. As with the 10,000-year case, there would be no meaningful trend due to thermal load in a comparison of this table to the similar table for higher thermal load scenarios.

Table 5-10. Maximally exposed individual doses from groundwater releases of radionuclides during 1 million years after repository closure for the intermediate thermal load scenario.

	Mean[b]		95th-percentile[c]	
MEI[a]	Peak dose rate (millirem/year)	Time of peak (years)	Peak dose rate (millirem/year)	Time of peak (years)
At 5 kilometers[d]	470	296,000	2,800	320,000
At 20 kilometers	170	804,000	900	712,000
At 30 kilometers	90	418,000	500	932,000
At discharge location[e]	30	872,000	120	702,000

a. MEI = maximally exposed individual.

b. Based on four sets, one for each distance, of 100 simulations of total system performance, each using random samples of uncertain parameters.

c. Represents a value for which 95 out of the 100 simulations yielded a smaller value.

d. To convert kilometers to miles, multiply by 0.62137.

e. 80 kilometers at Franklin Lake Playa

Table 5-11 lists peak radionuclide concentrations in water at four human exposure locations for the intermediate thermal load scenario. The peak concentrations would be from the first 10,000 years after

Table 5-11. Peak radionuclide concentrations (picocuries per liter) in water and associated annual drinking water dose at human exposure distances for 10,000 years after repository closure for the intermediate thermal load scenario.

	Mean consequence[a,b]				95th-percentile consequence[c]			
	Distance (kilometers)[d]				Distance (kilometers)			
Radionuclide	5	20	30	80	5	20	30	80
Carbon-14	1.2	1.1	4.4×10^{-1}	1.6×10^{-2}	9.6	5.9	6.7×10^{-1}	4.1×10^{-2}
Iodine-129	8.0×10^{-2}	5.5×10^{-2}	2.9×10^{-2}	1.1×10^{-3}	7.2×10^{-1}	4.3×10^{-1}	4.8×10^{-2}	2.8×10^{-3}
Neptunium-237	9.1×10^{-5}	8.0×10^{-9}	7.5×10^{-16}	2.2×10^{-23}	1.3×10^{-6}	4.2×10^{-14}	5.1×10^{-22}	2.4×10^{-24}
Protactinium-231	1.5×10^{-14}	5.0×10^{-26}	3.8×10^{-26}	3.8×10^{-26}	1.2×10^{-26}	1.6×10^{-24}	1.6×10^{-24}	7.6×10^{-27}
Plutonium-239	6.9×10^{-6}	3.2×10^{-9}	2.4×10^{-10}	7.0×10^{-13}	6.3×10^{-10}	3.0×10^{-10}	2.7×10^{-12}	2.5×10^{-11}
Plutonium-242	4.8×10^{-8}	2.2×10^{-11}	1.4×10^{-12}	4.8×10^{-15}	3.5×10^{-12}	1.8×10^{-12}	9.3×10^{-15}	1.7×10^{-13}
Selenium-79	9.4×10^{-2}	4.3×10^{-4}	2.6×10^{-6}	2.0×10^{-21}	5.0×10^{-1}	1.8×10^{-18}	1.3×10^{-18}	3.1×10^{-21}
Technetium-99	2.1×10^{1}	1.7×10^{1}	4.5	3.7×10^{-1}	4.3×10^{2}	1.8×10^{2}	1.7×10^{1}	1.1
Uranium-234	1.9×10^{-5}	4.0×10^{-11}	7.8×10^{-17}	2.9×10^{-23}	1.3×10^{-7}	6.3×10^{-16}	2.9×10^{-23}	2.1×10^{-23}
Gross alpha[e]	9.8×10^{-5}	1.1×10^{-8}	2.4×10^{-10}	7.0×10^{-13}	1.3×10^{-6}	3.1×10^{-10}	2.7×10^{-12}	2.5×10^{-11}
Annual drinking water dose (millirem)	4.1×10^{-2}	3.1×10^{-2}	1.1×10^{-2}	6.5×10^{-4}	6.2×10^{-1}	2.9×10^{-1}	2.9×10^{-2}	1.8×10^{-3}

a. Based on four sets, one for each distance, of 100 simulations of total system performance, each using random samples of uncertain parameters.

b. The concentrations for the mean and 95th-percentile consequences are the concentrations that yielded the mean and 95th-percentile doses listed in Table 5-8.

c. Represents a value for which 95 out of the 100 simulations yielded a smaller value.

d. To convert kilometers to miles, multiply by 0.62137.

e. By regulatory convention, the gross alpha does not include uranium.

repository closure. The table also lists the gross alpha-particle activity (excluding uranium). The drinking water dose is associated with drinking exactly 2 liters (approximately 0.5 gallon) of water each day. For both the mean and 95th-percentile consequences, the gross alpha activity would be much lower than the 15 picocuries per liter specified as the attainment limit for drinking water for community water systems [40 CFR Part 141 Subpart 15(a)]. The dose rates from drinking 2 liters (0.5 gallon) of water a day would also be below the 4-millirem-per-year limit for community water systems [40 CFR Part 141 Subpart 16(a)].

5.4.3 CONSEQUENCES FROM THE GROUNDWATER EXPOSURE PATHWAY FOR THE LOW THERMAL LOAD SCENARIO

Under the low thermal load scenario, the same inventory of materials would be placed in the repository as under the high thermal load scenario. This scenario would differ from the high thermal load scenario by increased spacing between the emplacement drifts and increased spacing between waste packages in the drifts. Thus, the radioactive and chemically hazardous contamination would be spread over about 10 square kilometers (2,500 acres) rather than the approximately 3 square kilometers (740 acres) used for the high thermal load scenario.

Table 5-12 lists the mean and 95th-percentile consequences of the set of 100 peak dose rates computed for the low thermal load scenario. It also lists the dose to the maximally exposed individual and the resultant probability of a latent cancer fatality. The radionuclides contributing the most to the individual dose in 10,000 years would be iodine-129, technetium-99, and carbon-14. Figure 5-6 shows how peak dose increases over the first 10,000 years at the 20-kilometer (12-mile) distance and would remain at or below 0.1 millirem per year during that time.

Table 5-12. Consequences for a maximally exposed individual from groundwater releases of radionuclides during 10,000 years after repository closure for the low thermal load scenario.

	Mean consequence[b]		95th-percentile consequence[c]	
MEI[a]	Peak dose rate (millirem/year)[d]	Probability of an LCF[e]	Peak dose rate (millirem/year)[d]	Probability of an LCF
At 5 kilometers[f]	1.3×10^{-1}	4.7×10^{-6}	1.6×10^{-1}	5.6×10^{-6}
At 20 kilometers	5.9×10^{-2}	2.1×10^{-6}	6.1×10^{-2}	2.1×10^{-6}
At 30 kilometers	4.0×10^{-2}	1.4×10^{-6}	2.3×10^{-2}	8.1×10^{-7}
At discharge location[g]	5.3×10^{-4}	1.9×10^{-8}	1.9×10^{-3}	6.6×10^{-8}

a. MEI = maximally exposed individual.
b. Based on four sets, one for each distance, of 100 simulations of total system performance, each using random samples of uncertain parameters.
c. Represents a value for which 95 out of the 100 simulations yielded a smaller value.
d. All peaks occur at or near 10,000 years, indicating that the dose rate would still be rising at the end of the simulation period.
e. LCF = latent cancer fatality; incremental lifetime (70 years) risk of contracting a fatal cancer for individuals, assuming a risk of 0.0005 latent cancer per rem for members of the public (NCRP 1993a, page 31).
f. To convert kilometers to miles, multiply by 0.62137.
g. 80 kilometers at Franklin Lake Playa.

Table 5-13 lists the population doses associated with the low thermal load scenario. The scaling factor for changing the dose rate for the maximally exposed individual into a dose rate for a member of the population was computed by diluting 57,000 cubic meters (46 acre-feet) of water infiltrating through the repository (see Section I.4.5.3) by the annual water use in the Amargosa Valley of about 17.3 million cubic meters (14,000 acre-feet). The repository infiltration rate would not increase in proportion to the decreased thermal load because, as the repository expanded, DOE would use additional areas where the infiltration rates would be different than those for the repository areas under the high thermal load scenario.

Table 5-13. Population consequences from groundwater releases of radionuclides during 10,000 years after repository closure for the low thermal load scenario.

	Mean consequence[a]		95th-percentile consequence[b]	
Case	Population dose (person-rem)	Population LCF[c]	Population dose (person-rem)	Population LCF
Peak 70-year lifetime	1.1×10^{-2}	5.3×10^{-6}	6.2×10^{-3}	3.1×10^{-6}
Integrated over 10,000 years	2.7×10^{-1}	1.3×10^{-4}	1.2×10^{-1}	6.0×10^{-5}

a. Based on four sets, one for each distance, of 100 simulations of total system performance, each using random samples of uncertain parameters.
b. Represents a value for which 95 out of the 100 simulations yielded a smaller value.
c. LCF = latent cancer fatality; expected number of cancer fatalities for populations, assuming a risk of 0.0005 latent cancer per rem for members of the public (NCRP 1993a, page 31).

Table 5-14 lists the same type of results as those in Table 5-12, but the interval is 1 million years after repository closure. The radionuclides that would contribute the most to the peak dose rate would be neptunium-237, plutonium-242, and plutonium-239. As with the 10,000-year case, this table indicates no meaningful trend due to thermal load in comparison to the similar table for higher thermal load scenarios.

Table 5-15 lists peak radionuclide concentrations in water at four human exposure locations for the low thermal load scenario for the 10,000-year period. It also lists the gross alpha particle activity (excluding uranium). For the mean and 95th-percentile consequences, the gross alpha activity would be much lower than 15 picocuries per liter at all distances. The dose rates associated with drinking exactly 2 liters (0.5 gallon) of water each day are provided. As with the other results in this section, this table indicates no meaningful trend due to thermal load in comparison to the similar table for higher thermal load scenarios (Table 5-7).

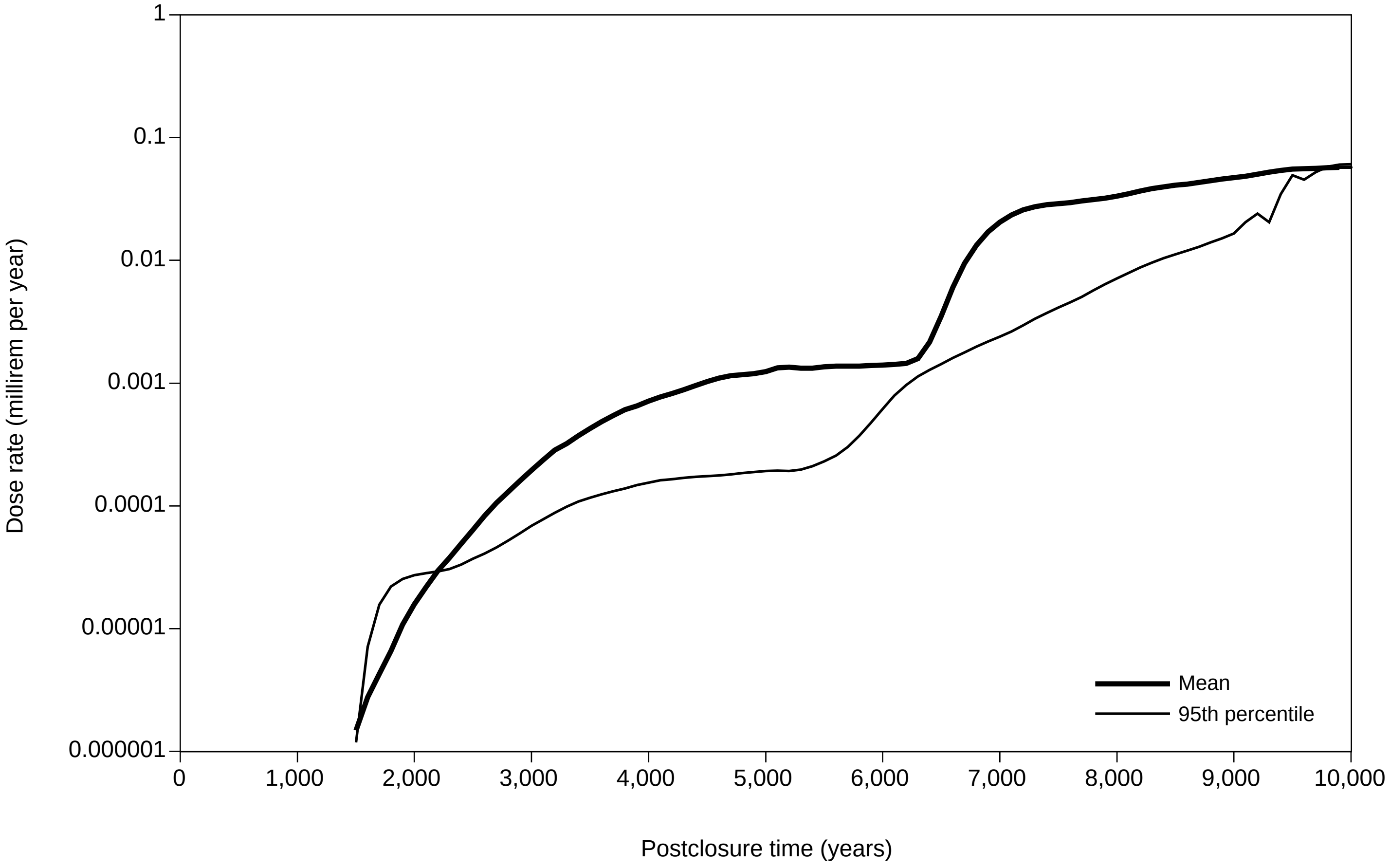


Figure 5-6. Peak dose increases over the first 10,000 years at 20 kilometers (12 miles) from the repository.

Table 5-14. Maximally exposed individual doses from groundwater releases of radionuclides during 1 million years after repository closure for the low thermal load scenario.

	Mean[b]		95th-percentile[c]	
MEI[a]	Peak dose rate (millirem/year)	Time of peak (years)	Peak dose rate (millirem/year)	Time of peak (years)
At 5 kilometers[d]	630	296,000	3,600	320,000
At 20 kilometers	160	804,000	860	334,000
At 30 kilometers	70	400,000	360	308,000
At discharge location[e]	40	824,000	160	726,000

a. MEI = maximally exposed individual.

b. Based on four sets, one for each distance, of 100 simulations of total system performance, each using random samples of uncertain parameters.

c. Represents a value for which 95 out of the 100 simulations yielded a smaller value.

d. To convert kilometers to miles, multiply by 0.62137.

e. 80 kilometers at Franklin Lake Playa.

Table 5-15. Peak radionuclide concentrations (picocuries per liter) in water and associated annual drinking water dose at human exposure distances for 10,000 years after repository closure for the low thermal load scenario.

	Mean consequence[a,b]				95th-percentile consequence[c]			
	Distance (kilometers)[d]				Distance (kilometers)			
Radionuclide	5	20	30	80	5	20	30	80
Carbon-14	1.6	7.9×10^{-1}	4.0×10^{-1}	6.7×10^{-3}	5.6	5.9	2.1×10^{-1}	3.1×10^{-2}
Iodine-129	1.0×10^{-1}	5.0×10^{-2}	2.3×10^{-2}	4.8×10^{-4}	4.0×10^{-1}	1.5×10^{-1}	1.8×10^{-25}	2.4×10^{-3}
Neptunium-237	7.3×10^{-4}	9.3×10^{-12}	2.2×10^{-16}	9.1×10^{-23}	1.4×10^{-6}	4.0×10^{-12}	7.1×10^{-25}	7.1×10^{-25}
Protactinium-231	1.4×10^{-16}	2.6×10^{-24}	7.8×10^{-26}	7.9×10^{-26}	1.6×10^{-16}	7.7×10^{-27}	2.2×10^{-27}	2.2×10^{-27}
Plutonium-239	9.4×10^{-5}	2.4×10^{-9}	1.1×10^{-9}	6.5×10^{-13}	2.5×10^{-13}	7.7×10^{-16}	4.0×10^{-14}	7.7×10^{-13}
Plutonium-242	6.9×10^{-7}	1.6×10^{-11}	5.5×10^{-12}	4.5×10^{-15}	3.2×10^{-16}	4.3×10^{-18}	2.8×10^{-16}	5.5×10^{-15}
Selenium-79	2.7×10^{-1}	4.4×10^{-6}	8.9×10^{-12}	7.8×10^{-22}	3.2	1.8×10^{-7}	1.7×10^{-21}	1.6×10^{-20}
Technetium-99	1.7×10^{1}	7.3	4.5	7.2×10^{-2}	1.9	1.4×10^{1}	6.3	3.4×10^{-1}
Uranium-234	3.1×10^{-6}	1.5×10^{-12}	4.1×10^{-16}	1.5×10^{-23}	2.0×10^{-7}	6.7×10^{-11}	6.2×10^{-24}	6.2×10^{-24}
Gross alpha[e]	8.2×10^{-4}	2.4×10^{-9}	1.1×10^{-9}	6.6×10^{-13}	1.4×10^{-6}	4.0×10^{-12}	4.0×10^{-14}	7.7×10^{-13}
Annual drinking water dose (millirem)	4.4×10^{-2}	1.9×10^{-2}	1.0×10^{-2}	1.8×10^{-4}	9.5×10^{-2}	5.3×10^{-2}	7.0×10^{-3}	9.1×10^{-4}

a. Based on four sets, one for each distance, of 100 simulations of total system performance, each using random samples of uncertain parameters.

b. The concentrations for the mean and 95th-percentile consequences would be the concentrations that yielded the mean and 95th-percentile doses reported in Table 5-12.

c. Represents a value for which 95 out of the 100 simulations yielded a smaller value.

d. To convert kilometers to miles, multiply by 0.62137.

e. By regulatory convention, the gross alpha does not include uranium.

5.4.4 SENSITIVITY STUDY ON THE FUEL CLADDING MODEL

The analysis assumed that the zirconium alloy cladding on about 0.1 percent of the fuel rods in commercial spent nuclear fuel would fail before the fuel was placed in the repository. This failure rate is two times higher than that reflected in data reported by the Electric Power Research Institute (TRW 1998k, pages 6-25 to 6-27). A modeling assumption underlying the groundwater-based consequences described in Sections 5.4.1 through 5.4.3 is that the intact cladding on the spent fuel rods would be very resistant to corrosion. Rothman (1984, all) compared the oxidation rates assessed by six different authors and estimated that corrosion amounts would vary from 4 to 53 micrometers (0.00016 to 0.0021 inch) for cladding exposed for 10,000 years at 180° C (356° F) in a wide variety of chemical conditions at lower and higher pHs than those estimated for the repository. The six corrosion models used a temperature dependency that estimated near-zero corrosion rates for long-term repository temperatures. A recent paper confirmed the ability of zirconium alloy cladding to resist corrosion in the Yucca Mountain environment (Hillner, Franklin, and Smee 1998, all). The typical cladding for fuel rods would be 570 micrometers (0.022 inch) thick. The cladding model used for this analysis estimated that between 0.3 and 40 percent of the zirconium alloy fuel rod cladding would fail after 1 million years (DOE 1998a, Volume 3, page 4-12).

Because zirconium alloy has been used as a cladding on fuel rods for a little over 40 years, there are different opinions about its ability to provide long-term protection (over thousands of years) of fuel rod contents. There is some uncertainty about whether the radioactive and thermal environment inside the waste packages would alter the zirconium alloy enough that it would not provide much protection against waste mobilization after the waste package failed. DOE performed a sensitivity analysis to assess the importance of cladding protection on dose impacts. Additional stochastic (random) runs for 10,000 and 1 million years after repository closure were performed under the assumption that the zirconium alloy cladding would provide no resistance to water or radionuclide movement after the waste package failed. Table 5-16 compares the peak dose rate from groundwater transport of radionuclides for the two different cladding models. The analysis used data representing the high thermal load scenario to calculate individual exposures for a 20-kilometer (12-mile) distance.

Table 5-16. Comparison of consequences for a maximally exposed individual from groundwater releases of radionuclides using different fuel rod cladding models under the high thermal load scenario.

	Mean consequence[a]		95th-percentile consequence[b]	
Maximally exposed individual	Dose rate (millirem/year)	Probability of an LCF[c]	Dose rate (millirem/year)	Probability of an LCF
Peak at 20 kilometers[d] within 10,000 years after repository closure with cladding credit	0.22	7.6×10^{-6}	0.58	2.0×10^{-5}
Peak at 20 kilometers within 10,000 years after repository closure without cladding credit	5.4	1.9×10^{-4}	15	5.3×10^{-4}
Peak at 20 kilometers within 1 million years after repository closure with cladding credit	260	9.0×10^{-3}	1,400	5.0×10^{-2}
Peak at 20 kilometers within 1 million years after repository closure without cladding credit	3,000	1.1×10^{-1}	10,800	3.8×10^{-1}

a. Based on sets of 100 simulations of total system performance, each using random samples of uncertain parameters.

b. Represents a value for which 95 out of the 100 simulations yielded a smaller value.

c. LCF = latent cancer fatality; incremental lifetime (70 years) risk of contracting a fatal cancer for individuals, assuming a risk of 0.0005 latent cancer per rem for members of the public (NCRP 1993a, page 31).

d. To convert kilometers to miles, multiply by 0.62137.

A comparison of the peak dose rates for the 10,000-year analysis showed that the estimated human health effects would increase if credit for the zirconium alloy cladding were eliminated. The estimated consequences would be approximately 25 times larger for both the mean and 95th-percentile consequences. A comparison of the peak dose rates for the 1-million-year analysis showed that the estimated human health effects would increase by a smaller amount if the zirconium alloy cladding were eliminated. The increase was about 12 times the mean consequence and 8 times the 95th-percentile consequence. Similar impacts would occur to drinking water concentrations.

The no-cladding analysis assumed that the zirconium alloy cladding would not provide any barrier to water movement and radionuclide mobilization after the waste package failed. However, DOE expects that the zirconium alloy would provide some impediment to radionuclide mobilization if the waste package was breached (DOE 1998a, Volume 3, page O-8). Therefore, the results for no cladding credit listed in Table 5-16 could be viewed as upper bounds on dose and health effects.

5.5 Atmospheric Radiological Consequences

After DOE closed the repository, there would be limited potential for releases to the atmosphere because the waste would be isolated far below the ground surface. Still, the rock is porous and does allow gas to flow, so the analysis must consider possible airborne releases. The only radionuclide in the analysis after screening (see Table 5-1) with a potential for gas transport is carbon-14 in the form of carbon dioxide. Iodine-129 can exist in a gas phase, but DOE expects it would dissolve in the groundwater rather than migrate as a gas. The solubility of iodine-129 is a great deal higher than that of carbon dioxide, and the water is already saturated in carbon dioxide because of interaction with carbonate rocks. After the carbon-14 escaped as carbon dioxide from the waste package, it would flow through the rock. About 2 percent of the carbon-14 in commercial spent nuclear fuel is in a gas phase in the space (or gap) between the fuel and the cladding around the fuel (Oversby 1987, page 92). The atmospheric model used a gas-phase inventory of 0.234 curie of carbon-14 per waste package of commercial spent nuclear fuel at the time of emplacement. The atmospheric model estimated human health impacts for the population in the 84-kilometer (52-mile) region surrounding the repository and for the global population.

5.5.1 CARBON-14 SOURCE TERM

The calculation of regional doses used an estimate of the annual release rate of carbon-14. The analysis based the carbon-14 release rate on the estimated time line of container failures for the high thermal load scenario, using average values for the stochastic (random) parameters that were input. The expected number of spent nuclear fuel waste package failures as a function of time was used to estimate the carbon-14 release rate after repository closure. The amount of material released from each package as a function of time was reduced to account for radioactive decay. As for the waterborne releases described in Section 5.4, some credit was taken for the intact zirconium alloy cladding (on approximately 99 percent of the spent nuclear fuel by volume) delaying the release of gas-phase carbon-14. The zirconium alloy cladding on 0.1 percent of the fuel was assumed to have failed in the reactor environment (DOE 1998a, Volume 3, page 3-97), and the stainless-steel cladding on approximately 1.2 percent of the total spent fuel inventory was also assumed to have failed before it was placed in the waste package. Thus, gas-phase releases from this fuel would have occurred before it was shipped to the repository. Appendix I contains more details on the release model and reports a sensitivity study that assumed some of the stainless-steel cladding was intact when placed in the waste package. The maximum annual-release rate would occur about 19,000 years after repository closure. The estimated maximum release rate is 9.8×10^{-8} curies per year.

5.5.2 ATMOSPHERIC CONSEQUENCES TO THE LOCAL POPULATION

DOE used the GENII program (Napier et al. 1997, all) to model the atmospheric transport and human uptake of the released carbon-14 for the 84-kilometer (52-mile) population dose calculation. Doses to the regional population around Yucca Mountain from carbon-14 releases were estimated using the population distribution shown in Chapter 3, Figure 3-21, which indicates that 28,000 people would live in the region surrounding Yucca Mountain in 2000. The computation also used current (1993 to 1996) annual average meteorology (see Appendix I, Table I-5). GENII calculated a dose factor of 2.2×10^{-9} person-rem per microcurie per year of release. For a 0.098-microcurie-per-year release, this corresponds to a 7.8×10^{-15} rem-per-year average dose to individuals in the population. Thus, a maximum 84-kilometer population dose rate is 2.2×10^{-10} person-rem per year. This dose rate corresponds to 1.1×10^{-13} latent cancer fatality in the regional population of 28,000 persons during each year at the maximum carbon-14 release rate. This annual dose yields an average lifetime dose of 1.5×10^{-8} rem over a 70-year lifetime, corresponding to 7.6×10^{-12} latent cancer fatality during the 70-year period of the maximum release rate.

5.6 Consequences from Chemically Toxic Materials

A number of materials that DOE would place in the repository are hazardous to human health at sufficient concentrations in water. This section examines the consequences to individuals in the Amargosa Valley from releases of nonradioactive materials. Appendix I, Section I.3.2 describes the screening analysis DOE used to select constituents for detailed analysis.

5.6.1 HUMAN HEALTH IMPACTS FROM CHROMIUM

There would be about 14,000 metric tons (15,000 tons) of chromium in the repository under the Proposed Action (see Table 5-2). About 70 percent of the chromium would be in the Alloy-22 used for the corrosion-resistant layer of the waste packages, and the remainder would be in stainless-steel components inside the waste packages (for example, brackets, fixtures, separators, some cladding, and additional interior canisters). Chemical modeling studies of the corroding waste packages showed that the hexavalent form of chromium would dominate, primarily because the environment at the point of corrosion would have a very low pH and because there would be enough oxygen to support the complete oxidation of chromium. The hexavalent form is highly soluble and toxic to humans.

There are two measures for comparing the human health effects for chromium. When the Environmental Protection Agency established its Maximum Contaminant Level Goals, it considered safe levels of contaminants in drinking water and the ability to achieve these levels with the best available technology. The Maximum Contaminant Level Goal for chromium is 0.1 milligram per liter (0.0000062 pound per cubic foot) (40 CFR 141.51). The other measure for comparison is the reference dose factor for chromium, which is 0.005 milligram per kilogram (0.0004 ounce per pound) of body mass per day (EPA 1998a, all). The reference dose factor represents a level of intake that has no adverse effect on humans. It can be converted to a threshold concentration level for drinking water. The conversion yields essentially the same concentration for the reference dose factor as the Maximum Contaminant Level Goal.

One hundred simulations were run to model the release and transport of chromium for 10,000 years following repository closure. The consequences were computed at the distances used for waterborne radionuclide impacts [5, 20, 30, and 80 kilometers (3, 12, 19, and 50 miles) from the repository]. Results from a two-stage model accounting for both chromium from the inner shell of Alloy-22 and the interior stainless-steel components in some of the waste forms (spacers, grids, hardware, cladding, additional containment cans, etc.) demonstrated that the interior stainless steel mass could be neglected in estimating peak chromium concentrations in the accessible environment. Therefore, the calculation of the release rate of chromium from the repository used the inventory and corrosion rate of Alloy-22. Appendix I contains details on the chromium modeling runs. Table 5-17 lists the peak chromium concentrations computed for each model run.

Table 5-17. Peak chromium concentrations (milligrams per liter)[a] in water for 10,000 years after closure at four locations by thermal load scenario.[b]

	High thermal load		Intermediate thermal load		Low thermal load	
MEI[c]	Mean	95th-percentile	Mean	95th-percentile	Mean	95th-percentile
At 5 kilometers[d]	0.0085	0.037	0.0029	0.0096	0.0046	0.016
At 20 kilometers	0.0028	0.012	0.0023	0.010	0.0018	0.0083
At 30 kilometers	0.0018	0.0063	0.00080	0.0038	0.00067	0.0033
At 80 kilometers	0.00022	0.00061	0.000031	0.00015	0.000053	0.00034

a. To convert milligrams per liter to pounds per cubic foot, multiply by 0.0000624.

b. Based on 100 simulations of total system performance using random samples of uncertain parameters.

c. MEI = maximally exposed individual.

d. To convert kilometers to miles, multiply by 0.62137.

For the high thermal load scenario, the mean peak concentrations would range from a high of 8.5×10^{-3} milligram per liter (5.3×10^{-7} pound per cubic foot) at 5 kilometers (3 miles) down to 2.2×10^{-4} milligram per liter (1.4×10^{-8} pound per cubic foot) at 80 kilometers (50 miles). The 95th-percentile peak concentrations would range from a high at 5 kilometers of 0.037 milligram per liter (2.3×10^{-6} pound per cubic foot) down to 6.1×10^{-4} milligram per liter (3.8×10^{-8} pound per cubic foot) at 80 kilometers. Because none of the estimated concentrations exceed the Maximum Contaminant Level Goal or reference dose factor, DOE anticipates no detrimental impacts to water quality due to chromium contamination under the high thermal load scenario.

For the intermediate thermal load scenario, the mean peak concentrations would range from a high of 2.9×10^{-3} milligram per liter (1.8×10^{-7} pound per cubic foot) at 5 kilometers (3 miles) down to 3.1×10^{-5} milligram per liter (1.9×10^{-9} pound per cubic foot) at 80 kilometers (50 miles).

The 95th-percentile peak concentrations would range from a high at 5 kilometers (3 miles) of 0.01 milligram per liter (6.2×10^{-7} pound per cubic foot) down to 1.5×10^{-4} milligram per liter (9.4×10^{-9} pound per cubic foot) at 80 kilometers (50 miles). Because none of the estimated concentrations exceed the Maximum Contaminant Level Goal or reference dose factor, DOE anticipates no detrimental impacts to water quality due to chromium contamination under the intermediate thermal load scenario.

For the low thermal load scenario, the mean peak concentrations would range from a high of 4.6×10^{-3} milligram per liter (2.9×10^{-7} pound per cubic foot) at 5 kilometers (3 miles) down to 5.3×10^{-5} milligram per liter (3.3×10^{-9} pound per cubic foot) at 80 kilometers (50 miles). The 95th-percentile peak concentrations would range from a high at 5 kilometers of 0.016 milligram per liter (1.0×10^{-6} pound per cubic foot) down to 3.4×10^{-4} milligram per liter (2.1×10^{-8} pound per cubic foot) at 80 kilometers. In some instances (for example, 5 and 80 kilometers), the chromium concentrations are higher for the low thermal load than the intermediate thermal load. This is caused by the effect of the repository-area shape on the calculation of the dilution factors used for the saturated zone and the correlative differences in the percolation flux. Section I.5.2 in Appendix I discusses these factors with respect to waterborne radioactive materials (this discussion is also applicable to waterborne chemically toxic materials). Because none of the estimated concentrations exceed the Maximum Contaminant Level Goal or reference dose factor; DOE anticipates no detrimental impacts to water quality due to chromium contamination under the low thermal load scenario.

At present, the carcinogenicity of hexavalent chromium by the oral route of exposure cannot be determined because of a lack of sufficient epidemiological and toxicological data (EPA 1998a, page 48; EPA 1998b, all). Therefore, the groundwater concentrations reported in Table 5-17 cannot be expressed in terms of human health effects (latent cancer fatalities).

5.6.2 HUMAN HEALTH IMPACTS FROM MOLYBDENUM

The Alloy-22 to be used as a waste package inner-barrier would contain 13.5 percent molybdenum. During the corrosion of Alloy-22, molybdenum would mobilize almost in the same manner as chromium. Due to the corrosion conditions, molybdenum would dissolve in a highly soluble hexavalent form. Because the releases of both chromium and molybdenum would be constrained by the degradation rate of Alloy-22, the source term concentration for molybdenum would be approximately 0.64 (13.5/21.25) times the source term concentration for chromium. Detailed transport modeling of molybdenum would use the same mechanisms and parameters as those for chromium, so modeling is unnecessary. Molybdenum in the water at concentrations 0.64 times those reported above for chromium is a reasonable estimate. No regulatory standard for molybdenum has been established. Because the concentrations are very low, DOE anticipates no detrimental impacts to water quality due to molybdenum contamination under any of the thermal load scenarios.

5.6.3 HUMAN HEALTH IMPACTS FROM URANIUM (AS A CHEMICALLY TOXIC MATERIAL)

DOE ran 100 simulations to model the release and transport of uranium for the Proposed Action inventory. The Proposed Action inventory would contain approximately 70,000 MTHM (see Table 5-2). While a small percentage of the heavy metal in the spent fuel would not be uranium, assuming that all of it is uranium is reasonable because such an assumption would have a very small effect on the result. Furthermore, the analysis would tend to overestimate health effects because it assumed that the MTHM basis of high-level radioactive waste is uranium when there is very little uranium in that material. This introduces an approximate 7-percent increase into the result (see Table 5-2 and the accompanying discussion). The simulations were based on the high thermal load scenario, and the consequences were computed for exposures at 5 kilometers (3 miles) from the repository. In addition, the analysis assumed that uranium did not undergo radioactive decay. Appendix I contains more details of the modeling runs. The maximum uranium concentration over 10,000 years was calculated for each model simulation. The mean peak concentration of uranium would be 6.7×10^{-8} milligram per liter (5.2×10^{-9} pound per cubic foot) and the 95th-percentile peak concentration would be 2.2×10^{-8} milligram per liter (1.7×10^{-9} pound per cubic foot). The Environmental Protection Agency has proposed a Maximum Contaminant Level of 0.02 milligram per liter (0.02 part per million) (56 *FR* 33050, July 18, 1991). Because the concentrations would be very low (about 1 million times less than the proposed Maximum Contaminant Level), DOE anticipates no detrimental impacts to water quality due to uranium contamination under any of the thermal load scenarios.

The reference dose for elemental uranium is 0.003 milligram per kilogram of body mass per day (Eckerman and Ryman 1993, all). Assuming a maximum individual exposure from the drinking water pathway, the analysis used a 2-liter (0.52-gallon)-per-day intake rate and a 70-kilogram (153-pound) body weight to convert the reference dose to a threshold concentration, which would be 0.105 milligram per liter (0.0000063 pound per cubic foot). There is no Maximum Contaminant Level for elemental uranium.

Based on trends in waterborne radioactive material results, the concentrations of elemental uranium at more distant locations [20, 30, and 80 kilometers (12, 19, and 50 miles)] would be even lower. This observation also applies to the intermediate and low thermal load scenarios at all distances. Because of the extremely low concentrations calculated from these simulations, further simulations were not performed to evaluate other thermal loads under the Proposed Action. The calculated concentrations were many orders of magnitude below the threshold. Therefore, DOE believes elemental uranium would not present a health risk as a chemically toxic material under the Proposed Action for any thermal load scenario.

5.7 Consequences from Disruptive Events

The postclosure performance estimates discussed above include the possible effects of changing climate but do not address events that could physically disturb the repository. In general, disruptive events have identifiable starting and ending times, in contrast to continuous processes such as corrosion. The disruptive events examined in this section are an inadvertent intrusion into the repository by a drilling crew, seismic activity, and basaltic igneous (volcanic) activity. The choice of these three events is consistent with the analyses in the Viability Assessment (DOE 1998a, Volume 3, pages 4-80 to 4-102). The results in Section 5.7 are derived from that document, with no new model runs being performed for this EIS. The Viability Assessment used a model run, called the base case, as a reference case to determine the magnitude of impacts from the disruptive events. The base case is the same as the analysis for 85 MTHM per acre thermal load doses evaluated at a 20-kilometer (12-mile) distance in this EIS (the results are summarized in Table 5-4). The base case discussed in this section used the mean values of all the stochastic (random) parameters as inputs.

5.7.1 DRILLING INTRUSIONS

Human intrusion is generally interpreted to mean inadvertent penetration of the repository (such as by drilling operations) that would either release radionuclides at the surface or accelerate radionuclide transport to the dose-exposure location. The National Academy of Sciences has recommended that the direct impact of human intrusion not be considered in Total System Performance Assessment (National Research Council 1995, Chapter 4). The analysis reported here used the consequences of human intrusion, in terms of potential increases in long-term doses to the exposed public rather than impacts to the drilling crew, to measure the resilience of the repository to such disturbances. The Viability Assessment contains further details of the analysis and its basis (DOE 1998a, Volume 3, pages 4-99 to 4-102).

The analysis of human intrusion assumed that 10,000 years after closure, a drilling operation would penetrate the repository. The drilling event was modeled as occurring at 10,000 years after repository closure because waste packages probably would be degraded enough that a drill could penetrate them. The analysis also assumed that the intrusion would penetrate a waste package with a 21-centimeter (8.3-inch) drill bit. It assumed that the drilling proceeded through the waste package and down to the level of the water table. When the drill bit was removed, radioactive waste would fall down the drill hole to the saturated zone beneath the repository. There, flowing water would dissolve the waste and carry it to the accessible environment.

The analysis modeled a case in which 550 kilograms (1,200 pounds) of waste dropped down the hole and then dissolved at a slow rate (Figure 5-7) [considered a lower bounding situation (DOE 1998a, pages 4-99 to 4-102)]. The peak dose for this case in the first 10,000 years after the intrusion would be about 3.7 times that of the base case peak dose. Another case was modeled in which 2,700 kilograms (5,950 pounds) of waste fell down the hole and dissolved at a high rate [considered an upper bounding situation (DOE 1998a, pages 4-99 to 4-102)]. The peak dose for this case in the first 10,000 years after the intrusion (between 10,000 and 20,000 years after repository closure) would be about 145 times that of the base case peak dose about 2,000 years after the intrusion. By 10,000 years after the intrusion, there would be little difference between the doses for the base case and the doses from the intrusion cases. At 50,000 years after the intrusion, the doses from the intrusion cases would rise above that of the base case and stay elevated for approximately 100,000 years. The short-term increase in dose would be caused largely by rapid mobilization of technetium-99 and iodine-129. The long-term increase in dose would be caused largely by slower moving radionuclides such as plutonium.

In terms of the peak dose to a critical group over 100,000 years, the effects of human intrusion would be small (an increase approximately four times greater than the base case peak dose rate for about 50,000 years). Over 1 million years, the increase over the base case peak dose rate would be very small. At times close to the human intrusion event, the increased dose rates could be much larger than the corresponding base case rates.

If the drilling mud carried waste package contents to the surface, it would result in direct exposure of the drilling crew to those contents. The exposure to the drilling crew probably would result in lethal doses to those workers.

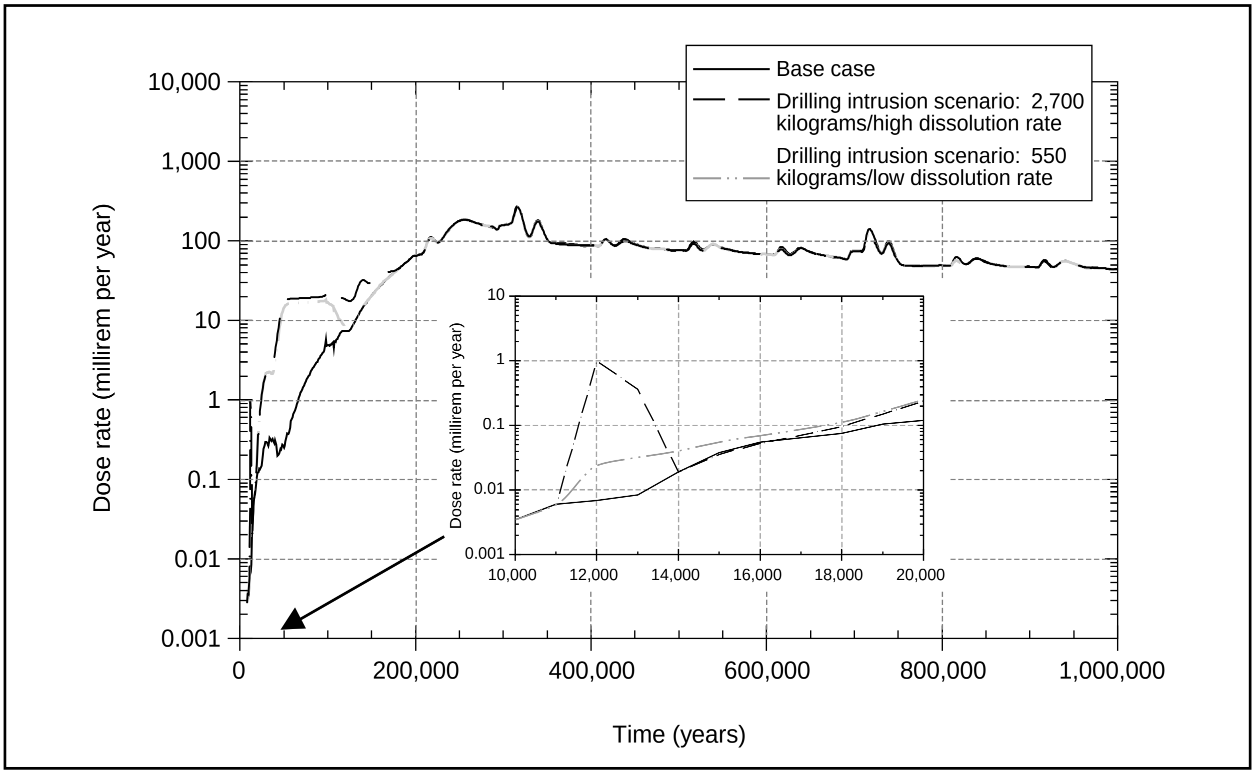


Figure 5-7. Comparison of time history of dose for the base case and under drilling intrusion scenarios 20 kilometers from the repository for the high thermal load scenario.

5.7.2 VOLCANIC DISTURBANCES

DOE has evaluated the probability of volcanic activity affecting the proposed repository (Geomatrix and TRW 1996, all). The primary criteria in defining the probability are the recurrence rate of future volcanic events and the spatial distribution of the events. The evaluation showed that it is unlikely that liquid magma or pyroclasts (hot gases that condense in air and form ash) from a volcano would intersect the repository. However, because there is a finite probability of such an occurrence, the analysis has evaluated it. The annual probability of this event occurring is 1.5×10^{-8} for the high thermal load scenario and 5.1×10^{-8} for the low thermal load.

DOE analyzed the effect on repository performance for three scenarios (DOE 1998a, Volume 3, pages 4-81 through 4-88):

- Direct release scenario: Radioactive material would be transported directly to the surface and atmosphere by a magma flow or pyroclastic flow.
- Enhanced source term scenario: Radioactive material would be entrained in magma that remained in the emplacement drift.
- Indirect igneous effects scenario: Magma would change the hydrologic flow in the saturated zone and alter the transport path of the radioactive material.

Direct Release Scenario

In this scenario the waste packages would be contacted by ascending magma or by pyroclastic flow. The Monte Carlo model determined when the volcanic event would occur, if a volcanic event would intersect an emplacement drift, if the event would intersect a container, if the waste package was breached how much material would be removed from a waste package, and if the ascending magma or pyroclasts could transport the waste. Because of its low velocity, the magma would not be removed from the waste package. Therefore, the dose to humans from this scenario was calculated based on the dispersal of radioactivity in volcanic ash. If the waste was not moved to the surface, it would collect somewhere underground and could contribute to the enhanced source term scenario. Less than 6 percent of all events would release contaminants into an ash cloud. Modeling of the direct release volcanism indicates that there would be very little impact from this scenario. The maximum dose rate from this scenario would be about 2 million times less than the maximum dose from the base case.

The calculation of radiation dose to humans from the air release scenario was based on the dispersal of contaminants in volcanic ash. The ash dispersal model (Jarzemba, LaPlante, and Poor 1997, all) uses information on eruption characteristics, wind direction and velocity, and ash and waste characteristics. Because the corrosion-resistant layers of the waste packages would maintain their structural integrity, few additional contaminant releases caused by eruptive events would be likely in the first 100,000 years after repository closure. The maximum dose from airborne ash caused by volcanism any time during the first 1 million years after repository closure would be about one million times less than the peak dose from the undisturbed groundwater transport of radionuclides.

Enhanced Source Term Scenario

The model for the enhanced source term scenario examined the interaction of the magma with waste packages in the emplacement drift and assumed that the magma would remain underground. The magma was predicted to contact between 0 and 170 packages, with an average of about 45. In this environment of high temperatures and aggressive gases, the waste package would fail. If the waste packages failed, the liquid magma could dissolve some of the uranium oxide in the spent fuel (Westrich 1982, all). When the basalt cooled [in about 10 years for a 2-meter (6.6-foot)-wide dike], groundwater would reenter the emplacement drifts. The basalt would crack as it cooled, allowing the groundwater to dissolve the uranium oxide and other radioactive materials in the contaminated basalt. The groundwater then would carry the contaminants through the geologic media to the accessible environment.

In one Monte Carlo calculation, the volcanic event would intersect waste packages at approximately 110,000 years after repository closure and would result in a peak dose four times the peak dose of the base case, with the peak occurring about 350,000 years after repository closure (DOE 1998a, Volume 3, pages 4-81 through 4-88). The other example assumed the event would occur about 740,000 years after repository closure and would result in a peak dose three times the base case peak dose. In both examples, the peak dose at the accessible environment would occur thousands of years after the event because of the time needed for groundwater to transport the radionuclides.

If an igneous event occurred in the first 100,000 years after repository closure, it would produce doses many times greater than the base case dose for the same period. The peak dose for the base case during the first 100,000 years after closure would range from 0 to 8 millirem per year. The corresponding peak dose if an igneous event occurred during the first 100,000 years after closure would range from 8 to about 64 millirem per year, which is much lower than the peak dose of about 200 millirem per year that would occur several hundred thousand years after closure. The increase in dose from an igneous event would be the result of the early rupture of a few waste packages. After doses from the waste released by interaction with the magma migrated in the groundwater to the accessible environment, the dose histories would coincide with the base case. The Viability Assessment (DOE 1998a, Volume 3, pages 4-81 to 4-88) provides detailed notes comparing results with and without volcanism.

Indirect Igneous Effects Scenario

Modeling of the indirect effects of nearby igneous events has shown that newly formed geologic structures (faults or dikes) upstream from the repository would have no effect on contaminant transport. To calibrate the flow model, it was necessary to make the hydraulic conductivity of existing structures very low (Wilson et al. 1994, Volume I, Table 11-1). Thus, making the structures even more of a barrier through igneous intrusion would cause no noticeable change in the groundwater flow patterns. When downgradient dikes are modeled as being more transmissive, there would be a small change in the groundwater flow pattern. Generally, flow would be directed more toward the east and could take longer to reach a water withdrawal well; thus, it would not be expected to increase the dose rates.

5.7.3 SEISMIC DISTURBANCES

The probability of earthquake occurrence in the Yucca Mountain vicinity is sufficiently high that DOE evaluated potential effects of seismic activity on repository performance (DOE 1998a, Volume 3, pages 4-88 to 4-92). The potential effects of seismic activity would be vibratory ground motion in the repository, causing falling rock to damage waste packages, and a nearby event causing changes in hydrologic properties. The *Probabilistic Seismic Hazard Analysis* (USGS 1998, all) estimated fault displacement and vibratory ground motion hazards in the Yucca Mountain vicinity. The results are in the form of annual frequencies that various levels of fault displacement and vibratory ground motion would exceed.

Seismic activity could cause rocks to fall from the ceilings or walls of the repository drifts. The size of falling rocks was correlated with vibratory ground motion. The distribution of the size of rocks available to fall was estimated from fracture spacing in the Exploratory Studies Facility at Yucca Mountain. Most rocks weigh less than 1,000 kilograms (2,200 pounds), with many weighing about 50 kilograms (110 pounds). There are very few rocks larger than 3,500 kilograms (7,700 pounds). Most waste package failures caused by seismic activity probably would occur when the waste package outer wall was completely corroded. After emplacement, rocks would have to be larger than any observed in the Exploratory Studies Facility to damage the waste packages. If the corrosion-allowance material and half of the corrosion-resistant material were corroded, a rock similar to the average-size rock in the Exploratory Studies Facility could damage a waste package. At times greater than 100,000 years after repository closure, damage from falling rocks would be more likely because the waste packages would be corroded. Because the waste packages would occupy about 40 percent of the space in a drift, a falling rock would have a 40-percent chance of hitting a waste package.

There is less than a 1 percent probability that a falling rock would breach a waste package during the first 10,000 years after repository closure because most waste package walls would still be thick enough to withstand such hits. Over 1 million years, falling rocks could breach about 30 percent of the waste packages in the repository. Such failures, when added to the normal failures from corrosion, would not change the overall probability of waste package failure much because they would occur mostly very late (more than 500,000 years) after emplacement. The calculations show that there would be almost no effect on repository performance from rockfall over a 1-million-year period after closure.

The Viability Assessment (DOE 1998a, Volume 3, pages 4-88 to 4-92) examined whether seismic activity in the Yucca Mountain vicinity would have the potential to affect repository performance, even if a new fault did not intersect the repository. Faulting in the saturated zone could potentially change water flow patterns and, therefore, repository performance. The saturated zone modeling assumed that most of the groundwater flow would occur in fractures, so the addition of a new fault would not be likely to alter repository performance.

5.8 Nuclear Criticality

Isolated nuclear criticality events could occur if the engineered control measures in the waste packages failed and other conditions (such as the presence of water) occurred. In addition, fissile material in the waste could form a critical configuration in the surrounding rock. Criticality has not been included in earlier total system performance analyses, but the DOE waste package design team performed an extensive investigation of this possibility (DOE 1998a, Volume 3, page 4-92). DOE found that the consequences of criticality would be relatively small in comparison to the measures for nominal repository performance.

An analysis of an in-package criticality scenario for commercial spent nuclear fuel used conditions and waste characteristics that potentially maximize the effects of the criticality (DOE 1998a, Volume 3, page 4-96). There are three possible ways that criticality could contribute to additional long-term impacts:

- Internal criticality of the package that would cause an increase of heat, the effect of which could change the properties affecting mobilization of waste

- Internal criticality that would cause an increase in the amount of radioactive material in the waste package

- External criticality resulting from a reaccumulation in the rock of fissile material that had leaked from the package

The analysis showed that the increase in heat from a highly unlikely internal criticality event would be only about 2 kilowatts per package, which is inconsequential in comparison to the overall repository heat load. The increase in radioactivity would be only 24 percent of the original radioactivity in the waste package for a 10,000-year criticality duration. Because of the small increases in radioactivity and heat output, there is no chance that a criticality would cause mechanical disruption of the waste package and engineered barrier system (DOE 1998a, Volume 3, page 4-98).

Criticalities outside the waste packages primarily would require some mechanism to accumulate the fissile material in a localized area. The estimated concentrations would be less than 0.01 percent by volume for plutonium, which is much too low to make criticality possible (DOE 1998a, Volume 3, page 4-98).

Based on these results, DOE concluded that an explosive nuclear criticality is not credible (could not occur). If a nuclear criticality event occurred (highly unlikely) it would not have a significant effect on long-term impacts from the repository.

5.9 Consequences to Biological Resources and Soils

DOE considered if the proposed repository would affect biological resources in the Yucca Mountain vicinity after closure through heating of the ground surface and through radiation exposure as the result of waste migration through groundwater to discharge points. After closure, heat from the radioactive decay of the waste would cause temperatures in the rock near the disposal containers to rise above the boiling point of water [100°C (212°F)] (DOE 1998a, Volume 3, page 3-36). The period the subsurface temperature would remain above the boiling point would vary from a few hundred years to a few thousand years, depending on the thermal load scenario. Conduction and the flow of heated air and water through the rock (advection) would carry the heat from the disposal containers through the rock to the surface and to the aquifer.

Although the atmosphere would remove excess heat when it reached the ground surface, the temperature of near-surface soils probably would increase slightly. Predicted increases in surface soil temperatures range from approximately 10°C (18°F) at the bedrock-soil interface (Bodvarsson, Bandurraga, and Wu 1997, page 510) to 6°C (10.8°F) for dry soil at a depth of 2 meters (6.6 feet) (Table 5-18). To address soil heterogeneity (differences in depth and water content), a recent study (TRW 1999r, all) modeled soil temperature increases at various depths under wet (saturated) and dry (no water at all) soil conditions for the high thermal load. They predicted that temperatures of near-surface soils would be unlikely to rise more than a few degrees (Table 5-18) but would increase with depth from the surface. Surface soil temperatures would start to increase after approximately 200 years and would peak after about 1,000 years. Later, the temperature would gradually decline and would approximate prerepository conditions after 10,000 years (TRW 1999r, Figure 4-13). The maximum change in temperature would occur directly above the repository, affecting approximately 3 square kilometers (740 acres) under the high thermal load scenario. The effects of repository heat on the surface soil temperatures would gradually decline with distance from the repository (TRW 1999r, page 49). Although not modeled, the increase in surface soil temperature would be lower under the intermediate and low thermal load scenarios, and the area that could be affected would be larger [as much as 10 square kilometers (2,500 acres) above the repository for the low thermal load scenario].

Table 5-18. Predicted temperature changes of near-surface soils under the high thermal load scenario.[a]

Soil depth (meters)[b]	Predicted temperature increase [a]	
	Dry soil	Wet soil
0.5	1.5°C (2.7°F)	0.2°C (0.36°F)
1.0	3.0°C (5.4°F)	0.4°C (0.72°F)
2.0	6.0°C (10.8°F)	0.8°C (1.4°F)

a. Source: TRW (1999r, page 45).
b. To convert meters to inches, multiply by 39.37.

There is considerable uncertainty in the estimates of soil temperature increases due to uncertainties in the thermal properties of the soil at Yucca Mountain, particularly thermal conductivity (the amount of heat that can be conducted through a unit of soil per unit time) (TRW 1999r, page 50).

The predicted temperature increase for dry soil provides a conservative estimate of the temperature increase that could occur because even partially saturated soil has a much greater thermal conductivity than dry soil. Soil moisture content recorded at a depth of 15 centimeters (6 inches) was as low as 3 percent on some study sites during some months, but the soil was never completely dry (TRW 1999s, page 14).

A depth of 1 meter (3.3 feet) is within the root zone for many desert shrubs. A temperature increase of 3°C (5.4°F) could affect root growth and other soil parameters such as the growth of microbes or nutrient availability. Studies at Yucca Mountain (TRW 1999s, pages 11 to 46) show that some plant species experienced a spatial range in soil temperatures of 4°C (7.2°F) at a depth of 0.45 meter (18 inches), which is comparable to the 0.5-meter (20-inch) depth used by TRW (1999r, all). Impacts to biological resources probably would consist of an increase of heat-tolerant species over the repository and a decrease of less tolerant species. In general, areas affected by repository heating could experience a loss of shrub species and an increase in annual species. A gradual (over 1,000 years) temperature increase of the magnitude predicted (TRW 1999r, all) probably would have less effect on the plant community than a more rapid change, such as that predicted for global warming.

The predicted increase in temperature would extend as far as 500 meters (1,600 feet) beyond the edge of the repository, with the greatest increase in temperature occurring in soils directly above the repository. A shift in the plant species composition, if any, would be limited to the area within 500 meters of the repository footprint [that is, as much as 8 square kilometers (2,000 acres)], with the greatest change within the central 3 square kilometers (740 acres) for the high thermal load scenario. Although a larger area could be affected under the intermediate and low thermal loads, the magnitude of the increase in soil temperature would be smaller and the associated effects on plant species composition would not be as pronounced as under the high thermal load.

A shift in the plant community probably would lead to localized changes in the animal community that depends on it for food and shelter. Specific plant and animal species and community changes cannot be predicted with certainty because changes in climate or seasonal episodic events (droughts, high rainfall) can substantially change species responses to single factors. However, the variation in surface soil temperatures at Yucca Mountain that are caused by elevation, slope, aspect, and other natural attributes suggest that soil temperature increases of the magnitude predicted (TRW 1999r, pages 44 to 48) are probably within the adaptive range of some plant species now at Yucca Mountain (TRW 1999s, pages 11 to 46).

Some reptiles, including the desert tortoise, exhibit temperature-dependent sex determination (Spotila et al. 1994, pages 103 to 116). Nest temperatures have a direct effect on sex determination, with lower temperatures resulting in predominately male hatchlings and higher temperatures resulting in predominately females. Although existing experimental data do not adequately represent the large fluctuations in nest temperatures in natural settings, an increase in soil temperature due to thermal load could influence the sex ratio and other aspects of the life history of the desert tortoise population residing over the repository footprint. However, depth to the top eggs of 23 nests at Yucca Mountain during 1994 averaged 11 centimeters (4.3 inches). Predicted temperature increases of clutches at that depth based on modeling results (TRW 1999r, pages 44 to 48) would be less than 0.5ºC (0.9°F). Given the ranges of critical temperatures reported by Spotila et al. (1994, all), an increase of this magnitude would be unlikely to cause adverse effects.

Changes in plant nutrient uptake, growth, and species composition, as a result of increases in soil temperature over long periods of time, could influence vegetation community dynamics and possibly alter desert tortoise habitat structure in areas immediately above the repository. However, little is known about the effects that minor alterations in habitat would have on desert tortoise population dynamics.

As discussed in Sections 5.4 and 5.6, in the distant future water at certain discharge points would be likely to carry concentrations of radionuclides and chemically toxic substances. DOE did not quantify impacts to biological resources from irrigation water discharged 5, 20, and 30 kilometers (3, 12, and 19 miles) from the repository, or from the evaporation of water at Franklin Lake Playa (where there is no surface water at present). The estimated doses to humans exposed to this water would be very small. In a similar manner, assumed doses to plants and animals would be small and the impacts from those doses would be unlikely to affect the population of any species because the doses would be much lower than the 100-millirad-per-day limit, at which there is no convincing evidence that chronic radiation exposure will harm plant or animal populations (IAEA 1992, page 54).

The desert tortoise is the only threatened or endangered species in the analyzed repository land withdrawal area (TRW 1999k, page 3-14). Desert tortoises are rare or absent on or around playas (Rautenstrauch and O'Farrell 1998, pages 407 to 411; Bury and Germano 1994, pages 64 and 65); therefore, DOE anticipates no impacts to this species from contaminated water resources at Franklin Lake Playa in the future.

Impacts to surface soils would be possible. Changes in the plant community as a result of the presence of the repository could lead to an increase in the amount of rainfall runoff and, therefore, an increase in the erosion of surface soils, thereby increasing the sediment load in surface water in the immediate Yucca Mountain vicinity.

5.10 Summary

Potential impacts to human health in the far future from a repository at Yucca Mountain would be dominated by impacts from radioactive materials in the waterborne pathway under all three thermal load scenarios of the Proposed Action. Although future disruptive events (human intrusion, volcanic activity, and seismic activity) would change radiation exposure rates, the effect of these on the reported impacts for the undisturbed case would be small under all thermal load scenarios. Large impacts from chemically toxic materials would be unlikely.

Tables 5-4, 5-8, and 5-12 list estimated radiation dose rates for a maximally exposed individual from the groundwater release pathway during the first 10,000 years after repository closure for the three thermal load scenarios. Table 5-19 summarizes the health effects based on the average peak-dose rates to the affected population (see Section 5.3) for these three scenarios. The fact that all of the numbers in Table 5-19 are much smaller than 1.0 means that it is most likely that no person would die due to groundwater contamination by radiological material in the 10,000-year period after repository closure. The number of cancer fatalities that would normally occur each year in the population in the Amargosa Valley (assuming a population of about 1,150 persons) would be about 2. This number is based on approximately 163 cancer fatalities per year per 100,000 population for males in the United States (NIH 1999, all). This comparison clearly indicates that the human health impacts associated with the Proposed Action would be very small for the population in general.

Table 5-19. Summary of health effects for the three thermal load scenarios for the Proposed Action.[a]

Thermal load	Peak 70-year lifetime LCFs[b]	10,000-year integrated LCFs
High	7.5×10^{-6}	1.8×10^{-4}
Intermediate	3.3×10^{-6}	6.7×10^{-5}
Low	5.3×10^{-6}	1.3×10^{-4}

a. Values based on the mean peak-dose rates from 100 simulations of total system performance using random samples of uncertain parameters.

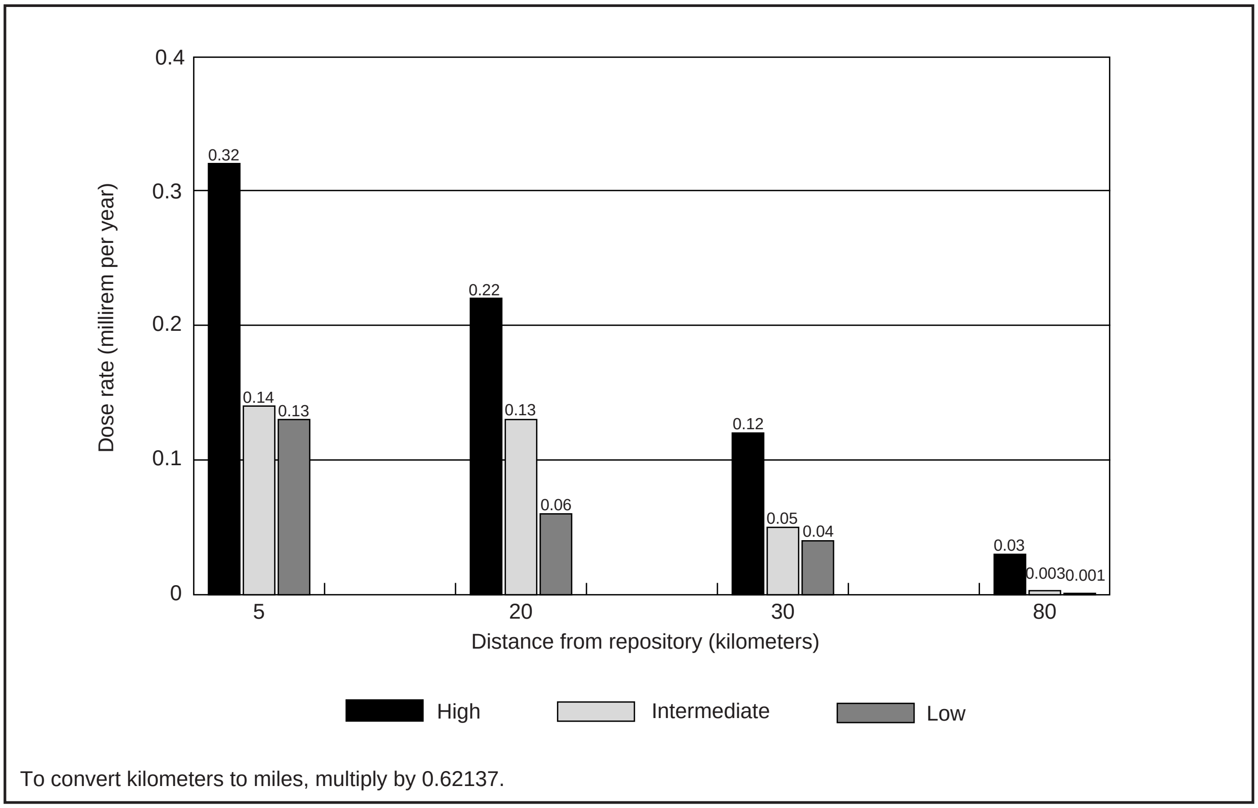
b. LCFs = latent cancer fatalities.

It is appropriate to conclude that environmental justice impacts of long-term repository performance would not be disproportionately high and adverse because minority and low-income populations and Native Americans in the Amargosa Valley would experience a very small impact from radiological dose and there would be no other impacts relevant to environmental justice issues.

As discussed, overall human health impacts to Amargosa Valley residents would be small. The reference person studied to calculate human health impacts was defined as a person who lived year-round in the Valley, consumed locally produced foods, and ingested water from potentially contaminated sources. Estimated doses to plants and animals would also be small. The definition of the reference person and the dose rate to plants and animals address several issues of concern to environmental justice populations, such as relative immobility and dependence on local sources for food and water.

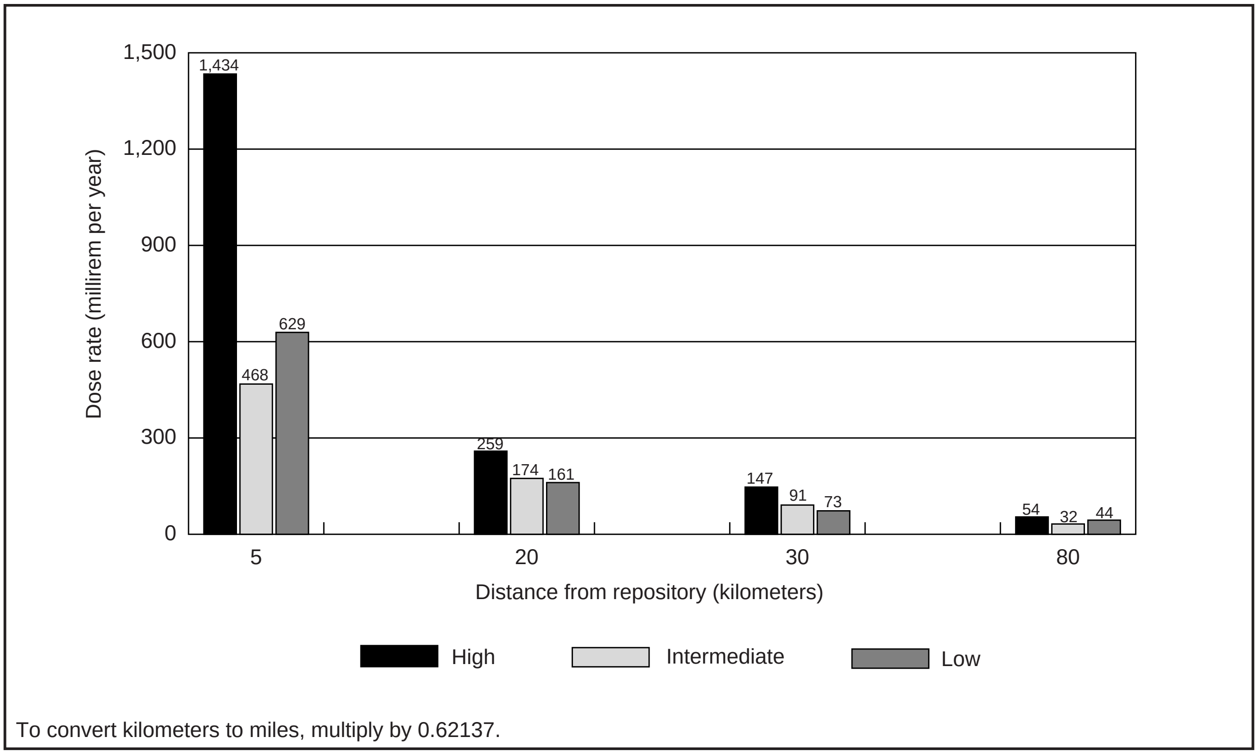
Figure 5-8 shows the mean peak dose rates from Tables 5-4, 5-8, and 5-12. The mean values were based on 100 simulations of total system performance, with each simulation using random samples of uncertainty parameters. Tables 5-6, 5-10, and 5-14 contain the corresponding radiation dose rates in the first 1 million years after repository closure for the three scenarios. Figure 5-9 shows the mean peak dose rates in the first 1 million years after repository closure. The doses shown in these figures do not include the effects of disruptive events.

The analysis indicates (as shown in Figures 5-8 and 5-9 and through a comparison of Tables 5-4, 5-8, and 5-12) that there would be no clear effect of thermal load on the doses, even though the impacts for the high thermal load scenario appear to be slightly larger than the impacts for the other scenarios. One



To convert kilometers to miles, multiply by 0.62137.

Figure 5-8. Comparison of the mean peak dose rates from contaminated groundwater in the first 10,000 years after repository closure for the three thermal load scenarios.



To convert kilometers to miles, multiply by 0.62137.

Figure 5-9. Comparison of the mean peak dose rates in the first 1 million years after repository closure for the three thermal load scenarios.

reason for the lack of difference in dose rates among thermal loads is that more than 99 percent of the waste packages would last beyond the time at which the repository temperature would be elevated much above ambient rock temperatures (DOE 1998a, Volume 3, pages 3-36 to 3-88). Thus, most radionuclides would not be released until long after the thermal effects had subsided and, therefore, thermal load would not have a large effect on the doses. The differences among thermal loads would be due to the placement of waste in different areas of the mountain, with different amounts of water infiltrating through the different areas. More details on the effect of spatially varying infiltration rates are provided in Appendix I.

The analysis also indicated that the dose to the maximally exposed individual would depend strongly on distance from the repository. The dose rates would be much higher at a 5-kilometer (3-mile) distance than at longer distances.

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6

Environmental Impacts of Transportation

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6. ENVIRONMENTAL IMPACTS OF TRANSPORTATION

This chapter describes the potential environmental consequences of transporting spent nuclear fuel and high-level radioactive waste from 72 commercial and 5 U.S. Department of Energy (DOE) sites to the Yucca Mountain site under the Proposed Action. This chapter also separately describes the impacts of transportation activities in the State of Nevada.

This environmental impact statement (EIS) analyzes a Proposed Action to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. The EIS also analyzes a No-Action Alternative, under which DOE would not build a repository at the Yucca Mountain site, and spent nuclear fuel and high-level radioactive waste would remain at 72 commercial and 5 DOE sites across the United States. The No-Action Alternative is included in the EIS to provide a baseline for comparison with the Proposed Action. DOE has developed the information about the potential environmental impacts that could result from either the Proposed Action or the No-Action Alternative to inform the Secretary of Energy’s determination whether to recommend Yucca Mountain as the site of this Nation’s first monitored geologic repository for spent nuclear fuel and high-level radioactive waste. In making that determination, the Secretary would consider not only the potential environmental impacts identified in this EIS, but also other factors as provided in the Nuclear Waste Policy Act, as amended.

As part of the Proposed Action, the EIS analyzes the potential impacts of transporting spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site from 77 sites across the United States. This analysis includes information on such matters as the comparative impacts of truck and rail transportation, alternative intermodal (rail to truck) transfer station locations, associated heavy-haul truck routes, and alternative rail transport corridors in Nevada. Although it is uncertain at this time when DOE would make any transportation-related decisions, DOE believes that the EIS provides the information necessary to make decisions regarding the basic approaches (for example, mostly rail or mostly truck shipments), as well as the choice among alternative transportation corridors. However, follow-on implementing decisions, such as selection of a specific rail alignment within a corridor, or the specific location of an intermodal transfer station or the need to upgrade the associated heavy-haul routes, would require additional field surveys, state and local government consultations, environmental and engineering analyses, and National Environmental Policy Act reviews.

The analysis evaluated potential impacts from two basic national transportation activities—the loading of spent nuclear fuel and high-level radioactive waste in heavily shielded shipping casks certified by the U.S. Nuclear Regulatory Commission at commercial and DOE facilities, and the transportation of these materials to Yucca Mountain using legal-weight truck or rail shipments. The Nevada transportation activities include the transportation of spent nuclear fuel and high-level radioactive waste shipments from the State borders to Yucca Mountain. Nevada transportation also includes the transportation of materials, equipment, and personnel to and from Yucca Mountain for the construction, operation and monitoring, and eventual closure of the proposed repository. The analysis also evaluated the potential impacts of the possible construction of an intermodal transfer station and related highway upgrades that might be needed for heavy-haul trucks, and the possible construction of a branch rail line to Yucca Mountain. Section 6.1 provides a summary of both national and Nevada transportation activities. Chapter 2, Section 2.1.2, also contains detailed descriptions of national transportation and Nevada transportation activities.

Section 6.2 assesses and compares the potential impacts of national transportation from the 77 sites to Yucca Mountain. Because the mode of transportation used to ship from each site would depend on several factors that DOE does not control (for example, future capabilities of shipping sites, rail service to shipping sites, and labor agreements), DOE recognizes that it cannot predict the specific transportation mode (truck or rail) of each shipment to the repository. Therefore, this section evaluates the potential impacts of two national transportation modes (legal-weight truck and rail), which are represented in this section by two analytical scenarios—*mostly legal-weight truck* and *mostly rail*—to address the range of impacts that could occur in Nevada for the transportation modes that DOE could ultimately use. In addition, as part of the mostly rail scenario, this section assesses short hauls of commercial spent nuclear fuel in heavy-haul trucks or barges that could occur from some commercial sites to railheads.

Section 6.3 assesses potential impacts from transportation activities in Nevada. This section uses three analytical scenarios—*mostly legal-weight truck* (corresponding to that portion of the national transportation scenario that would occur in Nevada), *mostly heavy-haul truck*, and *mostly rail*—to address the range of impacts that could occur in Nevada for the transportation modes that DOE could ultimately employ. In addition, Section 6.3 evaluates the potential consequences in Nevada of using legal-weight trucks on existing routes, one of five potential highway routes for heavy-haul trucks, or one of five potential branch rail lines. The potential highway routes for heavy-haul trucks and potential branch rail corridors are called *implementing alternatives*. The EIS includes information, such as the comparative impacts of truck and rail transportation, alternative intermodal (rail to truck) transfer station locations, associated heavy-haul truck routes, and alternative rail transport corridors in Nevada, that might not lead to near-term decisions. It is uncertain at this time when DOE would make these transportation-related decisions. If and when it is appropriate to make such decisions, DOE believes that the EIS provides the information necessary to make these decisions. However, measures to implement those decisions, such as selection of a specific rail alignment within a corridor, or the specific location of an intermodal transfer station or the need to upgrade the associated heavy-haul routes, would require additional field surveys, State of Nevada and local government consultations, environmental and engineering analyses, and National Environmental Policy Act reviews.

National transportation and Nevada transportation modes must be integrated to operate effectively, as shown in Figure 6-1. Therefore, this analysis used only certain combinations of the national and Nevada transportation modes. Figure 6-2 shows the relationship of the rail and truck modes to the national and Nevada transportation analysis scenarios and the Nevada transportation implementing alternatives.

Appendix J contains details on transportation analysis methods and results. Chapter 4 evaluates potential environmental impacts from the offsite manufacturing of shipping casks for commercial and DOE (including naval) spent nuclear fuel and DOE high-level radioactive waste; the receipt and unloading of shipping casks; the preparation at the repository of empty casks for reshipment; and the construction and operation of a cask maintenance facility at the proposed Yucca Mountain Repository. Chapter 8 discusses cumulative impacts of transportation for the Proposed Action and anticipated future transportation activities that could affect members of the public and workers.

6.1 Summary of Impacts of Transportation

6.1.1 OVERVIEW OF NATIONAL TRANSPORTATION IMPACTS

This section provides an overview of the potential impacts of using the Nation's highways and railroads to transport spent nuclear fuel and high-level radioactive waste from 72 commercial and 5 DOE sites to the repository at Yucca Mountain. Detailed discussions of national transportation impacts are in Section 6.2 and analytical methods are in Appendix J. All potential impacts are related to the health and safety of populations and hypothetical maximally exposed individual members of the general public and workers. This summary includes estimated impacts from loading operations, incident-free transportation, and accidents for the mostly legal-weight truck and mostly rail national transportation scenarios. (National transportation includes transportation in Nevada to Yucca Mountain.)

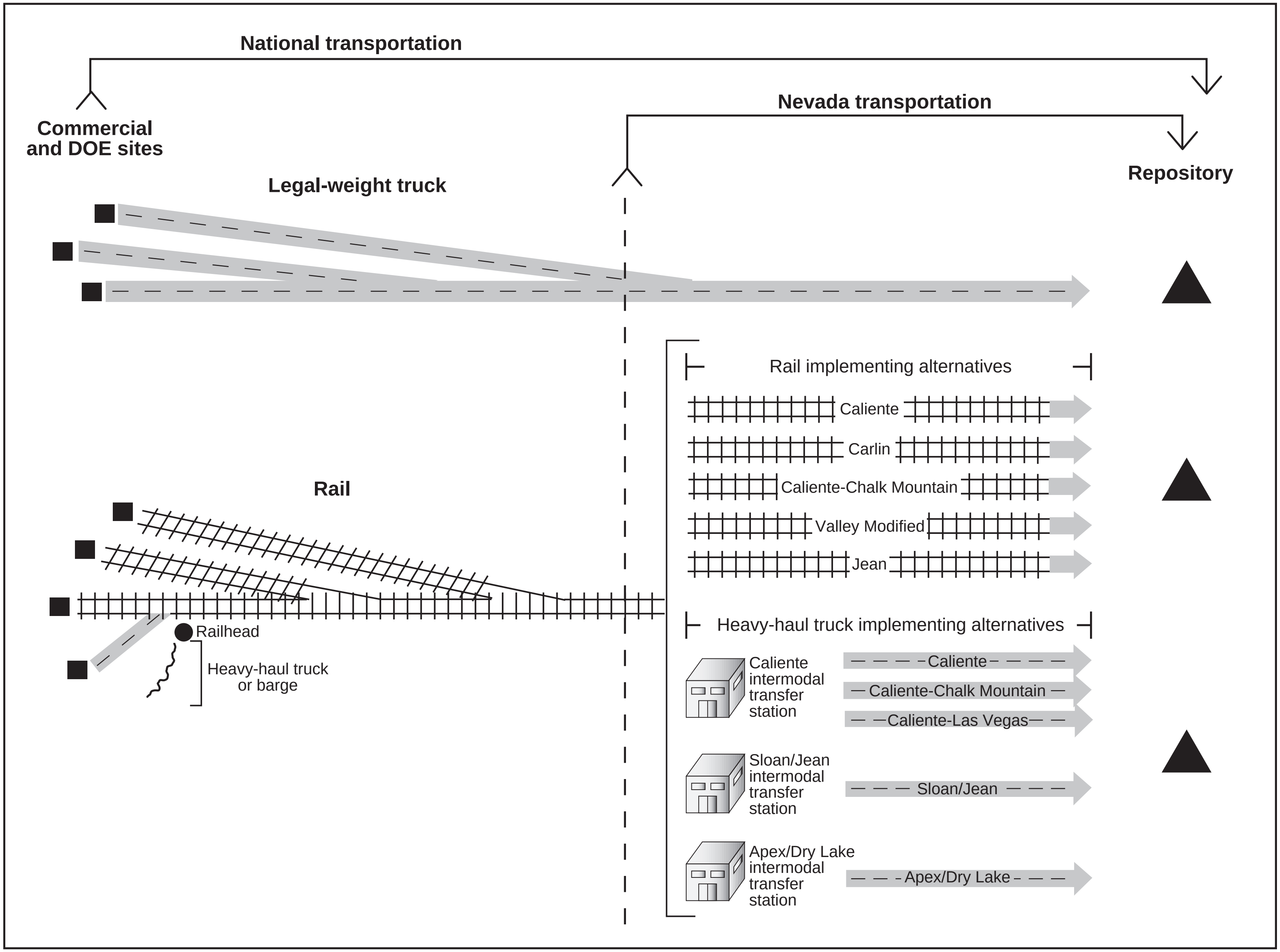


Figure 6-1. Relationship of Nevada and national transportation.

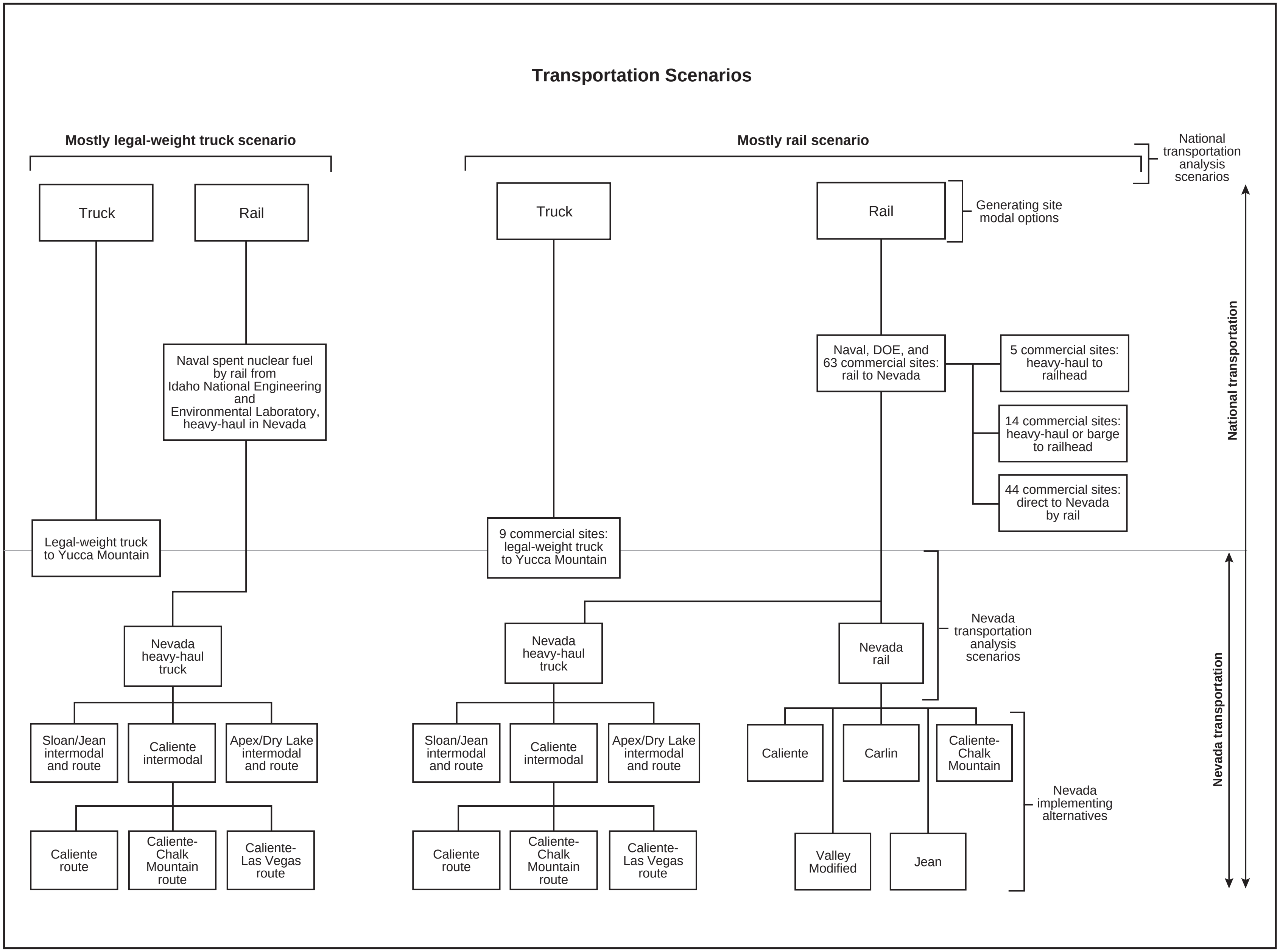


Figure 6-2. Relationship between transportation modes, national and Nevada analytical scenarios, and Nevada transportation implementing alternatives.

IMPLEMENTING ALTERNATIVES AND SCENARIOS

Implementing alternatives and scenarios are used to describe the range of reasonably foreseeable transportation actions with environmental impacts that could result from the Proposed Action.

Implementing alternatives represent feasible selections that DOE could make based in part on this EIS (for example, selecting a branch rail line corridor or an intermodal transfer station location and an associated route for heavy-haul trucks). Analytical scenarios, on the other hand, are feasible combinations of actions that DOE would have limited ability to direct (for example selecting the use of rail or truck casks for shipments from a specific nuclear powerplant). The scenarios are selected such that the analysis results bound the range of impacts that could result from the Proposed Action.

The transportation modes that make up the analytical scenarios and implementing alternatives include the following:

Legal-weight truck transportation: Legal-weight trucks have gross vehicle weights, including cargo, that do not exceed 80,000 pounds, which is the loaded weight limit for commercial vehicles operated on Interstate and U.S. highways without special state-issued permits. In addition, these vehicles would have dimensions that are within the constraints of Federal and state regulation limits.

Permitted overweight, overdimension truck transportation: Semi- and tandem tractor-trailer trucks with gross vehicle weights over 80,000 pounds must obtain permits from state highway authorities to use public highways. States often permit vehicles that have gross weights above 80,000 pounds as *overweight, overdimension* vehicles with operating restrictions to protect public safety. Nine-axle tractor-trailer trucks (steering axle and three drive axles on the tractor and three axles on the trailer) with weights greater than 80,000 pounds that meet Federal bridge formulas and dimensional limits can carry payloads of 70,000 pounds.

Rail transportation: Rail transportation includes railroad transportation of spent nuclear fuel and high-level radioactive waste in large rail transportation casks (rail casks). The casks would be placed on railroad cars at commercial and DOE sites or at nearby intermodal transfer facilities for shipment on trains operated by commercial railroad companies over existing tracks. Because of the weight of the casks, only one cask would be transported on a railcar.

Heavy-haul truck transportation: Heavy-haul truck transportation includes the movement of large rail casks—both loaded and empty—on large heavy-haul trucks traveling on existing highways. For the transportation of spent fuel and high-level radioactive waste rail casks, these vehicles would weigh as much as 500,000 pounds; they would be more than 100 feet long and 10 to 12 feet wide, and would stand as high as 15 feet above the road surface. Heavy-haul trucks would require special permits issued by a state transportation agency. The permits would normally restrict the times of operation (typically daylight, non-rush-hour), operating speeds, and highways used [see TRW (1999d, Request #031)].

Barge transportation: Barge transportation would be the transportation of loaded and empty rail casks between a commercial facility and a nearby railhead using navigable waterways. Barge terminals would have intermodal transfer capabilities sufficient to transfer casks from barges to railcars.

Estimated national transportation impacts are based on 24 years of transportation activities during the Proposed Action and average annual shipments of about 2,100 (2,100 truck, 13 rail) for the mostly legal-weight truck scenario and 560 (450 rail, 110 truck) for the mostly rail scenario. From all causes, about 23 fatalities could occur in the nationwide general population from incident-free transportation activities of the mostly legal-weight truck scenario and about 6 fatalities from the mostly rail scenario during the 24-year transportation period (impacts of a maximum reasonably foreseeable accident are not included).

Impacts of Loading Operations

All spent nuclear fuel and high-level radioactive waste would be loaded onto trucks or railcars at the 77 sites for transport to the Yucca Mountain site. Some health and safety impacts would be associated with these loading operations. There would be small (0.04 latent cancer fatality) impacts to members of the public from loading operations. Over the 24 years of the Proposed Action, an estimated 6 and 2 latent cancer fatalities, respectively, could occur in involved worker populations from radiation exposure for the mostly legal-weight truck and mostly rail scenarios. The probability of a latent cancer fatality to the maximally exposed involved worker would be about 0.005 for both scenarios. No worker fatalities from industrial accidents would be expected. No or very small impacts to workers or members of the public would be expected from postulated loading accidents. About 0.5 traffic fatality could occur in the worker population from commuting under the mostly legal-weight truck scenario, while about 0.2 traffic fatality could occur under the mostly rail scenario. Loading operations and potential impacts are discussed further in Section 6.2.2.

Impacts of Incident-Free Transportation

Incident-free transportation is the expected norm for transportation of spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site. Impacts of incident-free transportation would include those from external radiation emitted from transportation casks and vehicle exhaust emissions along the transportation routes.

Over the 24 years of the Proposed Action, an estimated 18 latent cancer fatalities could occur in the general population along transportation routes from radiation exposure under the mostly legal-weight truck scenario and an estimated 2 latent cancer fatalities could occur under the mostly rail scenario. Under the mostly legal-weight truck and mostly rail scenarios, the probability of a latent cancer fatality to the maximally exposed member of the public would be no more than 0.0012 and 0.00016, respectively. Under these same scenarios, about 0.6 and 0.3 vehicle emission-related fatality, respectively, could occur in the general population along transportation routes.

For involved workers, an estimated 5 latent cancer fatalities could occur in the involved worker population from radiation exposure for the mostly legal-weight truck scenario, and an estimated 1 latent cancer fatality could occur for the mostly rail scenario. The probability of a latent cancer fatality to the maximally exposed involved worker would be no more than 0.02 for either the mostly legal-weight truck or mostly rail scenarios. DOE expects impacts to noninvolved workers to be low, smaller than those to involved workers.

The differences in incident-free impacts between the mostly legal-weight truck and mostly rail scenarios are principally because of (1) the difference in the number of shipments for the two scenarios, and (2) differences in analysis assumptions about the numbers of in-transit stops, the number of potentially exposed persons, and their proximity to shipping casks that could result in external radiation exposure.

No environmental justice impacts were identified for incident-free transportation. Incident-free national transportation and the potential impacts to workers and the public are discussed further in Section 6.2.3.

Impacts of Transportation Accidents

The analysis evaluated transportation accident impacts to human health and safety, collectively including the health and safety of the public and transportation workers. Thus, impacts to populations from transportation accidents would include impacts to affected workers. Because of the large differences between the populations of transportation workers and the general public, radiological accident risks and

TRANSPORTATION RADIOLOGICAL ACCIDENT RISK

Transportation radiological accident risk is determined by calculating the number of latent cancer fatalities that would be caused per rem of exposure to radioactive materials from transportation accidents and multiplying this value by the probability of the accidents.

An estimated 0.0005 cancer would be caused by exposure to a dose of 1 rem. An individual exposed to a dose of 0.3 rem per year, which is approximately equal to background radiation, for a lifetime of 72 years would have a lifetime exposure of about 22 rem. This dose would result in a risk of a latent cancer fatality of 0.01. This is a probability of 1 in 100 of death over a lifetime from exposure to radiation approximately equal to natural background radiation and medical sources.

If each person in a population of 1,000 was exposed to a dose of 22 rem, the population dose would be 22,000 person-rem. Using 0.0005 latent cancer fatality per rem of dose, an analysis would estimate 11 latent cancer fatalities from this population dose.

consequences for workers would be a very small fraction of the risks and consequences evaluated for the public.

Accident impacts include the consequences where shipping casks could be breached with subsequent release of radioactive material to nearby individuals and populations. In addition, there could be impacts to individuals from “normal” traffic accidents, in which there would be no release of radioactive material from shipping casks and only those directly involved in the accident would be affected. The analysis examined radiological consequences under the maximum reasonably foreseeable accident scenario, and overall accident risk. The maximum reasonably foreseeable accident scenario is the one with the greatest potential consequences. It must also have an occurrence likelihood of 1 in 10 million per year or greater to be considered “reasonably foreseeable.” Accident risk considers the potential consequences of all accident scenarios and their occurrence likelihood, from accident scenarios that are likely to occur but would have no release of radioactive material to those accident scenarios that are extremely unlikely to occur but could have large consequences (for example, the maximum reasonably foreseeable accident scenario).

The overall radiological accident risk, as described in Appendix J, Section J.1.4.2.1, from all accident scenarios over the 24 years of transportation activities during the Proposed Action would be about 0.07 latent cancer fatality for the mostly legal-weight truck scenario and about 0.02 latent cancer fatality for the mostly rail scenario. These estimated latent cancer fatalities would occur in the hypothetically exposed population residing within 80 kilometers (50 miles) of the accident site.

The maximum reasonably foreseeable accident scenario for the mostly legal-weight truck scenario would result in about 5 latent cancer fatalities in the exposed population. It is postulated to involve a release of radioactive material from a truck cask in an urbanized area under stable (still air) weather conditions. The probability of this accident scenario would be about 0.00000019 per year (a rate of about 2 in 10 million years). The maximum reasonably foreseeable accident scenario for the mostly rail scenario would result in about 31 latent cancer fatalities in the exposed population. It is postulated to involve a release of radioactive material from a rail cask in an urbanized area under stable (still air) weather conditions. The probability of this accident scenario would be about 0.00000014 per year (a rate of about 1.4 in 10 million years). The probability of a latent cancer fatality occurring in the hypothetical maximally exposed individual would be about 0.002 for the mostly legal-weight truck scenario and about 0.013 for the mostly rail scenario.

Nationwide, during the 24 years of the Proposed Action transportation activities, about 4 fatalities could result from traffic accidents under the mostly legal-weight truck scenario. For the same time period, about 4 fatalities could also result from traffic accidents under the mostly rail scenario. These fatalities would all be related to physical injuries associated with traffic accidents, not radiological impacts.

No environmental justice impacts were identified for transportation accident scenarios. Transportation accident scenarios and potential impacts are discussed further in Section 6.2.4.

6.1.2 OVERVIEW OF NEVADA TRANSPORTATION IMPACTS

This section provides an overview of the environmental impacts associated with transportation of spent nuclear fuel and high-level radioactive waste in the State of Nevada. Although this section provides a more detailed, regional subset of some of the information gathered and analyses conducted for national transportation (see Section 6.1.1), it also includes information analyzed specifically for Nevada. This includes impacts from construction and operation of branch rail lines, heavy-haul truck routes and intermodal transfer stations, commuter transportation for construction and operations activities, and transportation of other materials in support of Yucca Mountain operations. Detailed discussions of potential impacts in Nevada are in Section 6.3 and Appendix J. The following areas were evaluated for potential impacts in Nevada from Yucca Mountain transportation activities:

- Transporting spent nuclear fuel and high-level radioactive waste by legal-weight truck in Nevada
- Constructing a branch rail line in Nevada and using it to transport spent nuclear fuel and high-level radioactive waste by rail to the repository
- Upgrading highways in Nevada for use by heavy-haul trucks to transport spent nuclear fuel and high-level radioactive waste to the repository
- Constructing and operating an intermodal transfer station in Nevada
- Transporting materials, consumables, supplies, equipment, waste, and people to support construction, operation and monitoring, and closure of the repository

Overviews are presented for the 12 environmental resource areas analyzed in this chapter and for the transportation of other materials and supplies, which is presented in further detail in Appendix J. The summaries provide information for assessing the relative impacts in these resource areas from the mostly legal-weight truck transportation scenario, the five implementing alternatives for rail transportation, and the five implementing alternatives for heavy-haul truck transportation.

6.1.2.1 Land Use

Land-use impacts would be greatest for the mostly rail scenario, with disturbed land areas ranging from about 5 square kilometers (1,200 acres) for the Valley Modified route to 19 square kilometers (5,000 acres) for the Carlin route (see Figure 6-3). The Carlin route would also affect the most private land [7 square kilometers (1,730 acres)]. Disturbed land area would be very similar for all of the heavy-haul implementing alternatives, ranging from 0.2 to 0.28 square kilometers (50 to 70 acres). No more than 0.2 square kilometers of private land would be affected for any route. There would be no land-use impacts from legal-weight trucks using existing highways. Land-use impacts are discussed for Nevada transportation rail implementing alternatives and for Nevada transportation heavy-haul truck implementing alternatives in Sections 6.3.2 and 6.3.3, respectively.

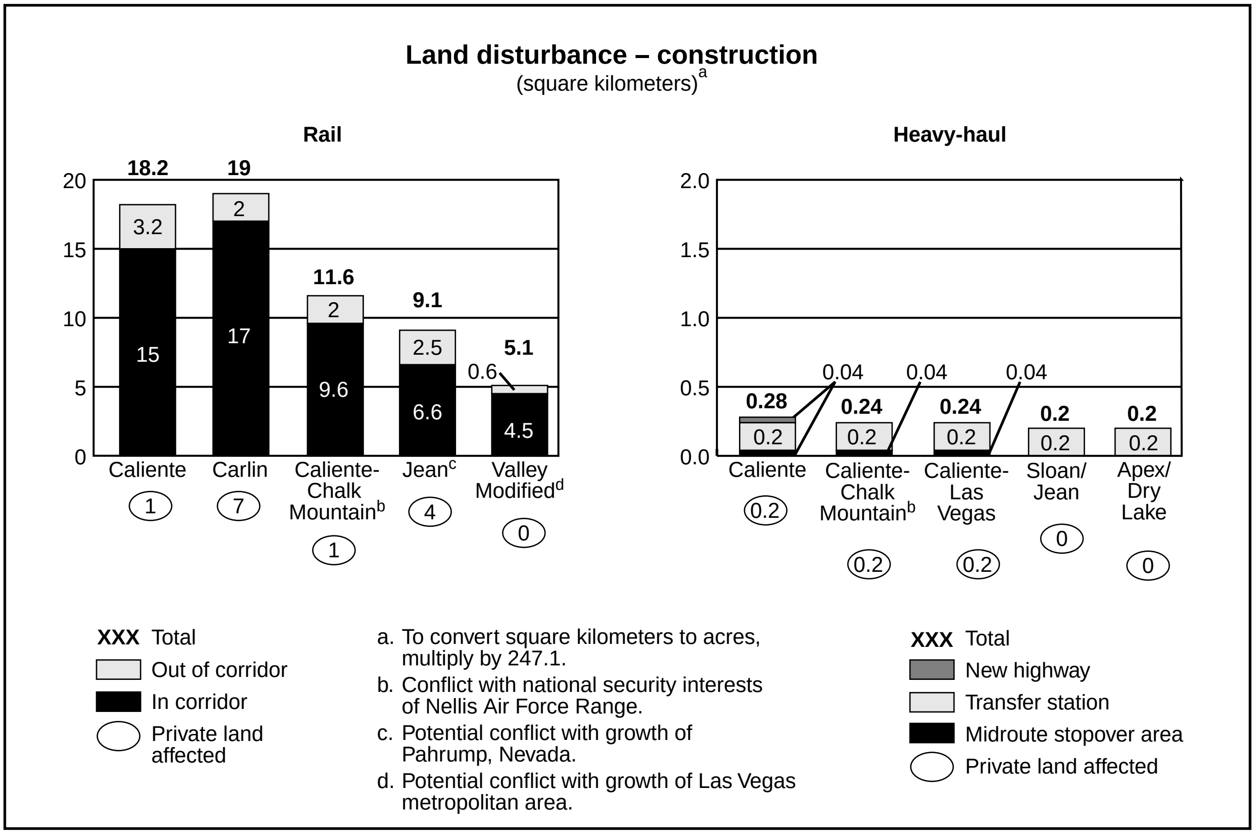


Figure 6-3. Land disturbed for construction of branch rail lines and upgrades to Nevada highways for heavy-haul use.

The U.S. Air Force has identified national security issues regarding a Chalk Mountain rail corridor or Caliente-Chalk Mountain route for heavy-haul trucks, citing interference with Nellis Air Force Range testing and training activities (Henderson 1997, all). In response to Air Force concerns, DOE regards these routes as “non-preferred alternatives.” The Jean and Valley Modified rail corridors could have conflicts with the future community growth of Pahrump and Las Vegas, respectively. Potential rail and legal-weight and heavy-haul truck routes could pass through or near the Moapa and Las Vegas Paiute Indian Reservations.

6.1.2.2 Air Quality

The main air pollutants would be fugitive dust and equipment emissions (mainly carbon monoxide and nitrogen dioxide) from construction or upgrade activities associated with the rail and heavy-haul truck implementing alternatives, and vehicle emissions associated with legal-weight truck, heavy-haul truck, and rail transportation. None of these emissions are expected to exceed applicable annual or short-term air quality limits. Dust (such as PM_{10} and $PM_{2.5}$) from construction would be suppressed by the use of best management practices such as water spraying. Pollutants from vehicle traffic would be small in all cases, although the largest repository-related source of vehicle emissions would be the vehicles used by employees commuting to and from the Yucca Mountain site. This traffic would originate in and return to the Las Vegas area and be a minor contributor to traffic emissions in the Las Vegas Valley. Air quality impacts are discussed for Nevada transportation rail implementing alternatives and for Nevada transportation heavy-haul truck implementing alternatives in Sections 6.3.2 and 6.3.3, respectively.

6.1.2.3 Hydrology

Surface-water resources are most prevalent among the Caliente and Carlin rail corridors and could be affected by construction activities. The potential Caliente intermodal transfer station is about 0.19 kilometer (0.12 mile) from a perennial stream, and the Caliente, Caliente-Chalk Mountain, and Caliente-Las Vegas routes for heavy-haul trucks would pass within 1 kilometer (0.6 mile) of water resources. Surface-water impacts during construction would be avoided by implementing good management practices to prevent and mitigate spills of pollutants and would avoid, minimize, or otherwise mitigate possible changes to stream flows. Therefore, DOE does not anticipate impacts to surface waters from the construction of a rail or heavy-haul truck implementing alternative. In addition, surface-water impacts would be unlikely from legal-weight truck, rail, or heavy-haul truck operations or the operation of an intermodal transfer station.

Potential for groundwater impacts would be limited. There would be the potential for temporary withdrawals of water from groundwater sources during the construction of a branch rail line or upgrades to highways and construction of an intermodal transfer station. Estimated water use would be greater for construction of branch rail lines than for upgrades for heavy-haul truck routes (see Figure 6-4). Such withdrawals would require temporary permits from the State of Nevada. If groundwater could not be withdrawn for construction, water would be transported from permitted sources to the construction sites by truck.

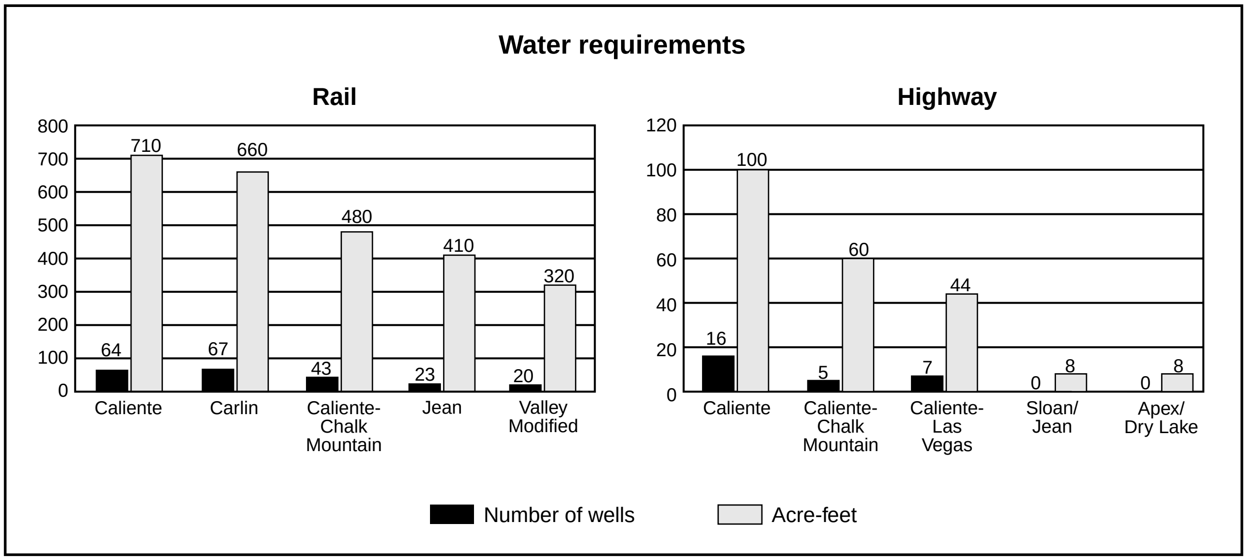


Figure 6-4. Water and number of wells required for construction of branch rail lines and upgrades to Nevada highways for heavy-haul use.

Legal-weight truck shipments, operations of a branch rail line, or operations of heavy-haul trucks, including the operation of an intermodal transfer station, would not affect groundwater resources. Hydrology impacts are discussed for Nevada transportation rail implementing alternatives and for Nevada transportation heavy-haul truck implementing alternatives in Sections 6.3.2 and 6.3.3, respectively.

6.1.2.4 Biological Resources and Soils

Loss of habitat from construction of a branch rail line would be the greatest potential impact to biological resources, potentially affecting the desert tortoise, a threatened species. Loss of desert tortoise habitat would be approximately 2.4 square kilometers (590 acres) for the Caliente-Chalk Mountain route, 3 square kilometers (740 acres) for the Caliente and Carlin routes, 5 square kilometers (1,200 acres) for the Valley Modified route, and more than 11 square kilometers (2,700 acres) for the Jean route. All of these potential routes have low abundance of desert tortoise except for some limited areas of the Jean route where abundance is higher. The potential for impacts from upgrading Nevada highways for heavy-haul truck use would be small because modifications to roads would occur in previously disturbed rights-of-way. An intermodal transfer station constructed in association with a heavy-haul truck implementing alternative would potentially disturb only about 0.2 square kilometer (50 acres) of potential desert tortoise habitat. Other special status species could be affected based on the route chosen. Impacts from operations, with the exception of infrequent wildlife kills by vehicles, would be unlikely. As with heavy-haul trucks, legal-weight truck shipments that used existing highways would cause only very small impacts to biological resources.

For highway upgrades, DOE or the State of Nevada would reduce concerns about soil contamination or erosion as a result of implementing alternatives for transportation by incorporating appropriate considerations during construction. These considerations would include the proper control of hazardous materials and use of dust suppression and other control techniques to reduce erosion. As a result, the implementing alternatives for transportation in Nevada would be unlikely to have impacts on soil. Impacts to biological resources and soils are discussed for Nevada transportation rail implementing alternatives and for Nevada transportation heavy-haul truck implementing alternatives in Sections 6.3.2 and 6.3.3, respectively.

6.1.2.5 Cultural Resources

Based on available information, the construction and operation of a branch rail line in any of the candidate corridors could present the potential for direct or indirect impacts (such as crushing or disturbing of sites; soil erosion exposing or covering sites) to archaeological resources, including those related to Native American culture. None of the five potential rail corridors passes through reservation lands. Additional archaeological surveys and ethnographic studies would be needed for any of the five rail corridors to determine impacts and mitigation needs. The determination of the potential for impacts to archaeological resources and Native American cultural values from the upgrading and use of Nevada highways for heavy-haul truck shipments would also require more study. The Caliente-Las Vegas, Sloan/Jean, and Apex/Dry Lake routes for heavy-haul trucks follow a portion of U.S. Highway 95 that passes through approximately 1.6 kilometer (1 mile) of the Las Vegas Paiute Indian Reservation. The Caliente-Las Vegas route segment on U.S. Highway 93 passes within about 5 kilometers (3 miles) of the Moapa Indian Reservation. An Apex/Dry Lake intermodal transfer station would be within 3 kilometers (2 miles) of the Moapa Indian Reservation. Legal-weight trucks arriving from the northeast on I-15 and rail transportation arriving from the northeast on the existing Union Pacific railroad mainline would pass through the Moapa Indian Reservation. The American Indian Writers Subgroup has commented that ethnographic field studies will be needed to determine potential impacts to Native American cultural values (AIWS 1998, page 4-6).

6.1.2.6 Occupational and Public Health and Safety

Impacts to occupational and public health and safety include industrial safety impacts to workers from construction and operations, radiological impacts to workers and the general public from external radiation exposure and exposure to vehicle emissions during normal operations and incident-free transportation, radiological impacts from transportation accident scenarios, radiological impacts from hypothetical severe accident scenarios that would breach shipping casks, and impacts from traffic accidents.

Potential industrial safety impacts to workers from construction and operations are shown in Table 6-1. Postulated fatalities from industrial accidents would be higher for rail than for heavy-haul trucks, but

Table 6-1. Industrial safety impacts to workers from construction and operation of Nevada transportation implementing alternatives.[a]

Impact	Branch rail line[b]				
	Caliente	Carlin	Caliente-Chalk Mountain	Jean	Valley Modified
Total recordable cases	250	240	220	170	130
Lost workday cases	130	120	110	90	70
Fatalities (industrial accidents)	1.3	1.2	1.0	0.9	0.5
	Heavy-haul truck[b]				
	Caliente	Caliente-Chalk Mountain	Caliente-Las Vegas	Sloan/Jean	Apex/Dry Lake
Total recordable cases	340	330	300	180	180
Lost workday cases	190	180	160	100	100
Fatalities (industrial accidents)	0.7	0.6	0.6	0.4	0.4

a. Impacts are totals for 24 years of operations. There are no impacts for the legal-weight truck scenario.
b. Includes impacts to workers at an intermodal transfer station.

more recordable cases and lost workday cases were postulated to occur for heavy-haul trucks. The industrial safety-related fatalities were postulated to occur during construction of four of the five branch rail lines, while none were predicted for upgrades to routes for heavy-haul trucks and construction of an intermodal transfer station. No industrial safety-related fatalities would be expected to occur during operations.

Potential radiological impacts and vehicle emission-related impacts from normal operations and incident-free transportation in Nevada for each of the rail and heavy-haul truck implementing alternatives and for the mostly legal-weight truck scenario are presented in Table 6-2. Radiological impacts to members of the public from external radiation exposure and risks from exposure to vehicle emissions during incident-free transportation would be lowest for rail, intermediate for heavy-haul trucks, and highest for legal-weight truck transportation, where 1.4 latent cancer fatalities were estimated to occur over 24 years. Impacts from vehicle emissions would be low in all cases (0.028 or fewer fatalities).

The overall radiological accident risk from all accidents over the 24 years of transportation activities in Nevada would be no higher than about 0.002 latent cancer fatality in the potentially exposed population within 80 kilometers (50 miles). Accident risk would be highest for the heavy-haul implementing alternatives and lower for the mostly legal-weight truck scenario and rail implementing alternatives. The Jean rail and Sloan/Jean heavy-haul truck implementing alternatives would have higher accident risks than other implementing alternatives. The estimated accident risks are presented in Table 6-2. More operations jobs would be created to support heavy-haul truck transportation than for rail transportation. Socioeconomic impacts from operations activities would also be small except for Lincoln County, where impacts would be moderate. However, these impacts would not be greater than historic short-term socioeconomic changes that have occurred in the county in the past.

The Nuclear Regulatory Commission published a draft Addendum 1 (NRC 1999, all) to NUREG-1437, Volume 1, *Generic Environmental Impact Statement for License Renewal of Nuclear Plants* (NRC 1996, all) to provide a technical basis to amend Commission regulations with the objective of improving the efficiency of renewing nuclear plant operating licenses by documenting well-understood environmental impacts to avoid repetitive reviews. The addendum addresses two aspects of spent nuclear fuel transportation that the original analysis did not address—the cumulative impacts of transportation of commercial spent nuclear fuel in the vicinity of the proposed repository at Yucca Mountain, and the impacts of transporting higher-burnup fuel. The results of the EIS analysis appear to be consistent with the Nuclear Regulatory Commission conclusion in the addendum, which is that “radiological and accident

Table 6-2. Worker and public health and safety impacts from Nevada transportation implementing alternatives.[a]

Impact	Legal-weight truck	Branch rail line[b]				
		Caliente	Carlin	Caliente-Chalk Mountain	Jean	Valley Modified
Workers						
Maximally exposed individual probability of LCF[c]	0.02	0.02	0.02	0.02	0.02	0.02
Worker population LCFs	0.63	0.17	0.19	0.16	0.16	0.15
Public						
Maximally exposed individual probability of LCF	0.00012	0.00016	0.00016	0.00016	0.00016	0.00016
General population LCFs	1.4	0.20	0.21	0.19	0.21	0.19
Vehicle emissions-related health effects (fatalities)	0.05	0.0019	0.025	0.0017	0.014	0.0018
Accident risk						
Population LCFs	0.00006	0.000047	0.000051	0.000045	0.000076	0.000045
Maximum reasonably foreseeable accident scenario						
Population LCFs	4.7	31	31	31	31	31
Maximally exposed individual probability of LCF	0.002	0.013	0.013	0.013	0.013	0.013
Traffic accident fatalities	0.46	2.0	2.0	1.6	1.3	1.0
		Heavy-haul truck[b]				
		Caliente	Caliente-Chalk Mountain	Caliente-Las Vegas	Sloan/Jean	Apex/Dry Lake
Workers						
Maximally exposed individual probability of LCF[c]		0.02	0.02	0.02	0.02	0.02
Worker population LCFs		0.31	0.29	0.30	0.29	0.28
Public						
Maximally exposed individual probability of LCF		0.00016	0.00016	0.00016	0.00016	0.00016
General population LCFs		1.0	0.62	0.77	0.51	0.47
Vehicle emissions-related health effects (fatalities)		0.0053	0.0033	0.0041	0.015	0.0030
Accident risk						
Population LCFs		0.0001	0.0001	0.0004	0.002	0.0003
Maximum reasonably foreseeable accident scenario						
Population LCFs		31	31	31	31	31
Maximally exposed individual probability of LCF		0.013	0.013	0.013	0.013	0.013
Traffic accident fatalities		6.3	3.3	4.0	2.3	2.3

a. Impacts are totals for 24 years of operations.
b. Includes impacts to workers at an intermodal transfer station.
c. LCF = latent cancer fatality.

risks of SNF [spent nuclear fuel] transport in the vicinity of Las Vegas are within regulatory limits and small."

6.1.2.7 Socioeconomics

Socioeconomic impacts of transportation would take place from construction and operation of branch rail lines and heavy-haul routes, including intermodal transfer stations. Figure 6-5 shows regional workforce changes for construction and operations activities. The largest number of jobs would be created by construction of branch rail lines. Because of the large population and workforce in the socioeconomic region of influence (principally Clark County), impacts from construction activities would be small for the rail and heavy-haul truck implementing alternatives except for Lincoln County (the two rail corridors and three heavy-haul truck routes originating in Caliente). Impacts in Lincoln County would be moderate; however, these impacts would not be greater than historic short-term socioeconomic changes in the county. In general, regional workforce changes from construction would be small and transient; changes in per capita real disposable income would be smaller. Changes to the baseline regional populations would be unlikely to have consequences.

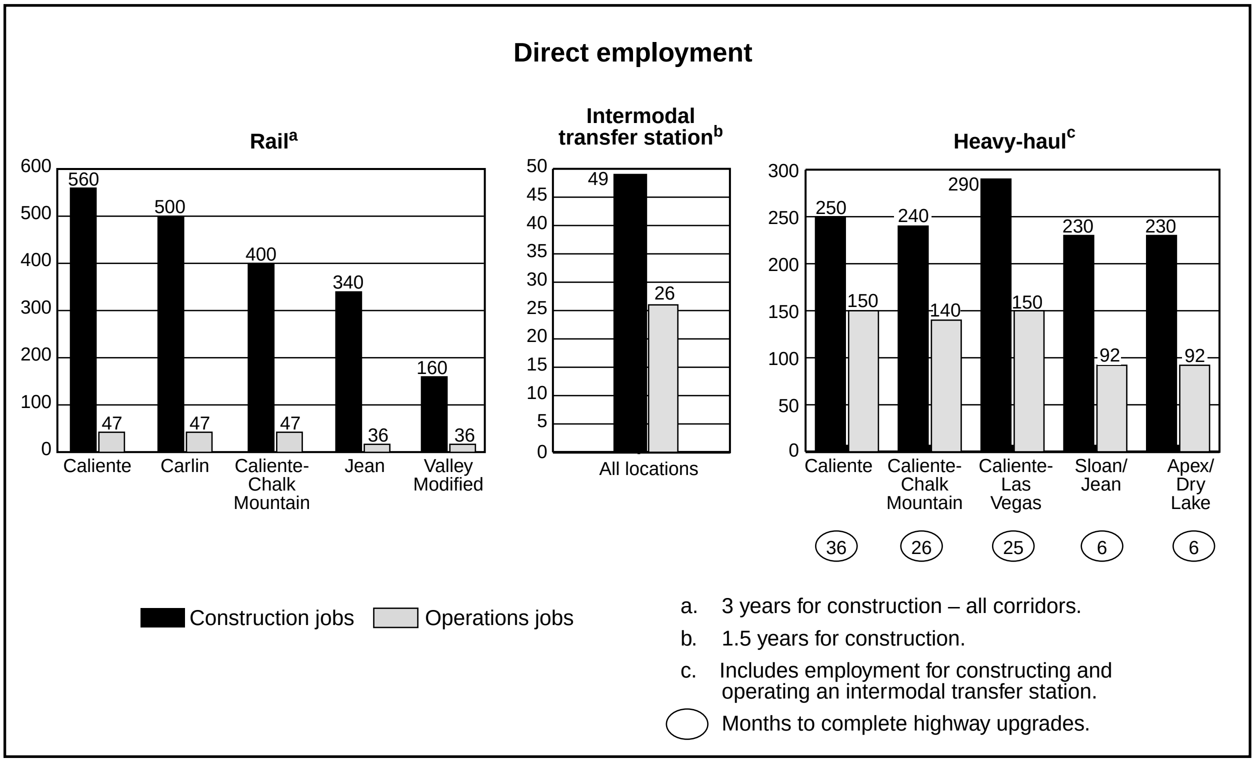


Figure 6-5. Impacts to employment from Nevada transportation alternatives.

More operations jobs would be created to support heavy-haul truck transportation than for rail transportation. Socioeconomic impacts from operations activities would also be small except for Lincoln County, where impacts would be moderate. However, these impacts would not be greater than historic short-term socioeconomic changes that have occurred in the county in the past.

6.1.2.8 Noise

Noise from the construction of a branch rail line or upgrades to highways for heavy-haul trucks would be transient and not excessive. In addition, noise from trains, which would occur during as many as five weekly round trips, would not be excessively disruptive. Heavy-haul truck operations would use existing highways that already had traffic, including semi-trailer trucks. There could be a need to identify the location of potential residents to refine the present assessment. The American Indian Writers Subgroup identified noise from transportation as a concern because of its effects on ceremonies and the solitude necessary for healing and praying.

6.1.2.9 Aesthetics

Studies have identified a potential visual resource impact for the northeastern portion of the Jean rail corridor that passes through the Spring Mountains. The character of Class II lands (defined in Chapter 3, Section 3.1.10) in that part of the corridor would change, possibly in conflict with visual resource management goals. No other rail corridors would have large or lasting aesthetic impacts. The upgrades of existing highways would present short-term aesthetic impacts during construction but these would be temporary and transient, resulting largely from widening the highways. Routes originating in Caliente could cause impacts on the Class II lands of Kershaw Ryan State Park, the entrance of which is on the east side of the Meadow Valley Wash across from a potential location for an intermodal transfer station. However, the character of this area of the Meadow Valley Wash has been modified by the Union Pacific rail line, the City of Caliente water treatment facility, and agricultural uses of lands in the vicinity. All heavy-haul truck routes and all branch rail lines except Carlin would pass through Class III lands. Aesthetic conditions would not be affected by legal-weight trucks on existing, well-traveled highways.

6.1.2.10 Utilities, Energy, and Materials

Impacts to utility, energy, and material resources from the construction and operation of any of the rail or heavy-haul truck implementing alternatives would be small compared to usage in Nevada. For example, Nevada fossil-fuel consumption during 1996 was about 3.8 billion liters (1 billion gallons) [BTS 1999a, Table MF-21]. By comparison the largest fossil-fuel use for any of the implementing alternatives would be about 50 million liters (13 million gallons), less than 2 percent of the Nevada annual use. Similarly, concrete use for the largest implementing alternative would be about 120,000 metric tons (51,000 cubic meters), also less than 2 percent of the Nevada annual use of 7.4 million metric tons (3.2 million cubic meters) (Sherwood 1998, all). Figures 6-6 and 6-7 compare the use of resources for construction of the rail and heavy-haul truck implementing alternatives, respectively.

6.1.2.11 Wastes

Wastes from the construction of an intermodal transfer station and upgrades to highways or from the construction of a branch rail line in Nevada would be recovered for recycling, placed in permitted industrial landfills, or reused. In addition, hazardous wastes, if any, would be sent to a permitted hazardous waste facility. The operation of an intermodal transfer station and heavy-haul trucks or of a branch rail line would produce small quantities of waste. The quantities from legal-weight truck operations in Nevada would also be small. Thus, impacts from the wastes generated during Nevada transportation to support the Proposed Action would be small.

6.1.2.12 Environmental Justice

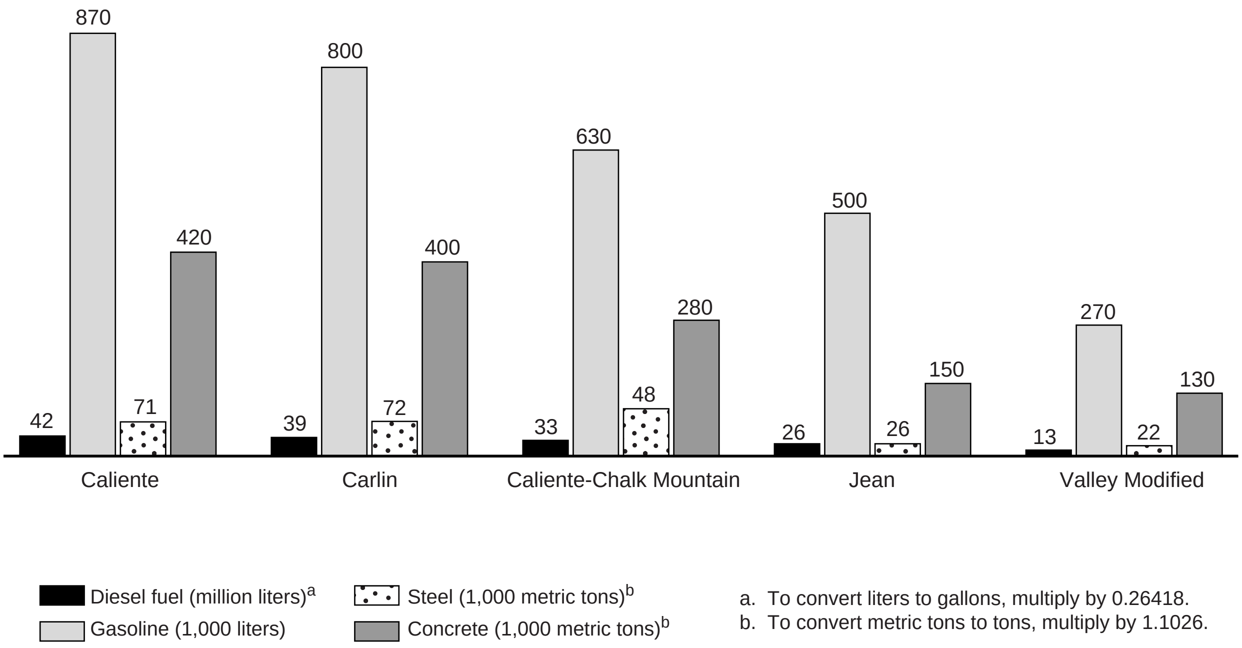
This section uses the results of analyses from other disciplines to determine if disproportionately high and adverse impacts on minority or low-income populations would be likely to occur from transportation activities. DOE does not expect disproportionately high and adverse impacts to minority or low-income populations from the Proposed Action. The environmental justice analysis involved a two-stage assessment of the potential for disproportionately high and adverse impacts on minority and low-income populations:

- First, a review of the activities included in the Proposed Action to determine if they would be likely to result in high and adverse human health impacts or in environmental impacts that could affect human populations

- Second, if the first-stage review identified high and adverse impacts to human populations in general, an analysis of these impacts as described above to determine if they could be disproportionately high and adverse for minority or low-income populations

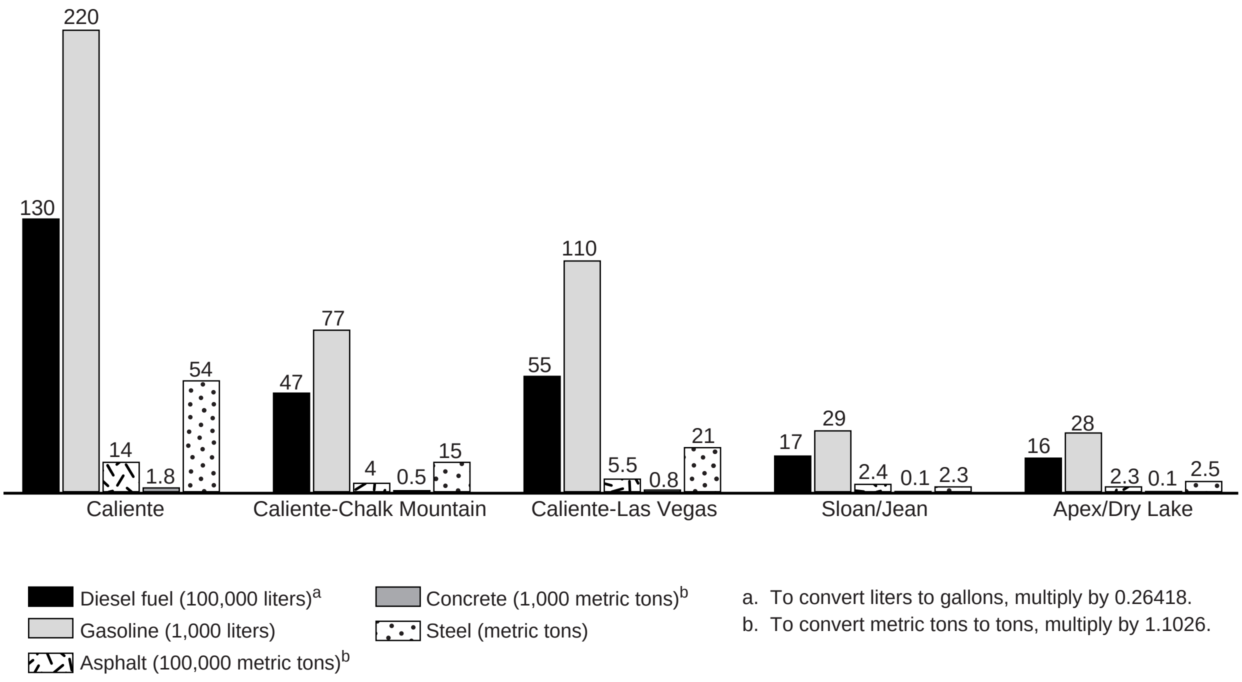
If the first-stage review does not identify impacts to human populations, a second-stage analysis for potential environmental justice impacts is not required because there would not be high and adverse impacts to any part of the human population, including minority and low-income populations.

No potentially disproportionately high and adverse impacts to minority or low-income populations were identified in areas of land use; air quality; hydrology; biological resources and soils; socioeconomics; aesthetics; and occupational and public health and safety for construction or operations under the mostly legal-weight truck scenario in Nevada or any of the 10 rail and heavy-haul truck transportation



a. To convert liters to gallons, multiply by 0.26418.
b. To convert metric tons to tons, multiply by 1.1026.

Figure 6-6. Utility, energy, and material use for construction of a branch rail line in Nevada.



a. To convert liters to gallons, multiply by 0.26418.
b. To convert metric tons to tons, multiply by 1.1026.

Figure 6-7. Utility, energy, and material use for upgrading of Nevada highways for heavy-haul truck use.

implementing alternatives. Potential visual resource (aesthetic) impacts were identified for the Jean rail corridor but these were determined to not be disproportionate. Potential impacts to cultural resources and noise impacts to Native American values have not been determined in all areas and may require further ethnographic study. However, no potentially disproportionately high and adverse impacts would occur in these areas for legal-weight truck transportation that would use existing highways. If DOE identified potentially high and adverse impacts for a corridor or route, it would mitigate them (as discussed in Chapter 9).

Because impacts to humans and other impacts that could affect minority or low-income populations or populations of Native Americans would not be disproportionately high and adverse, including mitigation as needed, an additional environmental justice analysis is not required. Chapter 4, Section 4.1.13.4, contains an environmental justice discussion of a Native American perspective on the Proposed Action.

6.1.3 TRANSPORTATION OF OTHER MATERIALS AND PERSONNEL

Other types of transportation activities associated with the Proposed Action would involve the transportation of personnel and of materials other than the spent nuclear fuel and high-level radioactive waste discussed above. These other materials include construction materials and consumables for repository construction and operation, including disposal containers; waste including low-level waste, construction and demolition debris, sanitary and industrial solid waste, and hazardous waste; and office and laboratory supplies, mail, and laboratory samples.

Detailed analyses of the impacts of these transportation activities are provided in Appendix J. Overall, transportation of these materials and personnel could result in as many as 8 additional traffic fatalities. During operations, the additional traffic in the Las Vegas Valley would result in increased emissions of carbon monoxide. Because the Las Vegas Valley is a nonattainment area for carbon monoxide, an air quality conformity analysis may be required because estimated emissions are near the General Conformity Rule emission threshold (40 CFR Part 93). Impacts in other environmental resource areas would be unlikely to occur.

6.2 National Transportation

This section describes national transportation impacts from shipping spent nuclear fuel and high-level radioactive waste from 72 commercial and 5 DOE sites throughout the United States to the proposed Yucca Mountain Repository. This section includes the following:

- Definition and an overview of the analysis scenarios (Section 6.2.1)
- Impacts to workers and the public from spent nuclear fuel and high-level radioactive waste loading operations at commercial and DOE sites (Section 6.2.2)
- Potential incident-free (routine) radiological impacts and vehicle emission impacts (Section 6.2.3)
- Potential accident scenario impacts (Section 6.2.4)

National transportation of spent nuclear fuel and high-level radioactive waste, which would use existing highways and railroads, would average 14.2 million truck kilometers (8.8 million miles) per year for the mostly truck case and 3.5 million railcar kilometers (2.2 million miles) per year for the mostly rail case. Barges used to ship rail casks to nearby railheads from commercial sites not served by a railroad could travel an average of as much as 10,700 kilometers (6,650 miles) per year. The national yearly average for total highway and railroad traffic is 186 billion truck kilometers (116 billion miles) and 49 billion railcar kilometers (30 billion miles) (BTS 1998, page 5)]. Spent nuclear fuel and high-level radioactive waste transportation would represent a very small fraction of the total national highway and railroad traffic (0.008 percent of truck kilometers and 0.007 percent of railcar kilometers). Domestic waterborne trade in 1995 accounted for about 1 billion metric tons (910 million tons) (MARAD 1998, all). This represents about 1 million barge shipments per year. Thus, shipments of spent nuclear fuel by barge would only be a very small fraction of the total annual domestic waterborne commerce.

With the exception of occupational and public health and safety impacts, which are evaluated in this section, the environmental impacts of this small fraction of all national transportation would be very small in comparison to the impacts of other nationwide transportation activities. Thus, the national transportation of spent nuclear fuel and high-level radioactive waste would have very small impacts on land use and ownership; air quality; hydrology; biological resources and soils; cultural resources; socioeconomics; noise; aesthetics; utilities, energy, and materials; or waste management.

Radiological impacts of accidents on biological resources would be very small. The analysis focused the impacts from accidents on human health and safety. A severe accident scenario, such as the maximum reasonably foreseeable accident scenarios discussed in Section 6.2.4.2, that would cause a release of contaminated materials would be very unlikely. The probabilities of the severe accident scenarios discussed in Section 6.2.4.2 are less than 2 in 10 million per year for both the mostly legal-weight truck and mostly rail transportation scenarios. Because of the low probability of occurrence, an accident scenario during the transport of spent nuclear fuel and high-level radioactive waste would be unlikely to cause adverse impacts to any endangered or threatened species, and impacts to other plants and animals would be small. Therefore, the analysis did not evaluate the impacts for these environmental parameters for national transportation activities further.

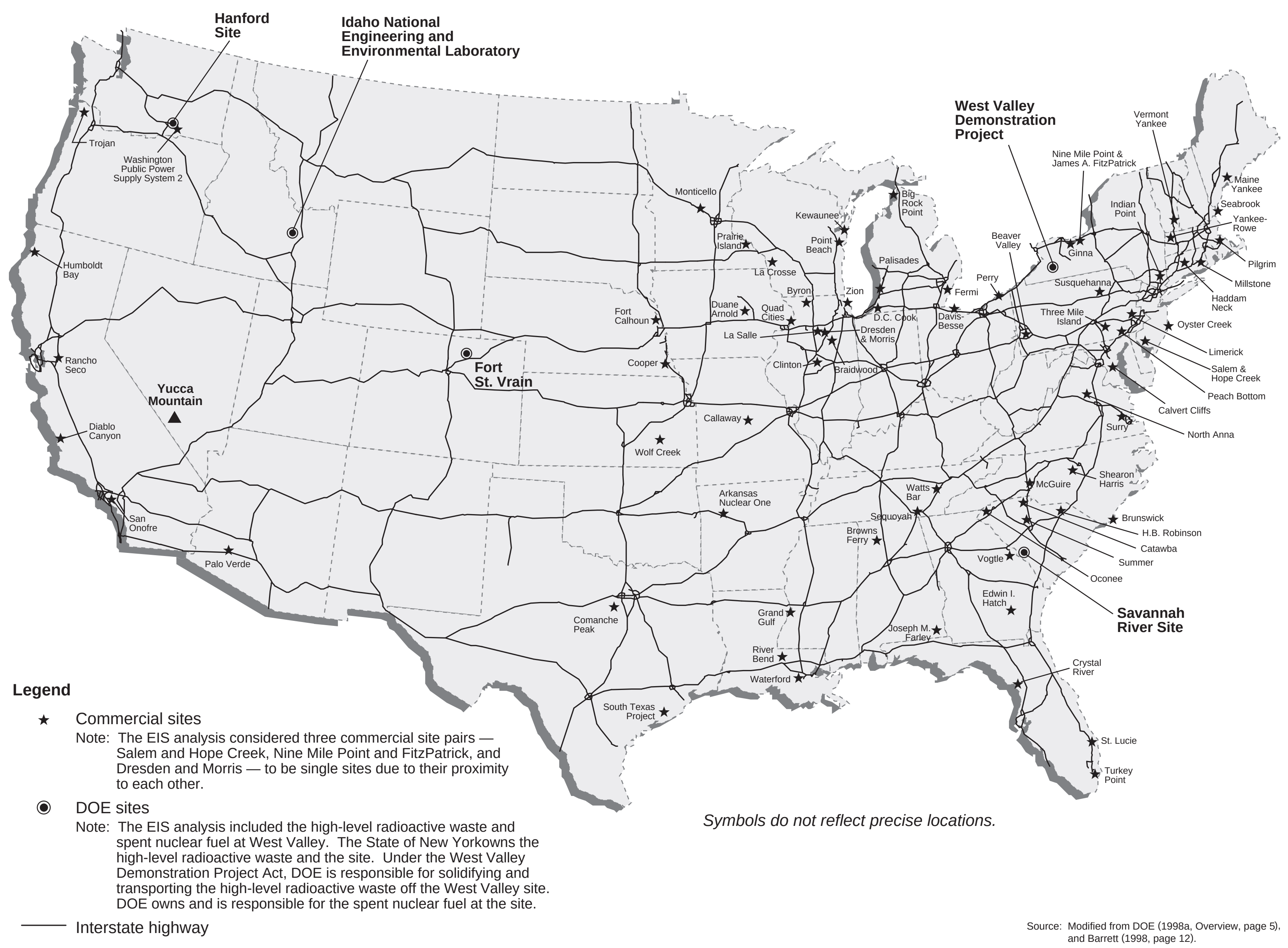
6.2.1 ANALYSIS SCENARIOS AND METHODS

Under the mostly legal-weight truck scenario for national transportation, DOE would transport shipments (with the exception of naval spent nuclear fuel and possibly some DOE high-level radioactive waste) by legal-weight truck to Nevada. Naval spent nuclear fuel would be shipped by rail from the Idaho National Engineering and Environmental Laboratory. Under the mostly-legal weight truck scenario, DOE assumed that some shipments of DOE high-level radioactive waste would use overweight trucks. With the exception of permit requirements and operating restrictions, the vehicles for these shipments would be similar to legal-weight truck shipments but might weigh as much as 52,200 kilograms (115,000 pounds).

MOSTLY LEGAL-WEIGHT TRUCK AND MOSTLY RAIL SCENARIOS

The Department does not anticipate that either the mostly legal-weight truck or the mostly rail scenario represents the actual mix of truck or rail transportation modes it would use. Nonetheless, DOE used these scenarios as a basis for the analysis of potential impacts to ensure the analysis addressed the range of possible transportation impacts. Thus, the estimated numbers of shipments for the mostly legal-weight truck and mostly rail scenarios represent only the two extremes in the possible mix of transportation modes. Therefore, the analysis provides estimates that cover the range of potential impacts to human health and safety and to the environment for the transportation modes DOE could use for the Proposed Action.

States routinely issue special permits for trucks weighing up to 58,600 kilograms (129,000 pounds). Figure 6-8 shows the relationship of Interstate Highways, many of which would be preferred routes (see 49 CFR 397.101) for legal-weight truck shipments, and the locations of the commercial and DOE sites and Yucca Mountain.



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

—— Interstate highway

Symbols do not reflect precise locations.

Source: Modified from DOE (1998a, Overview, page 5), and Barrett (1998, page 12).

Figure 6-8. Commercial and DOE sites and Yucca Mountain in relation to the U.S. Interstate Highway System.

Under the national transportation mostly rail scenario, DOE would transport shipments (with the exception of commercial spent nuclear fuel at 9 sites that do not have the capability to load a rail cask) by rail to Nevada. In addition, this scenario assumes that 19 commercial sites that have the capability to handle and load rail casks, but that do not have railroad service, would make shipments to nearby railheads by barge or heavy-haul truck. Barge shipments of rail casks containing spent nuclear fuel could be possible from 14 commercial sites that are on or near navigable waterways. Figure 6-9 shows the relationship of mainline railroads, many of which would be used for rail shipments, and the locations of the commercial and DOE sites and Yucca Mountain.

This section evaluates radiological and nonradiological impacts to workers and the public from routine transportation operations and from accidents. DOE used a number of computer models and programs to estimate these impacts; Appendix J describes the analysis assumptions and models.

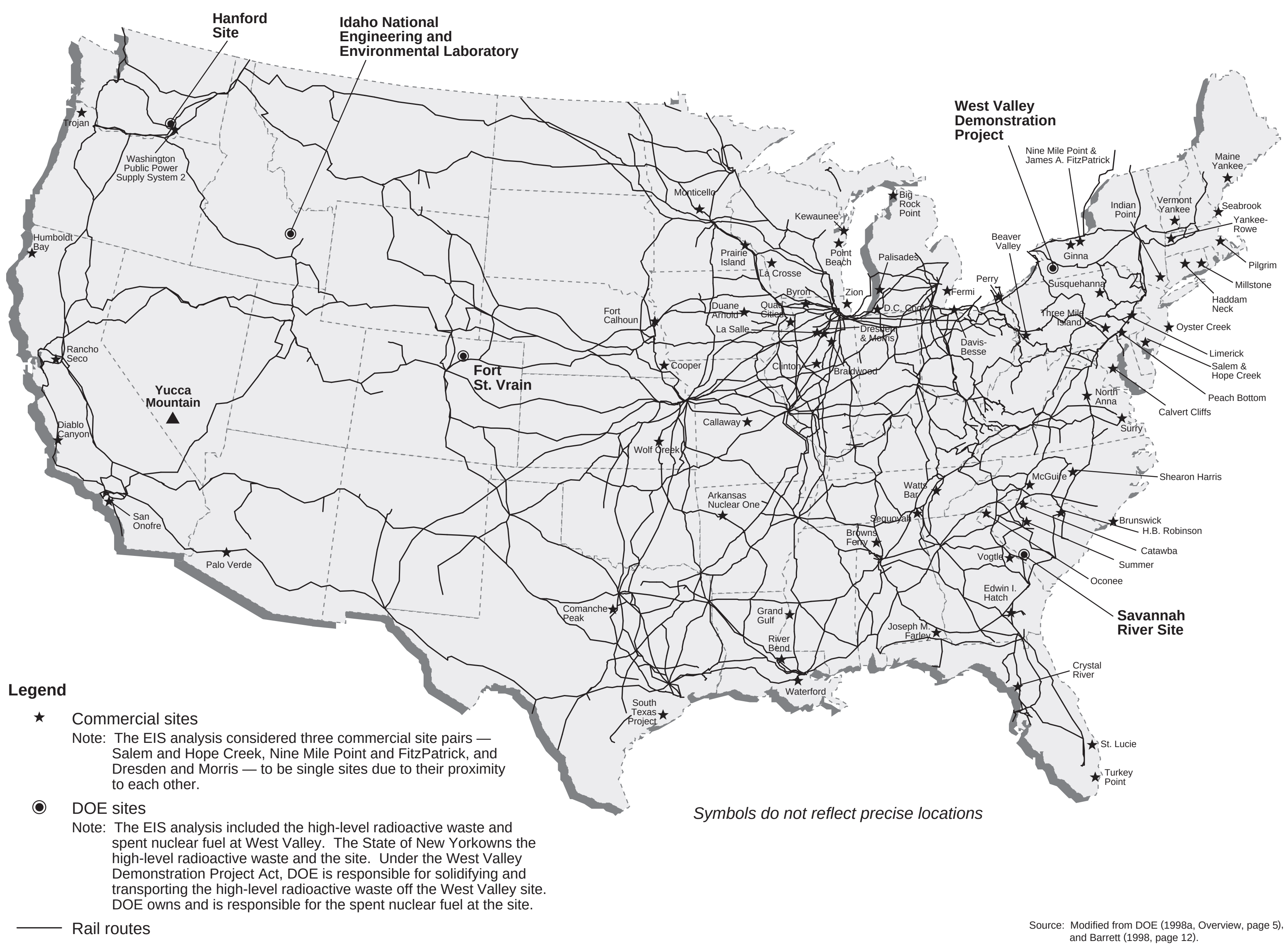
The CALVIN model (TRW 1998l, page 2 to 22) was used to estimate the number of shipments of commercial spent nuclear fuel for both the mostly legal-weight truck and mostly rail scenarios. The CALVIN program used commercial spent nuclear fuel inventories and characteristics from the *Report on the Status of the Final 1995 RW-859 Data Set* (DOE 1996i, all) (see Appendix A) to estimate the number of shipments. For DOE spent nuclear fuel and high-level radioactive waste, the analysis used inventories and characteristics for materials to be shipped under the Proposed Action that were reported by the DOE sites in 1998 (see Appendix A) to estimate the number of shipments. Chapter 2, Section 2.1.2, and Appendix J discuss the number of shipments.

The transportation analyses used the following computer programs:

- HIGHWAY (Johnson et al. 1993a, all) to identify the highway routes that it could use to transport spent nuclear fuel and high-level radioactive waste. All of the routes would satisfy U.S. Department of Transportation route selection regulations.
- INTERLINE (Johnson et al. 1993b, all) to identify rail and barge routes for the analysis.
- RADTRAN4 (Neuhauser and Kanipe 1992, all) to estimate radiological dose risk to populations and transportation workers during routine operations. This program also estimated radiological dose risks to populations and transportation workers from accidents.
- RISKIND (Yuan et al. 1995, all) to estimate radiological doses to the maximally exposed individuals and to the population during routine transportation. This program also estimated radiological doses to the maximally exposed individuals and to the population from transportation accidents.

6.2.2 IMPACTS FROM LOADING OPERATIONS

This section describes potential impacts from loading spent nuclear fuel and high-level radioactive waste in transportation casks and on transportation vehicles at the 72 commercial and 5 DOE sites. It also describes methods for estimating radiological and industrial hazard impacts from routine loading operations and radiological impacts of loading accidents to workers and members of the public. During loading operations, radiological impacts to workers could occur from normal operations and accidents. In addition, workers could experience impacts from industrial hazards. Members of the public could experience radiological impacts if a loading accident occurred but would not experience impacts from industrial hazards, including hazards associated with nonradioactive hazardous materials. Nonradioactive hazardous materials would be used only in small quantities, if at all, in loading operations. Chapter 4 addresses impacts from unloading operations at the repository.



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

—— Rail routes

Symbols do not reflect precise locations

Source: Modified from DOE (1998a, Overview, page 5), and Barrett (1998, page 12).

Figure 6-9. Commercial and DOE sites and Yucca Mountain in relation to the U.S. railroad system.

6.2.2.1 Radiological Impacts of Routine Operations

Radiological impacts to members of the public from routine operations would be very small. An earlier DOE analysis estimated that public dose from loading operations would be less than 0.001 person-rem per metric ton of uranium loaded (DOE 1986b, Volume 2, Figure 2.9, page 2.42) but did not provide a definite estimated lower value (see Appendix J for more information). Therefore, to be conservative this analysis estimated the dose to the public from loading operations by multiplying the value of 0.001 person-rem per metric ton uranium by the 70,000 metric tons of spent nuclear fuel and high-level radioactive waste DOE would transport under the Proposed Action. [DOE (1986b, Volume 2, all) uses the term “metric ton uranium,” which is essentially the same as metric tons of heavy metal for commercial spent nuclear fuel.] The resulting population dose is 70 person-rem, which, based on conversion factors recommended by the International Commission on Radiological Protection, would result in 0.04 latent cancer fatality.

Table 6-3 lists estimated involved worker impacts from loading spent nuclear fuel at commercial sites and loading DOE spent nuclear fuel and high-level radioactive waste at DOE facilities for shipment to the Yucca Mountain site under the Proposed Action. The impacts assume worker rotation and other administrative actions would follow guidance similar to that in the DOE *Radiological Control Manual* (DOE 1994c, Article 211) that would limit doses to individual workers to 500 millirem per year. The maximum individual dose would be 12 rem over the 24 years of loading operations for individuals who worked the entire duration of repository operations. The estimated probability of a latent cancer fatality for an involved worker from this dose would be about 0.005 (5 chances in 1,000).

Table 6-3. Estimated radiological impacts to involved workers from loading operations.[a]

Impact	Mostly rail	Mostly legal-weight truck
Maximally exposed individual		
Dose (rem)	12	12
Probability of LCF[b]	0.005	0.005
Involved worker population[c]		
Dose (person-rem)	5,200	14,200
Number of LCFs	2	6

a. Numbers are rounded.

b. LCF = latent cancer fatality.

c. All involved workers at all facilities, preparing about 13,400 shipments under the mostly rail scenario and about 49,800 shipments under the mostly legal-weight truck scenario over 24 years.

As many as 2 latent cancer fatalities from the mostly rail scenario and about 6 latent cancer fatalities from the legal-weight truck scenario could result in the involved worker population over 24 years. The mostly legal-weight truck scenario would result in more potential impacts than the mostly rail scenario because of the increased exposure time needed to load more transportation casks. DOE expects impacts to noninvolved workers to be even smaller than those to involved workers. Using information from the earlier studies (Schneider et al. 1987, all; Smith, Daling, and Faletti 1992, all; DOE 1986b, Volume 2, all), DOE estimated 0.04 latent cancer fatality to members of the public from routine loading operations.

6.2.2.2 Impacts from Industrial Hazards

Table 6-4 lists estimated impacts to involved workers from industrial hazards over 24 years of loading operations at the 77 sites. Fatalities from industrial hazards would be unlikely from loading activities under either national transportation scenario. The mostly legal-weight truck scenario would have about double the estimated number of total recordable cases and lost workday cases of the mostly rail scenario because there would be more shipments and more work time (full-time work years). Using the assumption that the noninvolved workforce would be 25 percent of the number of involved workers, the analysis determined that impacts to noninvolved workers would be about 25 percent of those listed in Table 6-4. In addition to industrial safety impacts, traffic fatality impacts to commuting workers during commuting and operations were estimated. Traffic involving commuting workers could result in 0.5 fatality under the mostly legal-weight truck scenario and 0.2 fatality under the mostly rail scenario.

Table 6-4. Impacts to involved workers[a] from industrial hazards during loading operations.[b]

Impact	Mostly rail	Mostly legal-weight truck
Total recordable cases[c]	65	150
Lost workdays[d]	29	66
Fatalities[e]	0.06	0.14

a. Includes all involved workers at all facilities during 24 years of repository operations. During the 24 years of shipments to the proposed repository, these workers would put in 1,700 work years (2,080 hours per work year) preparing about 13,400 shipments under the mostly rail scenario and 3,900 work years preparing about 49,500 legal-weight truck shipments and 300 naval spent nuclear fuel rail shipments under the mostly legal-weight truck scenario. Impacts in the noninvolved workforce would be about 25 percent of those listed.
b. Numbers are rounded to two significant digits.
c. Total recordable cases (injury and illness) based on a 1992-1997 DOE site loss incident rate of 0.03 (DOE 1999c, DOE and Contractor Injury and Illness Experience).
d. Lost workday cases based on a 1992-1997 DOE site loss incident rate of 0.013.
e. Fatalities based on a 1988-1997 DOE site loss incident rate of 0.000029.

6.2.3 NATIONAL TRANSPORTATION IMPACTS

The following sections discuss the impacts of transporting spent nuclear fuel and high-level radioactive waste to the proposed Yucca Mountain Repository under the mostly legal-weight truck and mostly rail scenarios. The analysis in this section addresses the impacts of incident-free transportation. Section 6.2.4 discusses accidents, and Appendix J contains the details on the analysis and its assumptions.

6.2.3.1 Impacts from Incident-Free Transportation – National Mostly Legal-Weight Truck Transportation Scenario

This section addresses radiological and nonradiological impacts to populations and maximally exposed individuals for incident-free transportation of spent nuclear fuel and high-level radioactive waste for the mostly-legal weight truck scenario.

Incident-Free Radiological Impacts to Populations. Table 6-5 lists the incident-free population dose and latent cancer fatalities to workers and the public for the mostly legal-weight truck scenario. The impacts include those for the shipment of naval spent nuclear fuel by rail to Nevada, intermodal transfer of rail casks to heavy-haul trucks, and subsequent heavy-haul transportation to the proposed repository. Section 6.3.3 and Appendix J contain additional information on worker impacts from intermodal transfer operations. Worker impacts would include radiological exposures of security escorts for legal-weight truck, rail, and heavy-haul truck shipments and from the transfer of naval spent nuclear fuel shipments from rail to heavy-haul truck. The collective dose to the security escorts, who would travel in separate vehicles, would be about 250 person-rem for legal-weight truck shipments. Doses to escorts of rail shipments of naval spent nuclear fuel, who would travel in railcars in sight of but separated from the cask cars, followed by escorted heavy-haul truck shipments in Nevada would be about 27 person-rem. (See Appendix J, Section J.1.3.2.2.2.)

Table 6-5. Population doses and impacts from incident-free transportation for national mostly legal-weight truck scenario.[a]

Category	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel[b]
Involved workers		
Collective dose (person-rem)	11,000	65
Estimated LCFs[c]	4.5	0.03
Public		
Collective dose (person-rem)	35,000	45
Estimated LCFs	18	0.02

a. Impacts are totals for shipments over 24 years.
b. Includes impacts from intermodal transfer operations (see Section 6.3.3.1).
c. LCF = latent cancer fatality.

The estimated radiological impacts would be 5 latent cancer fatalities for workers and 18 latent cancer fatalities for members of the public for the 24 years of operation. The population within 800 meters

(0.5 mile) of routes would be about 7.2 million. About 1.6 million members of this population would be likely to incur fatal cancers from all other causes (ACS 1998, page 10).

Incident-Free Radiological Impacts to Maximally Exposed Individuals. Table 6-6 lists estimates of doses and radiological impacts for maximally exposed individuals for the legal-weight truck scenario (which considers drivers and security escorts). The risks are calculated for the 24 years of shipment activities. Appendix J discusses analysis methods and assumptions. State inspectors who conducted frequent inspections of shipments of spent nuclear fuel and high-level radioactive waste and transportation vehicle operating crews would receive the highest annual radiation doses.

Table 6-6. Estimated doses and radiological impacts to maximally exposed individuals for national mostly legal-weight truck scenario.[a,b]

Individual	Dose (rem)	Probability of latent fatal cancer
Involved workers		
Crew member (including driver)	48[c]	0.02
Inspector	48[c]	0.02
Railyard crew member	0.13	0.00006
Public		
Resident along route	0.0054	0.000003
Person in traffic jam	0.04[d]	0.00002
Person at service station	2.4[e]	0.0012
Resident near rail stop	0.009	0.000005

a. The assumed external dose rate is 10 millirem per hour at 2 meters (6.6 feet) from the vehicle for all shipments.
b. Totals for 24 years of operations.
c. Assumes 2-rem-per-year dose limit.
d. Person in a traffic jam is assumed to be exposed one time only.
e. Assumes the person works at the service station for all 24 years of operations.

Impacts to the maximally exposed individuals in the general public would be very low. The highest impacts, to a service station employee, would still be very low (Table 6-6); the analysis estimated that a maximally exposed individual at a service station would receive 2.4 rem over 24 years under the legal-weight truck scenario. This estimate conservatively assumed the person would be exposed to 430 truck shipments each year for 24 years. For perspective, under the mostly legal-weight truck scenario, which assumes an average of 2,100 legal-weight truck shipments per year, about 430 truck shipments would pass through the Mercury, Nevada, gate to the Nevada Test Site in 1,800 hours. A worker at a truck stop along the route to Mercury would work about 1,800 hours per year. Thus, if every shipment stopped at that truck stop, the maximum number of shipments the worker would be exposed to in a year would be 430.

Impacts from Vehicle Emissions. Table 6-7 lists the estimated number of fatalities that vehicle emissions from shipments to the Yucca Mountain site would cause. These potential impacts would result principally from exposure to increases in levels of pollutants in urban areas where the additional pollutants would come from vehicles transporting spent nuclear fuel and high-level radioactive waste and the accompanying escort vehicles. In the context of the number of vehicle kilometers from shipments to the Yucca Mountain site, these emissions would be very small in comparison to the emissions from other vehicles.

6.2.3.2 Impacts from Incident-Free Transportation – National Mostly Rail Transportation Scenario

This section addresses radiological and nonradiological impacts to populations and maximally exposed individuals from the incident-free transportation of spent nuclear fuel and high-level radioactive waste for

Table 6-7. Population health impacts from vehicle emissions during incident-free transportation for national mostly legal-weight truck scenario.[a]

Category	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel	Total[b]
Estimated vehicle emission-related fatalities	0.6	0.002	0.6

a. Impacts are totals for shipments over 24 years.
b. Total differs due to rounding.

the mostly rail national transportation scenario. In addition, it identifies impacts of legal-weight truck shipments that would occur under the mostly rail scenario for the nine commercial sites that do not have the capability to load rail casks (about 2,600 legal-weight truck shipments over 24 years).

For this analysis, DOE assumed that it would use either a branch rail line or heavy-haul trucks in Nevada to transport rail casks to and from the repository. Accordingly, the results indicate the range of impacts for the rail and heavy-haul truck implementing alternatives that DOE could use for transportation to the repository after rail shipments arrived in Nevada. Section 6.3 and Appendix J present more information on the analysis of the environmental impacts of the Nevada rail and heavy-haul implementing alternatives. Appendix J also presents a comparison of the effects of using dedicated trains or general freight services for rail shipments.

The mostly rail scenario assumes that the 19 commercial sites not served by a railroad but with the capability to handle rail casks would use heavy-haul trucks to transport the casks to railheads for transfer to railcars. In addition, 14 of the 19 sites are adjacent to navigable waterways. At some of the 14 sites on navigable waterways, barges could be used for the initial trip segments (see Appendix J). The impacts estimated by the analysis include the impacts of heavy-haul truck or barge shipments of rail casks from the 19 sites to nearby railheads.

The analysis assumed that the truck shipments of spent nuclear fuel and high-level radioactive waste would make periodic stops for state inspections, changes of drivers, rest, and fuel. Rail shipments would also make periodic stops. However, the assumed frequency of the stops and the numbers of people nearby would be different from those for truck shipments and would result in a lower dose.

Incident-Free Radiological Impacts to Populations. Table 6-8 lists incident-free radiological impacts that would occur during the routine transportation of spent nuclear fuel and high-level radioactive waste under the mostly rail national transportation scenario. Because national impacts would result from transportation from the commercial and DOE sites to the repository, they include impacts from a Nevada rail or heavy-haul truck implementing alternative. For the case in which rail shipments would continue in Nevada, total impacts to members of the general public would differ depending on the implementing alternative (see Section 6.3.2 for additional details). The range of values listed in Table 6-8 includes the range of impacts from the Nevada implementing alternatives.

Impacts to members of the public from legal-weight truck shipments under the mostly rail transportation scenario would be greater than those for rail shipments. About 90 percent of the estimated impacts would involve persons at in-transit stops.

About 2 latent cancer fatalities would result from shipments of spent nuclear fuel and high-level radioactive waste under the mostly rail scenario over 24 years. The latent cancer fatalities would occur over the lifetimes of individuals in the exposed population. The population within 800 meters (0.5 mile) of routes in which these 2 fatalities would occur would be approximately 13 million. Approximately 2.9 million members of this population would incur fatal cancers from all other causes (ACS 1998, page 10).

Table 6-8. Population doses and radiological impacts from incident-free transportation for national mostly rail scenario.[a]

Category	Legal-weight truck shipments	Rail shipments[b]	Totals[c]
Involved workers			
Collective dose (person-rem)	850	1,100 - 1,500	1,900 - 2,300
Estimated LCFs[d]	0.34	0.43 - 0.59	0.77 - 0.93
Public			
Collective dose (person-rem)	2,400	880 - 2,600	3,300 - 5,000
Estimated LCFs	1.2	0.44 - 1.3	1.6 - 2.5

a. Impacts are totals for 24 years (2010 to 2033).

b. Barge transportation to a railhead on navigable waterways could be used for transportation from 14 commercial sites that do not have rail service but can load a rail cask. See Appendix J.

c. Totals might differ from sums of values due to rounding.

d. LCF = latent cancer fatality.

Incident-Free Radiological Impacts to Maximally Exposed Individuals. Table 6-9 lists the results of risk calculations for maximally exposed individuals for the mostly rail transportation scenario over 24 years. Truck and rail crew members would receive the highest doses. The mostly rail scenario would require transport crews for legal-weight trucks (2,600 total shipments over 24 years) and for rail shipments. Individual crew members who operated legal-weight trucks and escorts for rail shipments could be exposed to as much as 48 rem over 24 years of operations (maximum exposure of 2 rem each year). State inspectors who would conduct frequent inspections of rail shipments could receive annual radiation doses as high as 1.5 rem.

Table 6-9. Estimated doses and radiological impacts to maximally exposed individuals for national mostly rail scenario.[a,b]

Receptor	Dose (rem)	Probability of latent fatal cancer
Involved workers		
Crew member (rail, heavy-haul truck, or legal-weight truck)	48[c]	0.02
Inspector (rail)	35	0.014
Railyard crew member	4.4	0.0018
Public		
Resident along route (rail)	0.003	0.000002
Person in traffic jam (legal-weight truck)	0.04	0.00002
Person at service station (legal-weight truck)	0.14	0.00007
Resident near rail stop	0.31	0.00016

a. The assumed external dose rate is 10 millirem per hour at 2 meters (6.6 feet) from the vehicle for all shipments.

b. Totals for 24 years.

c. Assumes 2-rem-per-year dose limit.

Impacts from Vehicle Emissions. Fewer than 1 fatality (0.3) would result from exposure to vehicle emissions over 24 years under the mostly rail scenario. This potential increase would result principally from exposure of people in urban areas to very small increases in levels of pollutants caused by vehicles transporting spent nuclear fuel and high-level radioactive waste.

6.2.4 ACCIDENT SCENARIOS

6.2.4.1 Loading Accident Scenarios

The analysis used existing information from several different sources (TRW 1994b, all; CP&L 1989, all; PGE 1996, all; DOE 1997b, all) to estimate potential radiological impacts from accidents involving the loading of spent nuclear fuel or high-level radioactive waste for shipment and handling of shipping casks.

As summarized below, the results in these sources indicate that there would be no or very small potential radiological consequences from accidents in all cases. Appendix J presents a description of typical operations for loading spent nuclear fuel in a shipping cask at a commercial facility.

Lift-handling incidents involving spent nuclear fuel in a transfer facility would have an estimated probability of 0.0001 (1 in 10,000) per handling operation (TRW 1994b, pages 3 to 8). The estimated collective dose to workers from the incidents would be no more than 0.1 person-rem, and it would be much less to the public.

The total number of high-level radioactive waste canisters potentially handled would be approximately the same as the number of spent nuclear fuel canisters, and handling operations would be similar. DOE expects the consequences of handling incidents that involved high-level radioactive waste would be less than those involving spent nuclear fuel (Kappes 1998, page 3). Thus, impacts from high-level waste handling would be less than the estimated 0.1-person-rem from a spent nuclear fuel handling accident.

Reports on independent spent fuel storage installations and previous DOE analyses provide further evidence of the low probable impacts associated with a loading accident. Safety analysis reports prepared for independent spent fuel storage installations at the Trojan Nuclear Station and the Brunswick Steam Electric Plant concluded that there would be no or low radiological consequences from accidents that could occur at such facilities (PGE 1996, Section 8.2; CP&L 1989, Section 8.2). This analysis examined the potential magnitude of impacts from spent nuclear fuel storage facility operations. Only one event (loss of air outlet shielding blocks on a horizontal storage module, which a tornado projectile could cause) could result in a dose to an offsite member of the public. The estimated dose to an individual at a distance of 200 meters (656 feet) would be 0.0013 rem (a 0.0000007 probability—7 in 10 million—of a latent cancer fatality) from direct and air-scattered (skyshine) radiation for a single horizontal storage module. The estimated dose to involved workers to recover from the event would be less than 0.09 person-rem (0.00002 latent cancer fatality). No other credible accidents involving a horizontal storage module had associated radiological consequences (NUTECH 1989, Section 10.2.3). Similarly, previous DOE analyses (DOE 1997b, all; TRW 1994b, all) indicate that radiological consequences from accidents involving spent nuclear fuel and high-level radioactive waste management activities would be very small (Table 6-10). The low consequences listed in Table 6-10 are consistent with the results from an earlier DOE analysis (DOE 1986b, Volume 2, page xvii).

6.2.4.2 Transportation Accident Scenarios

Accidents could occur during the transportation of spent nuclear fuel and high-level radioactive waste. This section describes the risks and impacts to the public and workers from accident scenarios that are highly unlikely but that would have severe consequences (called *maximum reasonably foreseeable accident scenarios*) to accident scenarios that are more likely but that would have less severe consequences. The impacts would include those to the population and to hypothetical maximally exposed individuals. The following paragraphs describe the analysis approach. Appendix J contains more details.

The analysis did not address accident impacts to workers apart from impacts to the public. For example, fatalities from train and truck accident scenarios would include fatalities for vehicle operators. The collective radiological risk from accidents to highway vehicle and train crews would be much less than for the public because of the large difference in the numbers of individuals that could be affected. In addition, based on national accident statistics, motor carrier and train operators are much less likely to be fatalities in accidents than operators of other vehicles (NHTSA 1998, page 30).

The specific number, location, and severity of an accident can be predicted only in general terms of the likelihood of occurrence (the probability). Similarly, the weather conditions at the time an accident

Table 6-10. Radiological consequences of accidents associated with handling and loading operations.

Affected group	Impact (per year)[a]	24-year impact	Source
Involved workers			
Maximally exposed involved worker			
Dose (rem)	0.0005	0.01	--[b]
Probability of LCF[c]	0.0000002	0.000005	--
Worker population			
Collective dose (person-rem)	0.1	2.4	TRW (1994b, pages 3 to 8)
Number of LCFs	0.00004	0.001	--
Noninvolved workers			
Maximally exposed noninvolved worker			
Dose (rem)	0.0002	0.005	--
Probability of LCF	0.00000005	0.000001	--
Worker population	No information available		
Public			
Maximally exposed individual			
Dose (rem)	0.0013	0.03	NUTECH (1989, Section 10.2.3)
Probability of LCF	0.0000007	0.00002	--
Population			
Collective dose (person-rem)	0.000074	0.002	TRW (1994b, page 3-8)
Number of LCFs	0.00000004	0.000001	--

a. Average annual impact for 24 years.
b. -- = determined by analysis.
c. LCF = latent cancer fatality.

occurs cannot be precisely predicted. Therefore, the EIS analysis evaluated a variety of accident scenarios and conditions to understand the influence of various conditions on environmental impacts. The analysis of impacts to populations along routes assumed that an accident could occur at any location along a route.

MAXIMUM REASONABLY FORESEEABLE ACCIDENT SCENARIOS

Maximum reasonably foreseeable impacts from accident scenarios for the transportation of spent nuclear fuel and high-level radioactive waste would be characterized by extremes of mechanical (impact) forces, heat (fire), and other conditions that would lead to the highest reasonably foreseeable consequences. For postulated accident scenarios such as these, the forces and heat would exceed the design limits of transportation cask structures and materials. (The performance of transportation casks was demonstrated through a combination of tests and analyses.) In addition, these forces and heat would be applied to the structures and surfaces of a cask in a way that would cause the greatest damage and bring about releases of radioactive materials to the environment. The most severe accident scenarios analyzed in this chapter would release radioactive material. These accident scenarios correspond to those in the highest accident severity category, which represent events that would be very unlikely but, if they occurred, would result in human health effect consequences.

In general, this EIS considers accidents with conditions that have a chance of occurring more often than 1 in 10 million times in a year to be reasonably foreseeable. Accidents and conditions less likely than this are not considered to be reasonably foreseeable.

THE MODAL STUDY

Factors other than the environment can cause uncertainties in the prediction of accident impacts. Uncertainty can be the result of limited data and the computer programs used to predict accident impacts. To assess potential impacts of severe highway and railroad transportation accident scenarios, DOE used conservative estimates developed for the *Shipping Container Response to Severe Highway and Railway Accident Conditions* [Fischer et al. (1987, all); also called the *Modal Study*] for fractions of shipping cask contents (spent nuclear fuel or high-level radioactive waste) that such accident scenarios could release to the environment. The Modal Study was a large-scale, multiyear study of the degree of safety provided by shipping casks certified by the U.S. Nuclear Regulatory Commission for the transportation of spent nuclear fuel. The Lawrence Livermore National Laboratory conducted the study, which the Commission sponsored. One of the study's major purposes was to assess the adequacy of the Commission regulations for the packaging and transportation of radioactive materials.

The State of Nevada and the Nevada Nuclear Waste Project Office have commented that the study's projections of amounts of radioactive materials that accident scenarios would release and the probabilities of release in severe accident scenarios might significantly underestimate releases and probabilities in real accidents. The Nuclear Waste Project Office based its comments on its assessment that:

- Cask design and accident scenario parameters were significantly oversimplified.
- A great deal of data was "created" to fill missing data on the probabilities of different accident conditions.
- The interactions of physical stresses in shipping cask structures were not fully analyzed.
- Failure to examine the impact of human error limited the applicability of the analysis to the real world.
- Computer simulations of cask impacts on surfaces did not replicate a phenomenon known as "slap down."
- The treatment of spent fuel damage was too simplistic.
- The portrayal of the spent fuel was deficient.
- Available data on cladding and fuel damage were not referenced or utilized.

The Nuclear Waste Project Office did not suggest the use of alternative analyses or models and did not offer differing values for use in estimating consequences or risks of severe accidents. In addition, its comments did not identify examples of actual accident conditions and damage to structures that could support different values for release fractions or release probabilities.

In responding to comments from an independent peer group that the Nuclear Regulatory Commission asked to review the study, the authors of the Modal Study observed that a detailed analysis would reduce conservatism and show that the actual radiological hazard is lower than the hazard calculated in the study.

An assessment of uncertainty in the Modal Study recognized many of the limitations that the Nuclear Waste Project Office pointed out—limited data and information on past accidents, limitations of using mathematical models to model complex physical phenomena, and limitations on the resources to perform the analysis. Recognizing the uncertainties, the study authors stated that they tried to use realistic, yet conservative, models and probabilities. They observed that if the objective had been the precise definition of spent fuel transportation risks, they would need many improvements to calculate the probability and radioactive release estimates and to quantify the uncertainties in the estimates. The improvements would include tests to benchmark computer models; more sophisticated models of rock surfaces; improved probability distributions of accident parameters; and the consideration of human factors. These modifications were not considered because the objective was to estimate the level of safety in the shipment of spent fuel using casks licensed to Nuclear Regulatory Commission standards, and because the radiological risk in spent fuel shipments would be a small component of the total risks associated with the shipments. Therefore, DOE concluded that the most appropriate data available for the analysis of severe accidents are in the Modal Study.

TRANSPORTATION EMERGENCIES

DOE would, as requested, assist state, tribal, and local governments in several ways to reduce the consequences of accidents related to the transportation of spent nuclear fuel and high-level radioactive waste. Under Section 180(c) of the Nuclear Waste Policy Act, the Department would provide technical assistance and funding to train state, local, and tribal public safety officials in relation to such transportation. The training would cover safe transport procedures and emergency response. DOE would also require its transportation contractors to comply with ANSI N14.27-1986(R1993), *Carrier and Shipper Responsibilities and Emergency Response Procedures for Highway Transportation Accidents Involving Truckload Quantities of Radioactive Materials*. This standard requires the preparation of an emergency response plan and describes appropriate provisions of information and assistance to emergency responders. The standard also requires the carrier to provide appropriate resources for dealing with the consequences of the accident including isolating and cleaning up spills, and to maintain working contact with the responsible governmental authority until the latter has declared the incident to be satisfactorily resolved and closed. In addition, DOE maintains an active emergency response program through eight Regional Coordinating Offices across the United States. These offices are capable of responding to transportation radiological emergencies and are on call 24 hours a day. They respond to requests for radiological assistance from state or tribal authorities. Other DOE programs have provided training for transportation emergencies for many areas (for example, Colorado and South Carolina to support preparation or transportation for the Foreign Research Reactor and Waste Isolation Pilot Plant programs).

The analysis considered six categories of increasingly severe and increasingly unlikely accident scenarios. Appendix J describes those categories and their derivations. Further, the analysis hypothesized one accident scenario to represent each category, along with a corresponding projection for the amount of radioactive material the accident scenario would release from a transportation cask. In addition, the analysis estimated impacts of postulated releases from accident scenarios in three population zones—urban, suburban, and rural—under two meteorological (weather) conditions—stable (slowly dispersing) conditions that would not be exceeded (more still) about 95 percent of the time and neutral (moving air) conditions that would not be exceeded about 50 percent of the time. The analysis determined radiological risks from possible accident scenarios by multiplying the estimated impacts of each accident type by the likelihood of the accident scenario occurring in a population zone under a set of weather conditions, and summing the results for the 36 possible combinations of accident scenarios, population zones, and weather conditions. The analysis determined the likelihood that an accident scenario would occur in a population zone by using state-specific accident data, the lengths of routes in the population zones in states through which the routes would pass, and the numbers of shipments that would use the routes. Four of the scenarios would not have a probability greater than 1 chance in 10 million, so they were not considered further.

In addition, the analysis estimated impacts from an unlikely but severe accident scenario called a *maximum reasonably foreseeable accident* scenario to provide perspective about the consequences for a population that might live nearby. For maximum reasonably foreseeable accident scenarios, the analysis selected the accident scenario from the 32 possible combinations of weather conditions, population zones, and transportation mode that would have a likelihood greater than 1 in 10 million per year and would have the greatest consequences. For analysis of maximum reasonably foreseeable accident scenarios, the number of possible accident scenario combinations discussed above was reduced from 32 to 23 because suburban and urban population zones were considered jointly (see Appendix J).

6.2.4.2.1 *Impacts from Accidents – National Mostly Legal-Weight Truck Scenario*

This section summarizes the potential impacts and risks associated with accidents under the legal-weight truck scenario. The impacts and risks include those associated with the legal-weight truck and rail shipments to Nevada plus the transfer of the spent nuclear fuel and high-level waste to heavy-haul trucks and its transportation in Nevada. The section summarizes radiological impacts for six accident scenario categories, under two types of weather conditions, and in three population densities (urban, suburban, and rural), in terms of a collective dose risk and consequence (latent cancer fatalities). It describes the potential impacts from the maximum reasonably foreseeable accident scenario separately. It also describes nonradiological impacts in terms of accident fatalities.

Radiological Impacts to Populations from Accidents. The collective radiological accident dose risk as described in Appendix J, Section J.1.4.2.1, would be 134 person-rem for the population within 80 kilometers (50 miles) along the transportation routes. This calculated risk would be the total for 24 years of shipment operations (2010 to 2033). It would result in an estimated 0.07 latent cancer fatality, or approximately 7 chances in 100 of 1 latent cancer fatality for the population within 80 kilometers of the routes that the shipments would use. The accident risk for legal-weight truck shipments dominates the total risk, contributing more than 99.9 percent of the population dose and risk in comparison to the risk associated with the 300 proposed shipments of naval spent nuclear fuel.

Consequences of Maximum Reasonably Foreseeable Accident Scenario. The analysis evaluated the impacts of a maximum reasonably foreseeable accident scenario in urbanized and rural population zones for both legal-weight truck and rail shipments under the mostly legal-weight truck scenario. The maximum reasonably foreseeable transportation accident scenario that would have the greatest consequences for the mostly legal-weight truck scenario would be a legal-weight truck accident under stable (slowly dispersing atmospheric conditions that would not be exceeded 95 percent of the time) meteorological conditions in an urban area. Severe accidents in other population zones under stable or neutral weather conditions (atmospheric conditions that would not be exceeded 50 percent of the time) would have smaller consequences. The accident scenario assumes a breach of the shipping cask and the release of a portion of its contents to the air. This accident in combination with stable atmospheric conditions would be very unlikely (1.9 in 10 million per year). Table 6-11 summarizes the impacts of the accident scenario. This accident scenario could cause 5 latent cancer fatalities; in comparison, a population of 5 million within 80 kilometers (50 miles) of the center of a large U.S. metropolitan area such as that assumed in the analysis would be likely to experience more than 10,000 cancer fatalities each year from other causes (ACS 1998, page 10). For this accident scenario, the analysis projected that most of the dose to a population would come from inhalation, cloudshine, and groundshine sources. The maximally exposed individual, assumed to be about 360 meters (1,180 feet) from the accident, would receive a dose of about 3.9 rem (Table 6-11).

Table 6-11. Estimated radiological impacts of maximum reasonably foreseeable accident scenario for national mostly legal-weight truck scenario.

Impact	Urbanized area (stable atmospheric conditions)
Accident scenario probability (annual)	0.00000019 (about 1.9 in 10 million)
Impacts to population	
Population dose (person-rem)	9,400
Latent cancer fatalities	4.7
Impacts to maximally exposed individual	
Maximally exposed individual dose (rem)	3.9
Probability of a latent cancer fatality	0.002

Impacts from Traffic Accidents. Approximately 4 (3.9) traffic fatalities could occur in the course of transporting spent nuclear fuel and high-level radioactive waste under the mostly legal-weight truck national transportation scenario during the 24 years of operations for the Proposed Action. Essentially all of these fatalities would be from truck operations; none would occur from the 300 railcar shipments of naval spent nuclear fuel. The fatalities would be principally from traffic accidents; half would involve trucks transporting loaded casks to the repository and half would involve returning shipments of empty casks. The fatalities would occur over 24 years and approximately 350 million kilometers (220 million miles) of highway travel, which would include escort vehicle travel. Based on information extrapolated from the U.S. Department of Transportation Bureau of Transportation Statistics (BTS 1998, page 20), during the same 24-year period, about 1 million deaths would be likely to occur in traffic accidents on U.S. highways.

6.2.4.2.2 *Impacts from Accidents – National Mostly Rail Transportation Scenario*

This section discusses the results of the analysis of radiological impacts to populations and maximally exposed individuals and of traffic fatalities that would arise from accidents during the transportation of spent nuclear fuel and high-level radioactive waste for the national mostly rail transportation scenario.

DOE used the models and calculations described in Appendix J to estimate the impacts from rail accidents, and included impacts postulated to occur during the transportation of commercial spent nuclear fuel by legal-weight trucks from 9 commercial sites that do not have the capability to handle or load large rail casks. The analysis also included the impacts from accidents for heavy-haul truck or barge shipments to nearby railheads from 19 commercial sites that have the capability to load a rail cask but are not served by a railroad. DOE used the models and calculations described in Appendix J to estimate the impacts. Appendix J presents additional information on heavy-haul truck and barge transportation from the 19 commercial sites.

Accident Radiological Impacts for Populations. The collective radiological accident dose would be between 42 and 47 person-rem for the population within 80 kilometers (50 miles) along routes for the national mostly rail transportation scenario. The range of 42 to 47 person-rem reflects differences in rail and heavy-haul truck implementing alternatives that DOE could use in Nevada. This is the total for 24 years of shipment operations. This population dose would be likely to cause 0.024 latent cancer fatality.

Radiological risks from accidents for the mostly rail scenario would include impacts associated with about 10,815 railcar shipments (one cask to a railcar) and 2,600 legal-weight truck shipments. The accident risk for the legal-weight truck shipments would be about 20 percent of the total population dose and risk for the mostly rail scenario. National rail transportation of spent nuclear fuel and high-level radioactive waste would account for the remaining 80 percent of the population dose and risk to the public.

Impacts of Maximum Reasonably Foreseeable Accident Scenario. The analysis evaluated the impacts of a maximum reasonably foreseeable accident scenario in urbanized areas or rural population zones and under stable and neutral atmospheric conditions. The maximum reasonably foreseeable accident scenario under the mostly rail scenario would involve a release of a fraction of the contents of a rail cask in an urban area under stable meteorological conditions (slowly dispersing atmospheric conditions that would not be exceeded 95 percent of the time), where atmospheric dispersion of contaminants would occur more slowly only 5 percent of the time. This accident scenario would have a likelihood of about 1.4 in 10 million per year, and would result in about 31 latent cancer fatalities in the population (Table 6-12). The maximally exposed individual, assumed to be about 360 meters (1,180 feet) from the accident, would receive a dose of about 26 rem (Table 6-12).

Impacts From Traffic Accidents. The analysis estimated that across the United States, approximately 4 (3.6) traffic and train accident fatalities could occur during transportation of spent nuclear fuel and high-level radioactive waste under the national mostly rail transportation scenario. Half of the fatalities would occur during the return of empty casks to commercial and DOE sites. Essentially all of the fatalities would involve train operations; about half would involve highway vehicles hit by trains. There would be about a 40-percent chance of 1 fatality from the 2,600 legal-weight truck shipments of commercial spent nuclear fuel. These fatalities could happen during the 24 years of transportation operations involving approximately 84 million kilometers (52 million miles) of railcar travel and 22 million kilometers (14 million miles) of highway travel. On the basis of data presented by the Bureau of Transportation Statistics (BTS 1998, page 20), during the same 24-year period, about 1 million people will die in traffic accidents on U.S. highways.

Table 6-12. Estimated impacts from maximum reasonably foreseeable accident scenario for national mostly rail transportation scenario.

Impact	Urbanized area (stable atmospheric conditions)
Accident probability	0.00000014 per year (about 1.4 in 10 million)
Impacts to populations	
Population dose (person-rem)	61,000
Latent cancer fatalities	31
Impacts to maximally exposed individuals	
Maximally exposed individual dose (rem)	26
Probability of a latent cancer fatality	0.013

6.2.4.2.3 *Impacts of Acts of Sabotage*

The analysis considered the impacts of successful sabotage attempts on a cask. A sabotage event cannot be characterized as a random event and was, therefore, not addressed in the same way as an accident, which would be random. However, the analysis evaluated the consequences of possible credible sabotage events and found them to be comparable with the impacts of maximum reasonably foreseeable accident events. A study conducted by Sandia National Laboratories (Luna, Neuhauser, and Vigil 1999, all) estimated the amounts and characteristics of releases of radioactive materials from rail and truck casks subjected to the effects of two different high-energy density devices.

Devices considered in the Sandia study (Luna, Neuhauser, Vigil 1999, all) included possible devices that might be used in acts of sabotage against shipping casks. (Note: The shield walls of shipping casks for spent nuclear fuel and high-level radioactive waste are similar to the massive layered construction used in armored vehicles such as tanks.) These kinds of devices were demonstrated by the study to be capable of penetrating a cask’s shield wall, leading to the dispersal of contaminants to the environment.

The truck cask design selected for analysis was the General Atomics GA-4 Legal-Weight Truck Cask. This cask, which uses uranium for shielding, is a state-of-the-art design recently certified by the Nuclear Regulatory Commission to ship four pressurized-water reactor nuclear fuel assemblies (NRC 1998, all). The rail cask design used was based on the conceptual design developed by DOE for the dual-purpose canister system. This design is representative of large rail casks that could be certified for shipping spent nuclear fuel and high-level radioactive waste.

DOE used the RISKIND code (Yuan et al. 1995, all) to evaluate the radiological health and safety impacts of the estimated releases of radioactive materials. The analysis used assumptions about the concentrations of radioisotopes in spent nuclear fuel, population densities, and atmospheric conditions (weather) used to evaluate the maximum reasonably foreseeable accidents.

Because it is not possible to forecast the location or the environmental conditions that might exist for acts of sabotage, the analysis determined impacts for urbanized areas (see Appendix J, Section J.1.4.2.1) under neutral (average) weather conditions.

For legal-weight truck shipments, the analysis estimated that a sabotage event occurring in an urbanized area could result in a population dose of 31,000 person-rem. This dose would cause an estimated 15 fatal cancers among the population of exposed individuals. A maximally exposed individual 150 meters (490 feet) from the event would receive a dose of 67 rem, which would increase the risk of a fatal cancer by about 7 percent.

The impacts estimated for an act of sabotage involving a rail shipment would be less than those estimated for a legal-weight truck shipment. The smaller impact for the rail shipment would be because less of the radionuclides would be released from a rail transportation cask than from a legal-weight truck transportation cask. For rail shipments, the analysis estimated that a sabotage event in an urbanized area could result in a population dose of 4,900 person-rem. This dose would be likely to cause 2.4 fatal cancers among the population of exposed individuals. A maximally exposed individual 140 meters (460 feet) from the event would receive a dose of 11 rem, which would increase the risk of a fatal cancer by about 0.6 percent.

The estimated impacts would be greater for an act of sabotage against a legal-weight truck shipment than against a rail shipment, even though the amount of spent nuclear fuel in a rail cask would be as much as six times that in a truck cask. The greater impacts would be a result of the estimate that an event involving the smaller truck cask would release greater quantities of radioactive materials (Luna, Neuhauser, Vigil 1999, all).

6.2.5 ENVIRONMENTAL JUSTICE

Shipments of spent nuclear fuel and high-level radioactive waste would use the Nation’s existing railroads and highways. DOE expects that the impacts to land use; air quality; hydrology; biological resources and soils; cultural resources; socioeconomics; noise; aesthetics; utilities, energy, and materials; and waste management would be small. In addition, as described in the preceding sections, incident-free transportation and the risks from transportation accidents (the maximum reasonably foreseeable accident scenario would have 1.9 chances in 10 million of occurring per year) would not present a large health or safety risk to the population as a whole, or to workers or individuals along national transportation routes. The low effect on the population as a whole also would be likely for any segment of the population, including minorities, low-income groups, and members of Native American tribes.

A previous DOE analysis of the potential for environmental justice concerns from the transportation of DOE spent nuclear fuel to the Idaho National Engineering and Environmental Laboratory (DOE 1995a, Volume 1, pages L-2 and L-36) also concluded that impacts to minority and low-income populations and to populations of Native Americans in Idaho would not be disproportionately high and adverse. As part of that analysis, DOE consulted with the Shoshone Bannock Tribe to analyze impacts to tribal members because the shipments in question would cross the Fort Hall Reservation. The analysis (DOE 1995a, Volume 3, Part A, page 3-32) concluded that risks to the health and safety of the potentially affected tribal population in Idaho from incident-free transportation and from accidents would be very low.

Based on the analysis of incident-free transportation and transportation accidents in this EIS and the results of a transportation analysis conducted by DOE in a previous programmatic EIS, and the fact that DOE has identified no subsection of the population that would be disproportionately affected by transportation related to the Proposed Action, DOE has concluded that no disproportionately high and adverse impacts would be likely on minority or low-income populations from the national transportation of spent nuclear fuel and high-level radioactive waste to Yucca Mountain. Chapter 4, Section 4.1.13.4, contains a discussion of a Native American perspective on the Proposed Action.

6.3 Nevada Transportation

The analysis of impacts from national transportation includes those from transportation activities in the State of Nevada. This section discusses Nevada transportation impacts separately. Spent nuclear fuel and high-level radioactive waste shipped to the repository by legal-weight truck would continue in the same vehicles to the Yucca Mountain site. Material that traveled by rail would either continue to the repository on a newly constructed branch rail line or transfer to heavy-haul trucks at an intermodal transfer station that DOE would build in Nevada for shipment on existing highways that could require upgrades. Selection of a specific rail alignment within a corridor, or the specific location of an intermodal transfer station or the need to upgrade the associated heavy-haul routes, would require additional field surveys, environmental and engineering analysis, state and local government consultation, and National Environmental Policy Act reviews.

This section describes potential impacts of three transportation scenarios and their respective implementing alternatives. The three transportation scenarios are (1) mostly legal-weight truck (corresponding to that portion of the national impacts that would occur in Nevada), (2) mostly rail, and (3) mostly heavy-haul truck.

The mostly legal-weight truck scenario does not include implementing alternatives. Under this scenario, highway shipments would be restricted to specific routes that satisfy the regulations of the U.S. Department of Transportation (49 CFR Part 397). Because the State of Nevada has not designated alternative preferred routes, only one combination of routes for legal-weight truck shipments would satisfy U.S. Department of Transportation routing regulations (I-15 to U.S. Highway 95 to Yucca Mountain). This scenario assumes that over 24 years approximately 300 shipments of naval spent nuclear fuel would arrive in Nevada by rail from the Idaho National Engineering and Environmental Laboratory and that heavy-haul trucks would transport them to the repository from a railhead.

The mostly rail scenario has five implementing alternatives, each of which includes a corridor alignment for a branch rail line in Nevada. Each implementing alternative includes the construction and operation of a rail line. These alternatives would include about 2,600 legal-weight truck shipments (about 110 per year) from 9 commercial sites that do not have the capability to load rail casks.

The mostly heavy-haul truck scenario has implementing alternatives for five different routes on existing Nevada highways. The highways would have to be upgraded to enable heavy-haul trucks routinely to transport rail casks containing spent nuclear fuel and high-level radioactive waste from an intermodal transfer station to the repository. Each heavy-haul truck alternative includes the construction and operation of an intermodal transfer station that DOE would use to transfer loaded rail casks from railcars to heavy-haul trucks and empty rail casks from the trucks to railcars. The analysis considered three potential intermodal transfer station locations. Each heavy-haul implementing alternative would also include 2,600 legal-weight truck shipments over 24 years from the 9 commercial sites that cannot load rail casks.

Chapter 2, Section 2.1.3.3, contains detailed descriptions of the transportation scenarios and implementing alternatives in Nevada. Sections 6.3.1 through 6.3.3 discuss potential impacts for the three Nevada transportation scenarios. Section 6.3.1 discusses potential environmental impacts that could occur in Nevada for the national mostly legal-weight truck scenario. Section 6.3.2 discusses potential environmental impacts for each of the five Nevada rail transportation implementing alternatives, including those from the construction and operation of a branch rail line, and the impacts of 2,600 legal-weight truck shipments over 24 years. Section 6.3.3 discusses potential impacts of each of the five Nevada heavy-haul truck transportation implementing alternatives, including upgrading Nevada highways, the associated activities of constructing and operating an intermodal transfer station, and the impacts of 2,600 legal-weight truck shipments over the 24 years of operations. Appendix J presents an analysis of impacts of transporting people and materials that would be necessary to implement the Proposed Action. Appendix J also discusses the methods used to analyze impacts for the 12 resource areas.

The EIS analysis evaluated potential impacts that would occur in Nevada from the construction and operation of a branch rail line or from upgrades to highways and construction and operation of an intermodal transfer station for the following environmental resource areas: land use and ownership; air quality; hydrology (surface water and groundwater); biological resources and soils; cultural resources; occupational and public health and safety; socioeconomics; noise; aesthetics; utilities, energy, and materials; waste management; and environmental justice. The following paragraphs describe the methods used to evaluate potential impacts to these resource areas for each of the three Nevada transportation scenarios—legal-weight truck, rail, and heavy-haul truck—and their applicable implementing alternatives.

Land Use and Ownership

DOE determined that information useful for an evaluation of land-use and ownership impacts should identify the current ownership of the land that its activities could disturb, and the present and anticipated future uses of the land. The region of influence for land-use and ownership impacts was defined as land areas that would be disturbed or whose ownership or use would change as a result of the construction and use of a branch rail line, intermodal transfer station, midroute stopover for heavy-haul trucks, and an alternative truck route near Beatty, Nevada.

Air Quality

The evaluation of impacts to air quality considered potential emissions of criteria pollutants [nitrogen dioxide, sulfur dioxide, carbon monoxide, and particulates with aerodynamic diameters of less than 10 and 2.5 micrometers (PM_{10} and $PM_{2.5}$)] and ozone, the percentage of applicable standards and limits, and the potential for releases of these pollutants in the Las Vegas Valley. The region of influence for the air quality analysis included (1) the Las Vegas Valley for implementing alternatives that could contribute to the levels of carbon monoxide and PM_{10}, which are already in nonattainment of standards (FHWA 1996, pages 3-53 and 3-54), during the construction and operation of a branch rail line or highway for heavy-haul trucks, and (2) the atmosphere in the vicinity of the sources of criteria pollutants that transportation-related construction and operation activities would emit.

Hydrology

The analysis evaluated surface-water and groundwater impacts separately. The attributes used to assess surface-water impacts were the potential for introduction and movement of contaminants, potential for changes to runoff and infiltration rates, alterations in natural drainage, and potential for flooding or dredging and filling actions to aggravate or worsen any of these conditions. The region of influence for surface-water impacts included areas near construction activities, areas that would be affected by permanent changes in flow, and areas downstream of construction.

The analysis addressed the potential for a change in infiltration rates that could affect groundwater, the potential for introduction of contaminants, availability for use for construction and, if available, potential that such use would affect other users. The region of influence for this analysis included groundwater reservoirs.

Biological Resources and Soils

The evaluation of impacts to biological resources considered the potential for conflicts with areas of critical environmental concern; special status species (plants and animals), including their habitats; and jurisdictional waters of the United States, including wetlands and riparian areas. The evaluation also considered the potential for impacts to migratory patterns and populations of big game animals. The region of influence for this analysis included the following:

- Habitat, including jurisdictional waters of the United States, including wetlands and riparian areas
- Migratory ranges of big game animals that could be affected by the presence of a branch rail line

The analysis assessed soil impacts to determine the potential to increase erosion rates by water or wind. The region of influence for the analysis of soil impacts included areas where construction would take place and downwind or downgradient areas that would be affected by eroded soil.

Cultural Resources

The evaluation of impacts on cultural resources considered the potential for disrupting, or modifying the character of, archaeological or historic sites, artifacts, and other cultural resources.

The region of influence for the analysis included the lands in the 400-meter (1,300-foot)-wide rail corridors, lands near highways that would be upgraded for heavy-haul truck use, and sites where an intermodal transfer station could be constructed and operated.

Occupational and Public Health and Safety

The analysis of impacts to occupational and public health and safety from transportation-related activities in Nevada used the same methods, assumptions, attributes, and regions of influence used for the analysis of impacts of national transportation of spent nuclear fuel and high-level radioactive waste. However, it used the rail and highway accident rates reported for the State of Nevada (Saricks and Tompkins 1999, Table 4).

In addition, the analysis included potential impacts from industrial hazards to Nevada workers from constructing and operating a branch rail line, upgrading highways for use by heavy-haul trucks, and constructing and operating an intermodal transfer station. The region of influence for the analysis included branch rail line and highway construction work sites and highways that workers and other construction-related vehicle traffic would use.

The analysis considered potential radiological impacts from intermodal transfer station operations.

Socioeconomics

The analysis of socioeconomic impacts considered changes in employment, personal income, population, Gross Regional Product, and state and local government expenditures. The region of influence for the analysis included Clark, Lincoln, and Nye Counties. The other Nevada counties were included collectively.

Noise

Nevada does not have a noise code, so the analysis used daytime and nighttime noise standards adopted by most states for residential and commercial areas to evaluate the impacts of noise from construction and operation activities. The region of influence considered in the analysis included inhabited commercial and residential areas where noise from construction and noise from trains or trucks would have the potential to exceed 45 dBA.

Aesthetics

The analysis of potential impacts on aesthetic resources considered Bureau of Land Management ratings for land areas (BLM 1986, all). The regions of influence used in the analysis included the landscapes along the potential rail corridors and highway routes and near possible locations of intermodal transfer stations with aesthetic quality that construction and operations could affect.

The analysis of impacts was based on visual sensitivity ratings of viewsheds in Nevada and the Bureau of Land Management Visual Resource Management System objectives. It established ratings for scenery based on the number and types of users, public interest in the area, and adjacent land uses. The ratings are based on the scenic quality classes in the Bureau of Land Management Visual Resource Management System (BLM 1986, all).

Utilities, Energy, and Materials

The attributes used to assess impacts to utilities, energy, and materials included the requirements for electric power, fossil fuel for construction, and key consumable construction materials. The analysis compared needs to available capacity. The region of influence included the local, regional, and national supply infrastructure that would have to satisfy the needs.

Waste Management

Evaluations of impacts of waste management considered the quantities of nonhazardous industrial, sanitary, hazardous, mixed, and radioactive wastes that would be generated. The region of influence included construction areas and camps and facilities that would support transportation operations such as locomotive and railcar maintenance facilities.

Environmental Justice

The analysis of environmental justice for the Nevada transportation scenarios is identical to that described for national transportation in Section 6.2.5. Section 6.3.4 describes the results of that analysis for the Nevada transportation scenarios.

6.3.1 IMPACTS OF THE NEVADA MOSTLY LEGAL-WEIGHT TRUCK TRANSPORTATION SCENARIO

Legal-weight truck shipments in Nevada of spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site would use existing highways and would be a very small fraction of the total traffic [less than 1.2 million kilometers (750 thousand miles) per year for legal-weight truck shipments in Nevada in comparison to an estimated 1.2 billion kilometers (750 million miles) per year of commercial vehicle traffic on I-15 and U.S. Highway 95 in southern Nevada]. As a consequence, impacts to land use; hydrology; air quality; biological resources; cultural resources; socioeconomics; noise; aesthetics; utilities, energy, and materials; and waste management would not be large. Nonetheless, because of concern about additional threats to populations of desert tortoises, this section addresses the potential for impacts to this threatened species. This section focuses on impacts to occupational and public health and safety in Nevada. Section 6.3.4 contains a consolidated discussion of the potential for transportation activities to cause environmental justice impacts.

6.3.1.1 Impacts to Biological Resources

Legal-weight truck shipments in Nevada to a Yucca Mountain Repository would involve travel over highways that cross desert tortoise habitat, but none of the routes would cross habitat that the Fish and Wildlife Service has designated as critical for the recovery of this threatened species (50 CFR 17.95). Over the course of 24 years of operations under the Proposed Action and 49,500 shipments, vehicles probably would kill individual desert tortoises. However, under this scenario legal-weight trucks would contribute only about 1 percent to the daily traffic of vehicles to and from the repository site and only about 0.15 percent of all commercial truck traffic along I-15 and U.S. 95 in southern Nevada. Thus, any desert tortoises killed by trucks transporting spent nuclear fuel or high-level radioactive waste probably would be only a small fraction of all desert tortoises killed on highways. Loss of individual desert tortoises due to legal-weight truck shipments would not be a large threat to the conservation of this species.

6.3.1.2 Impacts to Occupational and Public Health and Safety

6.3.1.2.1 *Impacts from Incident-Free Transportation*

This section addresses radiological impacts to populations and maximally exposed individuals in Nevada from the incident-free transportation of spent nuclear fuel and high-level radioactive waste for the mostly legal-weight truck scenario. It includes potential impacts from exposure to vehicle emissions in Nevada.

Incident-Free Radiological Impacts to Populations. Table 6-13 lists the incident-free population dose and radiological impacts for the Nevada mostly legal-weight truck scenario. The impacts include those from the shipment of naval spent nuclear fuel by rail in Nevada, intermodal transfer activities, and subsequent heavy-haul truck transportation to the proposed repository. The analysis included the radiological impacts of intermodal transfer operations for naval spent nuclear fuel shipments. Occupational impacts would include estimated radiological exposures to security escorts for legal-weight truck, rail, and heavy-haul truck shipments. The estimated radiological impacts would be 0.6 latent cancer fatality for workers and 1.4 latent cancer fatalities for members of the public over the 24 years of operation.

Table 6-13. Population doses and radiological health impacts from incident-free transportation for Nevada mostly legal-weight truck scenario.[a]

Category	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel[b]	Totals[c]
Involved workers			
Collective dose (person-rem)	1,600	32	1,600
Estimated LCFs[d]	0.62	0.01	0.63
Public			
Collective dose (person-rem)	2,800	26	2,800
Estimated LCFs	1.4	0.01	1.4

a. Impacts are totals for shipments over 24 years.
b. Includes impacts at intermodal transfer stations.
c. Totals might differ from sums of values due to rounding.
d. LCF = latent cancer fatality.

Incident-Free Radiological Impacts to Maximally Exposed Individuals. Table 6-14 lists estimates of dose and radiological impacts for maximally exposed individuals for the Nevada legal-weight truck scenario from 24 years of shipment activity. The analysis used the assumptions presented in Section 6.2.1 and Appendix J.

The analysis assumed the annual dose to state inspectors who conducted frequent inspections of shipments of spent nuclear fuel and high-level radioactive waste would be limited to 2 rem.

The analysis estimated that a maximally exposed individual at a service station would receive 2.4 person-rem over 24 years under the legal-weight truck scenario. This estimate conservatively assumed the person would be exposed to 430 truck shipments each year for 24 years. For perspective, under the mostly legal-weight truck scenario, which assumes an average of 2,100 legal-weight truck shipments per year, about 430 truck shipments would pass through the Mercury, Nevada, gate to the Nevada Test Site in

Table 6-14. Estimated doses and radiological health impacts to maximally exposed individuals during incident-free transportation for Nevada mostly legal-weight truck scenario.[a,b]

Individual	Dose (rem)	Probability of latent fatal cancer
Involved workers		
Crew member	48[c]	0.02
Inspector	48[c]	0.02
Railyard crew member	0.13	0.00006
Public		
Resident along route	0.005	0.000003
Person in traffic jam	0.04[d]	0.00002
Person at service station	2.4[e]	0.0001
Resident near rail stop	0.009	0.000005

a. The assumed external dose rate is 10 millirem per hour at 2 meters (6.6 feet) from the vehicle for all shipments.
b. Impacts are totals over 24 years.
c. Assumes 2-rem-per-year dose limit.
d. Single occurrence.
e. Assumes the person works at the service station for all 24 years of repository operations.

1,800 hours. A worker at a truck stop along the route to Mercury would work about 1,800 hours per year. Thus, if every shipment stopped at that truck stop, the maximum number of shipments the worker would be exposed to in a year would be 430.

Impacts from Vehicle Emissions. There is potential for human health impacts to people in Nevada who would be exposed to pollutants emitted from vehicles transporting spent nuclear fuel and high-level radioactive waste, including escort vehicles. Table 6-15 lists the estimated number of vehicle emission-related fatalities from legal-weight trucks, heavy-haul trucks, escort vehicles, and rail locomotives under the mostly legal-weight truck scenario. Trucks would be the major contributors. No vehicle emission-related fatality (0.0055) would be likely.

Table 6-15. Population health impacts from vehicle emissions during incident-free transportation for Nevada mostly legal-weight truck scenario.[a]

Category	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel[b]	Total
Vehicle emission-related fatalities	0.005	0.0005	0.0055

a. Impacts are totals for shipments over 24 years.
b. Includes heavy-haul truck shipments in Nevada.

6.3.1.2.2 *Impacts from Accidents – Nevada Legal-Weight Truck Scenario*

This section discusses radiological impacts to populations and maximally exposed individuals in Nevada and the potential number of traffic accident fatalities from accidents during the transportation of spent nuclear fuel and high-level radioactive waste for the mostly legal-weight truck scenario. The analysis of accident impacts under this scenario includes impacts from accidents that would occur during the transportation of naval spent nuclear fuel by rail in Nevada to an intermodal transfer station and by heavy-haul truck to the repository. Section 6.3.3 discusses impacts to workers from industrial hazards during the operation of an intermodal transfer station for shipments of naval spent nuclear fuel.

Radiological Impacts from Accidents. The calculated collective radiological accident dose risk would be 0.5 person-rem for the population in Nevada within 80 kilometers (50 miles) along the routes under the mostly legal-weight truck transportation scenario. This is the total dose risk for 24 years of shipment operations (2010 to 2033), and would result in 0.0002 latent cancer fatality in the exposed population. The radiological risk from accidents would include impacts from approximately 49,500 legal-weight truck shipments and 300 naval spent nuclear fuel rail shipments. The accident risk for legal-weight truck shipments would account for essentially all of the population dose and radiological impacts. Because DOE would not build a branch rail line to the repository under this scenario, the accident risk for rail shipments of naval spent nuclear fuel includes risks from accidents that could occur during intermodal transfers from railcars to heavy-haul trucks and during heavy-haul transportation in Nevada. Section 6.3.3 provides additional information on heavy-haul truck implementing alternatives for transporting rail casks in Nevada.

Consequences of Maximum Reasonably Foreseeable Accident Scenarios. The analysis evaluated the impacts of a maximum reasonably foreseeable accident scenario presented in Section 6.2.4.2.1.

Impacts from Traffic Accidents. In Nevada, less than 1 (0.5) fatality from traffic accidents would be likely during the course of transporting spent nuclear fuel and high-level radioactive waste under the mostly legal-weight truck transportation scenario. This estimate includes traffic fatalities involving escort vehicles.

MAXIMUM REASONABLY FORESEEABLE ACCIDENT SCENARIOS IN NEVADA

Maximum reasonably foreseeable accident scenarios analyzed for transportation in Nevada were the same as maximum reasonably foreseeable accident scenarios analyzed in Section 6.2.4.2 for national transportation. That is, the EIS analysis assumed that an accident determined to be reasonably foreseeable for national transportation would occur in Nevada. Because the distances traveled in Nevada would be much less than the total national travel to deliver spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site, the likelihoods of these accident scenarios occurring in the State would be less than those for the rest of the Nation. The likelihoods of two of these accident scenarios occurring in national travel are reported in Section 6.2.4.2.

6.3.2 IMPACTS OF NEVADA RAIL TRANSPORTATION IMPLEMENTING ALTERNATIVES

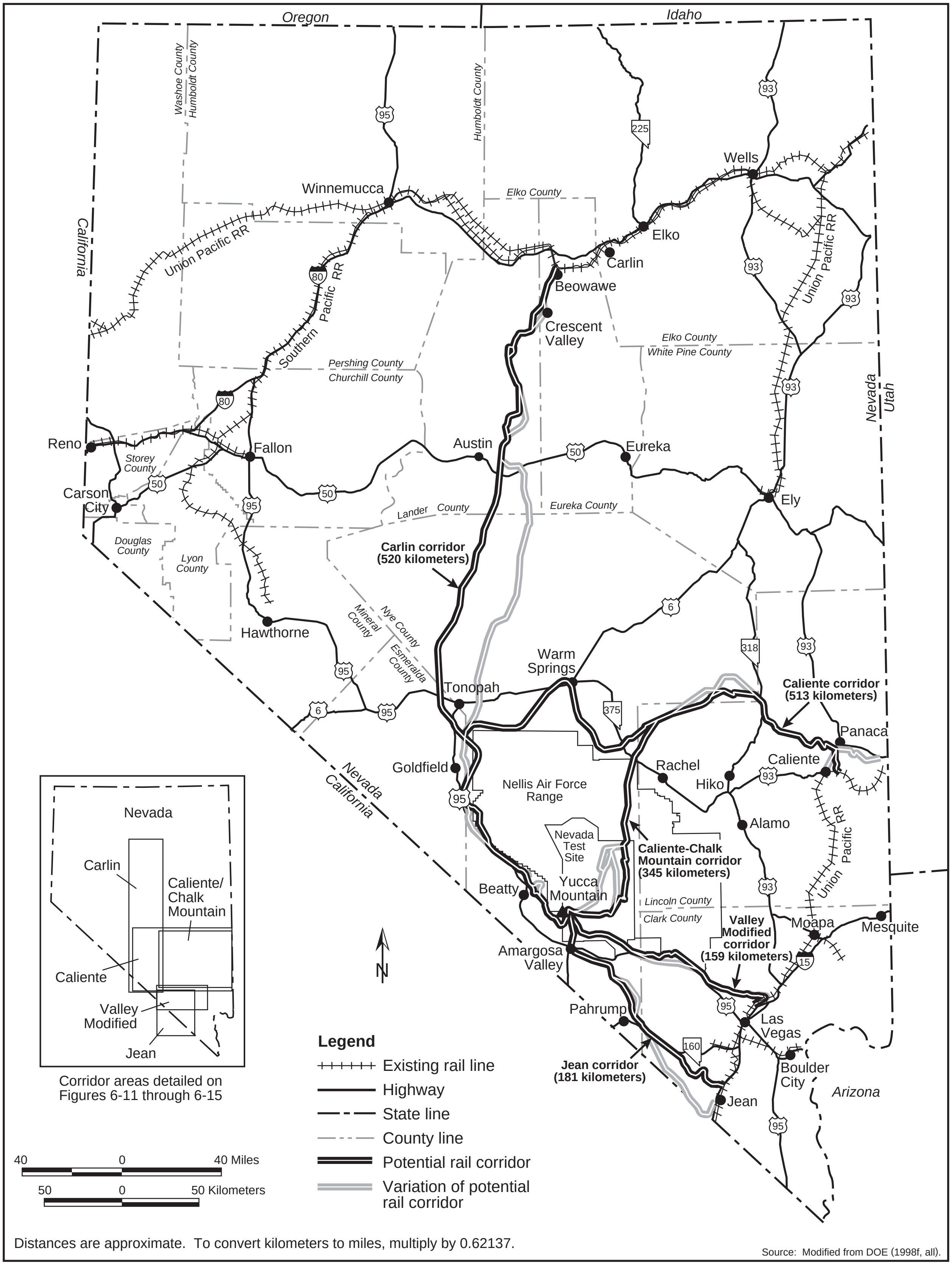
This section describes the analysis of human health and safety and environmental impacts for five rail transportation implementing alternatives, each of which would use a newly constructed branch rail line in Nevada to transport spent nuclear fuel and high-level radioactive waste to the repository. The branch line would transport railcars carrying large shipping casks from a mainline railroad to the repository (loaded) and back (empty). DOE has identified five 0.4-kilometer (0.25-mile)-wide corridors of land—Caliente, Carlin, Caliente-Chalk Mountain, Jean, and Valley Modified—for the possible construction and operation of the branch line (Figure 6-10). Chapter 2, Section 2.1.3.3.2 describes the corridors. Chapter 3 discusses their affected environments.

Appendix J contains additional information on the characteristics of possible alignment variations of each corridor. Figure 6-10 shows these variations. Section 6.3.2.1 discusses impacts that would be common among the five possible corridors, and Section 6.3.2.2 discusses impacts that would be unique for each corridor.

DOE identified the five rail corridors through a process of screening the potential rail alignments it had studied in past years.

- The *Feasibility Study for Transportation Facilities to Nevada Test Site* study (Holmes & Narver 1962, all) determined the technical and economic feasibility of constructing and operating a railroad from Las Vegas to Mercury.

- The *Preliminary Rail Access Study* (Tappen and Andrews 1990, all) identified 13 and evaluated 10 rail corridor alignment options. This study recommended the Carlin, Caliente, and Jean corridors for detailed evaluation.



Distances are approximate. To convert kilometers to miles, multiply by 0.62137.

Source: Modified from DOE (1998f, all).

Figure 6-10. Potential Nevada rail routes to Yucca Mountain.

- *The Nevada Railroad System: Physical, Operational, and Accident Characteristics* (DOE 1991b, all) described the operational and physical characteristics of the current Nevada railroad system.

- The *High Speed Surface Transportation Between Las Vegas and the Nevada Test Site (NTS)* report (Raytheon 1994, all) explored the rationale for a potential high-speed rail corridor between Las Vegas and the Nevada Test Site to accommodate personnel.

- The *Nevada Potential Repository Preliminary Transportation Strategy*, *Study 1* (TRW 1995a, all), reevaluated 13 previously identified rail routes and evaluated a new route called the Valley Modified route. This study recommended four rail routes for detailed evaluation—the Caliente, Carlin, Jean, and Valley Modified routes.

- The *Nevada Potential Repository Preliminary Transportation Strategy*, *Study 2* (TRW 1996, all), further refined the analyses of potential rail corridor alignments in Study 1.

Public comments submitted to DOE during hearings on the scope of this EIS resulted in the addition of a fifth potential rail corridor—Caliente-Chalk Mountain.

The analysis of impacts for the five Nevada rail transportation implementing alternatives assumed the mostly rail transportation scenario. Therefore, the analysis included the impacts of legal-weight truck transportation from nine commercial sites that do not have the capability to handle or load a large rail cask. About 2,600 legal-weight truck shipments over 24 years would enter Nevada and travel to the repository. These shipments would use the same transport routes and carry about the same amounts of spent nuclear fuel per shipment as those described for the mostly legal-weight truck scenario (Section 6.3.1).

The analysis evaluated impacts to land use and ownership; air quality; hydrology; biological resources and soils; cultural resources; occupational and public health and safety; socioeconomics; noise; aesthetics; utilities, energy, and materials; and waste management. Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.

6.3.2.1 Impacts Common to Nevada Branch Rail Line Implementing Alternatives

This section discusses impacts for the analysis areas listed above that would be common to all five branch rail line implementing alternatives. DOE evaluated these impacts as described in Section 6.3. The construction of the branch rail line would last about 2.5 years under each implementing alternative. Shipping operations in the rail corridor would begin at a mainline switching station where railcars carrying casks of spent nuclear fuel and high-level radioactive waste would switch from the mainline to the branch line for transport to the repository, and railcars carrying empty casks from the repository would switch to the mainline for transport back to the commercial and DOE sites. These shipments would continue for 24 years. Section 6.3.2.2 discusses impacts specific to each rail implementing alternative.

Land Use and Ownership

In calculating the amount of land affected by a rail corridor, the analysis assumed a corridor width of 400 meters (1,300 feet). The purpose of the 400-meter width was to provide sufficient space for final alignment to route the rail line around sensitive land features. Actual construction and operation in the corridor would mostly require less than about 60 meters (200 feet) of the 400-meter width. Thus, about 15 percent of the land in the corridor would be disturbed by construction at most. The analysis also assumed that about 2 square kilometers (500 acres) of land outside the corridor would be disturbed during the construction of a branch rail line for construction roads and camps and other construction-related activities.

In relation to rail line operations, train and track inspection and maintenance activities would be confined to the areas that construction activities had disturbed, so no additional disturbance would occur.

The rail corridors have possible alignment variations with slightly different land ownerships and projected disturbances. These possible variations in the corridor alignments would make little difference in land-use impacts, so this section does not discuss them in detail.

Each corridor has areas the public uses and areas available for sale and transfer. As a consequence, the rail line could result in limited access to areas currently in use by the public. Similarly, because of the corridor interface with grazing lands and wildlife areas, the rail line could create a barrier to livestock movement. Impacts to wildlife are discussed later in this section.

The analysis indicates no conflicts with commercial use and no identified conflicts with scientific studies for any of the proposed corridors. At present, the public land in each corridor, with the exception of portions of the Caliente-Chalk Mountain corridor, is open to mining and offroad vehicle use.

The potential land-use conflicts of greatest concern are those that would present long-term conflicts with other uses. One conflict in this category concerns the Caliente-Chalk Mountain corridor, which, according to the Air Force, would conflict with the national security mission on the Nellis Air Force Range (Henderson 1997, all). These lands were withdrawn for use as a high-hazard military weapons training and testing area; Air Force restrictions limit transportation options across these lands.

Air Quality

Construction. The construction of a branch rail line would comply with all applicable air quality regulations and associated requirements in the construction permits. Construction activities would increase pollutant concentrations in the areas near the rail corridor. Fuel use by construction equipment would emit carbon monoxide, nitrogen dioxide, sulfur dioxide, and particulate matter with diameters of 10 micrometers or less (PM_{10}) and 2.5 micrometers or less ($PM_{2.5}$). Construction activities would also emit PM_{10} in the form of fugitive dust from excavation and truck traffic. The emissions would be temporary and would cover a very large area as construction moved along the length of the corridor.

Operations. Fuel use by diesel train engines would emit carbon monoxide, nitrogen dioxide, PM_{10}, and $PM_{2.5}$. Based on the Federal standards for locomotives (EPA 1997a, all), there would be no significant emissions of sulfur dioxide.

No air quality impacts would be unique to the branch rail line implementing alternatives with the exception of the Valley Modified corridor, as described in Section 6.3.2.2.5.

Hydrology

This section describes impacts to surface water and groundwater.

Surface Water

Construction. Construction-related impacts could involve the possible release and spread of contaminants by precipitation or intermittent runoff events or, for corridors near surface water, possible release to the surface water, the alteration of natural drainage patterns or runoff rates that could affect downgradient resources, and the need for dredging or filling of perennial or ephemeral streams.

Construction-related materials that could cause contamination would consist of petroleum products (fuels and lubricants) and coolants (antifreeze) necessary to support equipment operations. In addition, remote work camps would include some bulk storage of these materials, and supply trucks would routinely bring new materials and remove used materials (lubricants and coolants) from the construction sites. These activities would present some potential for spills and releases. Regulatory requirements on reporting and remediating spills and properly disposing of or recycling used materials would result in a low probability of spills. If a spill occurred, the potential for contamination to enter flowing surface water would present the greatest risk of a large migration of a contaminant before remediation took place. If there was no routinely flowing surface water (most areas along the corridors), released material would not travel far or affect critical resources before remediation occurred. During construction activities, water spraying would control dust and achieve soil compaction criteria, but water would not be used in quantities large enough to support surface-water flow and possible contaminant transport for any distance.

During construction, a contractor would move large amounts of soil and rock to develop the track platform (subgrade) and the access road. These construction activities could block storm drainage channels temporarily. However, the contractor would use standard engineering design and best management practices to place culverts, as appropriate, to move runoff water from one side of the track or road to the other. These culverts or other means of runoff control would be put in place early in the construction effort, because standing water in the work area would generally hinder progress.

Depending on site-specific conditions, construction could include regrading such that a number of minor drainage channels would collect in a single culvert, resulting in water flowing from a single location on the downstream side rather than across a broader area. This would cause some localized changes in drainage patterns but probably would occur only in areas where natural drainage channels are small.

Operations. The use of a completed branch rail line would have little impact on surface waters beyond the permanent drainage alterations from construction. The road and rail beds probably would have runoff rates different from those of the natural terrain but, given the relatively small size of the potentially affected areas in a single drainage system, there would be little impact on overall runoff quantities.

There would be no surface-water impacts unique to any of the branch rail line implementing alternatives with the exception of their relative proximity to surface-water resources.

Appendix L contains a floodplain/wetlands assessment that examines the effects of branch rail line construction, operation, and maintenance on the following floodplains in the vicinity of Yucca Mountain: Fortymile Wash, Busted Butte Wash, Drill Hole Wash, and Midway Valley Wash. There are no delineated wetlands at Yucca Mountain.

If DOE selected rail to transport spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site, it would also select one of five routes (Figure 6-10). DOE would then prepare a more detailed floodplain/wetlands assessment of the selected alternative. The assessment in Appendix L presents a comparison of what is known about the floodplains, springs, and riparian areas and at the three alternative intermodal transfer station sites and along their associated heavy-haul routes. In general, wetlands have not been delineated along the alternative intermodal transfer station sites.

Groundwater

Construction. Potential groundwater impacts from rail line construction could include changes to infiltration rates, new sources of contamination that could migrate to groundwater, and depletion of groundwater resources resulting from increased demand. However, the potential for impacts would be spread over a large geographic area, so the probability would be low for a resource in a single area to receive adverse impacts. The above discussion of impacts to surface water identifies potential contaminants that branch rail line construction could release. These contaminants would be the same for groundwater.

Construction activities would disturb and loosen the ground, which could produce greater infiltration rates. However, this situation would be short-lived as the access road and railbed materials became compacted and less porous. In either case, localized changes in infiltration probably would cause no noticeable change in the amount of recharge in the area.

The analysis assumed that a number of wells would be required to support construction and that they would be installed along the rail corridor. It also assumed a 1-year period for construction activities in the vicinity of each well. Water withdrawal from these wells would not contribute to the depletion of a particular groundwater basin for two reasons: (1) the demand would be relatively short-term because it would stop when construction was complete, and (2) annual demands would be limited to a fraction of the perennial yields of the aquifers that would supply the water (see Table 3-35). In addition, the Nevada State Engineer would approve water production from any well installed to support rail corridor construction. To grant approval, the State Engineer would have to determine that the short-term demand would not cause adverse impacts for other uses and users of the groundwater resource.

For the case in which water was obtained from a source other than a newly installed well and brought to the construction site by truck, water would be obtained from appropriated sources. That is, the water would be from allocations that the Nevada State Engineer had previously determined did not adversely affect groundwater resources.

Impacts on groundwater would differ among the implementing alternatives. These impacts, which Section 6.3.2.2 describes for the implementing alternatives, would include the projected water needs to support the construction of each candidate rail corridor and the estimated number of wells DOE would install along each corridor to meet that need.

Operations. The use of a completed railway corridor would have little impact on groundwater resources. There would be no continued need for water along the corridor, and possible changes to recharge, if any, would be the same as those at the completion of construction.

Biological Resources and Soils

Construction. Construction activities would generally disturb no more than about 15 percent of the land inside a 400-meter (1,300-foot)-wide corridor. Vegetation would be cleared in an area generally less than 60 meters (200 feet) wide in the corridor to enable the construction of the railroad and a parallel access road. Vegetation would also be cleared from borrow areas and covered in disposal areas for excavated materials. Land for construction camps and in small areas where wells would be drilled would also be cleared of vegetation.

Impacts to biological resources from the construction of a branch rail line would occur due to a loss of habitat for some terrestrial species. Individuals of some species would be displaced or killed by construction activities. After the selection of a rail corridor, DOE would perform preconstruction surveys of potentially disturbed areas to identify and locate special status species that would need to be protected during construction.

Construction could affect the following biological resources:

- *Game and Game Habitat.* Each candidate rail corridor would cross or be near [within 5 kilometers (3 miles)] several areas the Bureau of Land Management and the Nevada Division of Wildlife have designated as game habitat (TRW 1999k, pages 3-23 to 3-32). Construction activities in these areas would result in a loss of some habitat. Each rail corridor has the potential to disrupt movement patterns of game animals. The design of fences, if built along the rail corridor, would accommodate the movement of these animals. Large animals including game species (elk, bighorn sheep, mule deer, etc.), wild horses, and burros probably would avoid contact with humans at construction locations and would temporarily move to other areas during construction. Numerous special status species occur along each of the proposed branch rail lines. Construction of a branch rail line could lead to habitat loss and fragmentation for the special status species, as well as to mortality of individuals.

- *Special Status Species.* The construction of a branch rail line in any of the five rail corridors would involve the loss of varying amounts [1.4 to 6.3 square kilometers (350 to 1,600 acres)] of desert tortoise habitat. None of the corridors cross areas designated by the Fish and Wildlife Service as critical desert tortoise habitat (50 CFR 17.95). The abundance of tortoises varies from very low to medium along the proposed corridors (Karl 1980, pages 75 to 87; Karl 1981, pages 76 to 92; Rautenstrauch and O’Farrell 1998, pages 407 to 411), but some desert tortoise deaths could occur during land-clearing operations. Loss of habitat and mortality of individuals of other special status species along specific routes could also occur.

- *Wetlands and Riparian Areas.* Each corridor could affect a number of wetlands, springs, and riparian areas (TRW 1999k, pages 3-23 to 3-32). These areas are generally important for biological resources and typically have high biodiversity. Potential impacts to these areas include destruction, alteration, or fragmentation of habitat; increased siltation in streams during construction; changes in stream flow; and loss of biodiversity.

All of the candidate rail corridors cross perennial or ephemeral streams that may be classified as jurisdictional waters of the United States. Section 404 of the Clean Water Act regulates discharges of dredged or fill material into such waters. After the selection of a rail corridor, DOE would identify any jurisdictional waters of the United States that the construction of a rail line would affect; develop a plan to avoid when possible, and otherwise minimize, impacts to those waters; and, as applicable, obtain an individual or regional permit from the U.S. Army Corps of Engineers for the discharge of dredged or fill material. By implementing the plan and complying with other permit requirements, DOE would ensure that impacts to waters of the United States would be small.

The general design criteria for a branch rail line would include a requirement that a 100-year flood would not inundate the rails at channels fed by sizable drainage areas. During the operation and monitoring phase of the repository, conditions more intense than those that would generate a 100-year storm could occur in the area. Such conditions, depending on their intensity, could wash out access roads and possibly even the rail line. Although DOE would have to repair these structures, there is no reason to believe that such an occurrence would unduly affect area resources. If necessary, a permit would be obtained from the U.S. Army Corps of Engineers for discharge of dredge and fill material to repair the rail line. There would be no contamination that floodwaters could spread and, with the exception of areas of steep terrain, debris would not travel far. The operation of a branch rail line would stop during conditions that could lead to the flooding of track areas and would not resume until DOE had made necessary repairs.

Soil impacts from rail line construction would be primarily the direct impacts of land disturbance in the selected corridor. The amount of land disturbance, both inside and outside the corridor, would vary by corridor. The disturbed areas probably would be subject to an increase in erosion potential for at least some of the construction phase. DOE would use dust suppression measures to reduce this potential. As construction proceeded, the railbed would be covered with ballast rock, which would virtually halt erosion from that area, and the access roads would be compacted, which would reduce erosion. As construction ended, disturbed areas (other than the railbed and access roads) would slowly recover. Other permanent erosion control systems would be installed as appropriate. Introduction of contaminants into the soil is also a potential concern. Proper control of hazardous materials during construction and prompt response to spills or releases would, however, reduce this concern. Impacts to soils would be limited to these areas disturbed and would be transitory and small.

Operations. Impacts to biological resources from shipments of spent nuclear fuel and high-level radioactive waste to the proposed repository along any of the five rail corridors would include periodic disturbances of wildlife from trains going by and from personnel servicing the corridor. Trains probably would kill individuals of some species.

Rail operations would not lead to additional habitat losses, although maintenance activities would prevent habitat recovery in the narrow band occupied by the rail line and access road. Operations could affect individuals of some species, but losses would be unlikely to affect the regional population of any species. Passing trains could disrupt wildlife but such effects would be transitory.

The use of a completed railway would not be likely to have an impact on soils. The rail track and roadbed would be maintained throughout the operations phase, including repairs of erosion damage to the access road and railbed.

Cultural Resources

Construction. Table 3-36 lists the cultural resource information currently available in each corridor that branch rail line construction could affect. Direct impacts to these cultural resources (such as disturbing the sites or crushing artifacts) could occur from a variety of construction-related activities, including building the rail line and the right-of-way. In addition, rail line construction activities would include borrow areas, areas for the disposal of excavated material, construction camps, and access roads that would be outside the defined right-of-way. Because archaeological sites sometimes include buried components, ground-disturbing actions could uncover previously unidentified cultural materials. If cultural resources were encountered, a qualified archaeologist would participate in directing activities to ensure that the resources would be properly protected or the impact mitigated. DOE would use procedures to avoid or reduce direct impacts to cultural resources in construction areas where surface-disturbing activities would occur (see Chapter 9).

Indirect impacts, such as non-project-related disturbances of archaeological sites by purposeful or accidental actions of project employees, could occur from construction activities as a result of increased access and increased numbers of workers near cultural resource sites. These factors would increase the probability for either intentional or inadvertent indirect impacts to cultural resources.

The EIS analysis identified no potential impacts to Native American resources along the corridors. However, systematic studies have not been completed to identify sites, resources, or areas that might hold traditional value for Native American peoples or communities. The corridors would not affect identified cultural resources on reservations because they would not pass through reservations. However, AIWS (1999, page 4-6) states that all wetlands are important cultural resources. If sites or resources important to Native Americans were discovered in the future, either in or near an identified right-of-way, adverse effects could occur through direct means, such as construction activities, or indirectly through visual or auditory impacts.

Operations. No additional direct or indirect impacts would be likely at archaeological and historic sites from the operation of the rail line.

At present, no specific impacts to Native American resources, traditional cultural properties, or other cultural values from rail operations have been identified. In general, the Consolidated Group of Tribes and Organizations has noted that the rail corridors pass through the traditional holy lands of the Southern Paiute, and that many of the corridors correspond, or are adjacent, to ancient pathways and trail systems. Native Americans believe that operation of a branch rail line that transports spent nuclear fuel and high-level radioactive waste would constitute adverse impacts to traditional values and have identified it as a very important concern. They have requested that the tribes and groups that make up the Consolidated Group of Tribes and Organizations be consulted regularly on transportation issues and scheduling to ensure impacts would be small.

Other than those described above, there would be no cultural impacts unique to any of the branch rail line implementing alternatives.

Occupational and Public Health and Safety

Incident-Free Transportation. Incident-free impacts of rail transportation in Nevada would be unique for each of the five Nevada rail transportation implementing alternatives; these are discussed for each implementing alternative in Section 6.3.2.2. That section also lists the incident-free impacts that would occur in Nevada from 2,600 legal-weight truck shipments, although they would be common among the rail implementing alternatives.

Accidents. Accident risks and maximum reasonably foreseeable accidents for rail shipments of spent nuclear fuel and high-level radioactive waste would be common to the Nevada rail transportation implementing alternatives. This section, therefore, discusses these risks.

Table 6-16 lists accident risks for transporting spent nuclear fuel and high-level radioactive waste in Nevada for the five Nevada rail transportation implementing alternatives. The data show that the risks, which are listed for 24 years of operations, would be low for each alternative. These risks include risks associated with transporting 2,600 legal-weight truck shipments made from the commercial sites that could not load rail casks. Small variations in the risk values, principally evident for the Jean branch rail line, are a result of risks that would be associated with transporting rail casks arriving from the east on the Union Pacific Railroad's mainline through the Las Vegas metropolitan area. The values that would apply for a Valley Modified or Caliente-Chalk Mountain branch line would be lower because of a shorter corridor (Valley Modified), or a more remote and mid-length corridor (Caliente-Chalk Mountain).

Table 6-16. Estimated health impacts[a] to the public from potential accident scenarios for Nevada rail implementing alternatives.

Risk	Caliente	Carlin	Caliente-Chalk Mountain	Jean	Valley Modified
Radiological accident risk					
Dose-risk (person-rem)	0.09	0.10	0.09	0.15	0.09
LCFs[b]	0.00005	0.00005	0.00004	0.00008	0.00004
Traffic fatalities	0.13	0.15	0.11	0.11	0.10

a. Data are reported for 24 years of operations.

b. LCFs = latent cancer fatalities.

Consequences of Maximum Reasonably Foreseeable Accidents. The national transportation analysis evaluated impacts of maximum reasonably foreseeable accidents (see Section 6.2.4.2).

Socioeconomics

There would be no socioeconomic impacts common to all the branch rail line implementing alternatives. Section 6.3.2.2 describes socioeconomic impacts for each implementing alternative.

Noise

Construction. Occupational Health and Safety Administration regulations (29 CFR) establish hearing protection standards for workers. DOE would meet these standards for workers involved in building a branch rail line in any of the five corridors. Estimated noise levels for railroad construction would range from 62 to 74 A-weighted decibels (dBA) within 150 meters (500 feet) of the noise source and from 54 to 67 dBA at 600 meters (2,000 feet) (ICC 1992, page 4-97). Trips to borrow and spoil areas would be another source of noise. Rail line construction would occur primarily during daylight hours, so nighttime noise would not be an issue unless there was a need to use accelerated construction to meet schedule constraints. There is a possibility that the construction of some structures associated with the rail line would occur during hours not in the normal workday, but the frequency and associated noise levels would be unlikely to be great. Because construction would progress along a corridor, construction noise would be transient in nearby communities. Noise levels could approach generally accepted limits for residential and commercial areas, but this would be for a brief time. Because there are no permanent residences, construction noise would not be an issue for activities inside the boundaries of Nellis Air Force Range, the Nevada Test Site, or the land withdrawal area that DOE analyzed for the proposed repository.

Operations. About five rail round trips (10 one-way trips) of spent nuclear fuel, high-level radioactive waste, or other material would occur weekly on the branch rail line during normal operations. To estimate noise impacts, the analysis assumed that trains would travel as fast as 80 kilometers (50 miles) an hour. The equivalent-continuous (average) sound level at 2,000 meters (6,600 feet) from a train consisting of two locomotives and 10 cars traveling at 80 kilometers an hour would be 51 dBA (Hanson, Saurenman, and Towers 1991, pages 1 to 8). The estimated noise level at 200 meters (660 feet) would be 62 dBA (Hanson, Saurenman, and Towers 1991, pages 1 to 8). Humans immediately outside a 400-meter (1,300-foot) corridor and the region of influence boundary would experience infrequent exposure to rail noise. In the more isolated regions, few people would be affected. Trains traveling through communities would normally operate at reduced speed, so their noise levels would decrease.

Noise impacts unique to the branch rail line implementing alternatives, with the exception of the Valley Modified implementing alternative (described in Section 6.3.2.2.5), would be unlikely.

Aesthetics

Construction. The greatest impact on visual resources from the construction of a rail line would be the presence of workers, camps, vehicles, large earth-moving equipment, laydown yards, and dust generation. These activities, however, would have a limited duration (about 2.5 years). Construction would progress along the selected corridor from its starting point to the proposed repository. Only a small portion of the overall construction time would be spent in one place; the exception to this would be places where major structures, such as bridges, would be built. In general, an individual construction camp would be active only for part of the 2.5-year construction period; after the completion of construction in an area, the camp would close.

Dust generation would be controlled by implementing best management practices such as misting or spraying disturbed areas. Construction activities would not exceed the criteria in the Bureau of Land Management Visual Resource Management guidelines (BLM 1986, all). If the rail line crossed Class II lands, more stringent management requirements would be necessary to retain the existing character of the landscape. The short duration of branch rail line construction activities, combined with the use of best management practices, would mitigate the impacts of activities that could exceed the management requirements for Class II lands. Visual impacts to scenic quality Class C lands on the Nevada Test Site would not occur because of the remoteness and inaccessibility of the location.

Operations. During proposed repository operations, visual impacts would be due to the existence of the branch rail line, access road, and borrow pits in the landscape and the passage of trains to and from the repository. The passage of 10 trains a week (coming and returning) would have a small impact, temporarily attracting the attention of the casual observer. In addition, the noise generated by the trains would attract attention to them, temporarily increasing their impact on the scenic quality of the landscape. There would be no aesthetic impacts unique to any of the branch rail line implementing alternatives.

Utilities, Energy, and Materials

Construction. Because all five corridors pass through sparsely populated areas with little access to support services, portable generators would provide electricity to support construction activities. The total fossil-fuel consumption in Nevada was about 3.8 billion liters (1 billion gallons) in 1996 (BTS 1999a, Table MF-21). Fuel consumption estimates for construction of heavy-haul routes indicate low impacts compared to the statewide consumption of petroleum fuel.

Steel for rails and concrete, principally for rail ties, bridges, and drainage structures, and rock for ballast would be the primary materials consumed in the construction of a branch rail line. DOE would buy precast concrete railbed ties, culverts, bridge beams, and overpass components from a number of suppliers. Actual onsite pouring of concrete [less than 120,000 metric tons (132,000 tons)] would account for less than 30 percent of the total mass of concrete and would be less than 2 percent of the concrete used in Nevada in 1998 (Sherwood 1998, all). Because DOE would buy precast concrete components from suppliers and because onsite concrete construction would involve a small amount of material for some abutments, the localized impact of concrete use in rail corridor construction would not be great for any of the corridors.

Because sources for rails and railroad ties are well established in the southwest and nationally, none of the quantities of materials required for constructing a rail line in Nevada would create demand or supply impacts in southern Nevada (Zocher 1998, all).

Impacts on utilities, energy, and materials differ among the implementing alternatives, as described in Section 6.3.2.2.

Operations. Impacts to utilities, energy, and materials from the operation of a branch rail line in Nevada would be small. Use of fossil fuel for train operations would be small. Chapter 10 discusses fossil fuel used for rail operations. No impacts would be unique to any of the branch rail line implementing alternatives.

Waste Management

Construction. The construction of a branch rail line would require construction materials such as rail ties and steel; rock ballast; concrete; oils, lubricants, and coolants for heavy machinery; and compressed gasses (hazardous materials) for welding. Construction in any of the five corridors would result in small amounts of wastes that would require disposal. Most would be nonhazardous industrial wastes or construction debris that DOE would dispose of in permitted industrial landfills or in permitted construction debris landfills, respectively. Hazardous waste such as lubricants and solvents would be shipped to a permitted hazardous waste treatment and disposal facility for appropriate disposition. In addition, much of the residual material from rail line construction would be saved for reuse or would be recycled. Excess excavated materials such as soil and rock would be placed in spoil areas that would be included in the amount of disturbed land. A commercial vendor would provide portable restroom facilities and manage the sanitary sewage. This waste would be handled such that there would be no adverse impacts from construction.

Operations. The use of a rail line in any of the five corridors would result in wastes from the maintenance of railroad equipment and track. These wastes would include waste lubricants from equipment and machinery; solvents, paint, and other hazardous material; sanitary waste; and industrial wastes typical for operations of a small branch rail line. Management and disposition of these wastes would comply with applicable environmental, occupational safety, and public safety regulations. Thus, waste would be handled such that there would be no impacts from rail corridor operations.

There would be no waste management impacts unique to any of the branch rail line implementing alternatives.

6.3.2.2 Specific Impacts of Rail Corridor Implementing Alternatives

6.3.2.2.1 *Caliente Rail Corridor Implementing Alternative*

The Caliente corridor originates at an existing siding to the Union Pacific mainline railroad at Eccles siding near Caliente, Nevada (Figure 2-30). The corridor travels west, traversing the Chief, North Pahroc, Golden Gate, and Kawich Mountain Ranges. The Caliente and Carlin corridors converge near the northwest boundary of the Nellis Air Force Range. Past this point, the corridors are identical. The Caliente corridor is 513 kilometers (319 miles) long from the Union Pacific line connection to the Yucca Mountain site. Figure 6-11 shows the alignment for this corridor, along with possible variations identified by engineering studies (TRW 1999d, page 2, Item 6). The alignment variations provide flexibility in addressing engineering, land-use, or environmental resource issues that could arise in a future, more detailed survey along the corridor. Appendix J assesses the attributes of these alignment variations. This section addresses impacts that would occur along the corridor alignment shown in Figure 6-11. With the exception of the differences identified in Appendix J, the impacts would be generally the same among the possible alignments.

Construction of a branch rail line in the Caliente corridor would require approximately 2.5 years. Construction would take place simultaneously at multiple locations along the corridor. An estimated six construction camps at roughly equal distances along the corridor would provide temporary living accommodations for construction workers and construction support facilities.

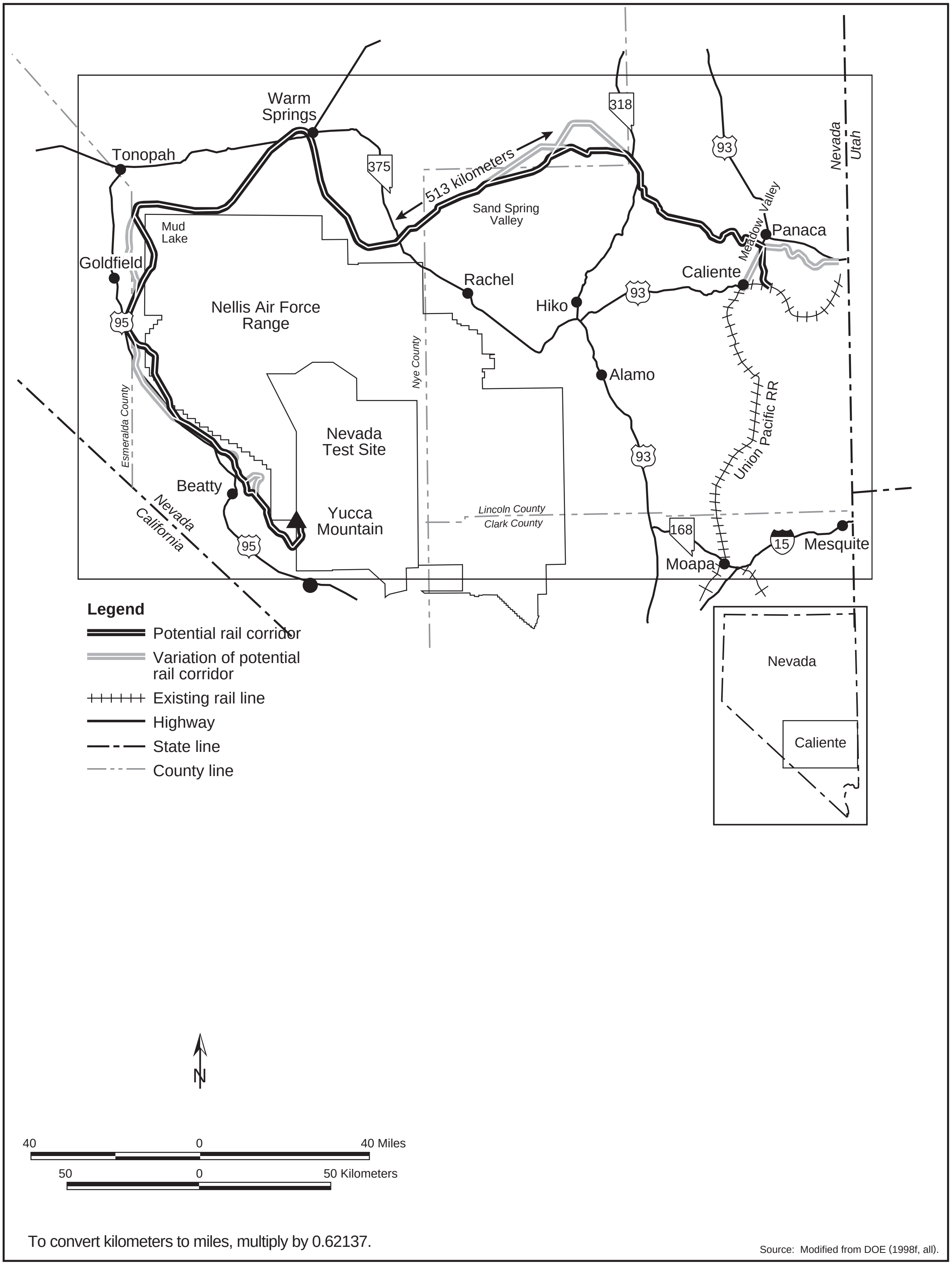
The following sections address impacts that would occur to land use; biological resources and soils; hydrology including surface water and groundwater; occupational and public health and safety; socioeconomics; noise; and utilities, energy, and materials. Impacts that would occur to air quality, cultural resources, aesthetics, and waste management would be the same as those described in Section 6.3.2.1 and are not repeated here. Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.

Land Use and Ownership

Construction. Table 6-17 summarizes the amount of land required for the Caliente corridor, its ownership, and the estimated amount of land that would be disturbed.

This branch rail line would cross several telephone, pipeline, highway, and power line rights-of-way. It also would cross six Bureau of Land Management grazing allotments (Reveille, Ralston, Stone Cabin, Montezuma, Magruder Mountain, and Razorback), seven wild horse and burro herd management areas, five areas leased for oil and gas exploration and extraction, and four areas designated as available for sale or transfer (TRW 1999f, Table 3).

If DOE decided to build and operate a branch rail line in the Caliente corridor, it would consult with the Bureau of Land Management, the U.S. Air Force, and other affected agencies to help ensure that it avoided or mitigated potential land-use conflicts associated with the alignment of a right-of-way. Because Public Law 99-606 withdrew and reserved the Nellis Air Force Range for use by the Secretary of the Air Force, the Secretary would need to concur with a decision to build and operate a branch rail line



To convert kilometers to miles, multiply by 0.62137.

Source: Modified from DOE (1998f, all).

Figure 6-11. Caliente rail corridor.

through the Range before DOE could build and operate this line. Alternatively, DOE could choose the corridor variations shown on Figure 6-11 that avoid crossing Nellis Air Force Range lands.

Based on currently available information, DOE is not aware of any conflicts with existing or planned land uses that would occur as a result of construction of a branch rail line in the Caliente corridor. Although there are no known community development plans that would conflict with the rail line, the presence of a rail line could influence future development and land use along the railroad in the communities of Beatty, Caliente, Goldfield, Scotty's Junction, and Warm Springs (that is, zoning and land use might differ depending on the presence or absence of a railroad). Construction of a branch rail line within the Caliente corridor would require conversion of land within existing grazing allotments and wild horse or wild horse and burro management areas; however, because the railroad would be unlikely to interfere with animal movements, the functionality of these areas would not be affected.

Table 6-17. Land use in the Caliente rail corridor.

Factor	Amount
Corridor length (kilometers)[a]	513
Land area in 400-meter[b]*-wide corridor (square kilometers)*[c]	210
Land ownership [square kilometers (percent)]	
Bureau of Land Management	180 (88)[d]
Air Force	20 (10)
DOE	4 (2)
Private	Small (~ 1)
Other	None
Disturbed land (square kilometers)	
Inside corridor	14.8
Outside corridor	3.2

a. To convert kilometers to miles, multiply by 0.62137.
b. 400 meters = about 0.25 mile.
c. To convert square kilometers to acres, multiply by 247.1.
d. Percentages do not total 100 due to rounding.

Operations. Rail corridor operations would involve the same land-use and ownership considerations as those discussed above for construction. No unique impacts were identified.

Hydrology

Surface Water

Surface-water resources along the Caliente rail corridor are discussed in Chapter 3, Section 3.2.2.1.3, and summarized in Table 6-18. As discussed in Section 6.3.2.1, impacts during construction or operations from the possible spread of construction-related materials by precipitation or intermittent runoff events, releases to surface water, or the alteration of natural drainage patterns or runoff rates that could affect downgradient resources would be unlikely.

Table 6-18. Surface-water resources along Caliente corridor.[a,b]

Resources in 400-meter[c] corridor			Resources outside corridor within 1 kilometer[d]		
Spring	Stream/ riparian area	Reservoir	Spring	Stream/ riparian area	Reservoir
1	4	--[e]	6	--	--

a. Source: reduced from Table 3-35.
b. Resources are the number of locations; that is, a general location with more than one spring was counted as one water resource.
c. 400 meters = about 0.25 mile.
d. 1 kilometer = about 0.6 mile.
e. -- = none.

Groundwater

Construction. The water used during construction would come largely from groundwater resources. The annual demands would be a fraction of the perennial yields of most producing aquifers (see Chapter 3, Section 3.2.2.1.3, for estimated perennial yields for the hydrographic areas over which the Caliente rail corridor would pass).

The amount of water needed for the construction of a rail line in the Caliente corridor for soil compaction and dust control would be about 880,000 cubic meters (710 acre-feet) (LeFever 1998a, all). For planning purposes, DOE assumed that this water would come from 64 wells installed along the rail corridor. The average amount of water withdrawn from each well would be approximately 13,700 cubic meters (11 acre-feet). Chapter 3, Section 3.2.2.1.3, discusses the hydrographic areas over which the Caliente rail corridor would pass, their perennial yields, and whether the State of Nevada considers each a Designated Groundwater Basin. If the hydrographic area is a Designated Groundwater Basin, permitted groundwater rights approach or exceed the estimated perennial yield, depleting water resources or requiring additional administration. Table 6-19 summarizes the status of the hydrographic areas associated with the Caliente rail corridor and the approximate portion of the corridor that would pass over Designated Groundwater Basins.

HYDROGRAPHIC AREA

The Nevada Division of Water Planning has divided the State into groundwater basins, or *hydrographic areas*. These areas are used in the management of groundwater resources. Hydrographic areas are generally based on topographic divides (that is, they typically comprise a valley, a portion of a valley, or a terminal basin), but can also be based on administrative divisions. The State classifies a hydrographic area as a Designated Groundwater Basin when the permitted water rights (or appropriations) approach or exceed the area's estimated perennial yield and the water resources are depleted or require additional administration. The Division of Water Planning's home page *http://www.state.nv.us/cnr/ndwp* identifies the hydrographic areas that are Designated Groundwater Basins.

The withdrawal of 13,700 cubic meters (11 acre-feet) a year from a well would have little impact on the hydrographic areas associated with the Caliente rail corridor based on their perennial yields (Chapter 3, Section 3.2.2.1.3). However, the installation of 64 wells along the corridor would mean that many hydrographic areas would have multiple wells. As Table 6-19 indicates, about 40 percent of the corridor length would be over Designated Groundwater Basins, which the Nevada State Engineer's office watches carefully for groundwater depletion. This does not mean that DOE could not obtain water appropriations in these areas; the State Engineer would have the authority to approve such appropriations. Because the DOE requests would be for a short-term construction action, the State Engineer would have even more discretion. Rather than spacing the wells evenly along the corridor, DOE could use locations that would make maximum use of groundwater areas that are not Designated Groundwater Basins. Another option would be to lease temporary water rights from individuals along the corridor. Obtaining a water appropriation from the State Engineer for short-term construction use or using an approved allocation should ensure that groundwater resources would not be adversely affected.

Table 6-19. Hydrographic areas along Caliente rail corridor.

	Designated Groundwater Basins	
Hydrographic areas	Number	Percent of corridor length
18	6	40

As an alternative, DOE could transport water by truck to meet construction needs. The construction of a branch rail line in the Caliente corridor would require about 47,000 tanker-truck loads of water or about eight truckloads each day for each work camp along the corridor. Again, water obtained from permitted sources, which would be within allocations determined by the Nevada State Engineer, would not affect groundwater resources.

Operations. Operations along a completed rail line would have little impact on groundwater resources. There would be no changes in recharge beyond those at the completion of construction.

Biological Resources and Soils

Construction. The construction of a rail line in the Caliente corridor would disturb approximately 18 square kilometers (4,500 acres) of land (Table 6-17). More than 50 kilometers (31 miles) along the southern end of the corridor is in desert tortoise habitat. Assuming that a maximum of about 0.06 square kilometer (15 acres) of land would be disturbed for each kilometer of rail line, construction activities would disturb about 3 square kilometers (740 acres) of desert tortoise habitat, none of which is classified as critical habitat. In addition, these activities could kill individual desert tortoises; however, their abundance is low in this area (Karl 1981, pages 76 to 92; Rautenstrauch and O'Farrell 1998, pages 407 to 411) so losses would be few. The only other Federally listed species near the corridor is the Railroad Valley springfish (Federally threatened), which has been found about 3 kilometers (1.9 miles) north of the corridor, and it should not be affected. This corridor would cross a portion of the Meadow Valley Wash, which is habitat for the Meadow Valley Wash speckled dace and the Meadow Valley Wash desert sucker. Construction of a branch rail line in this corridor could temporarily affect populations of these fish by increasing the sediment load in the wash during construction. Four other special status species occur along this route but could be avoided during land-clearing activities (TRW 1999k, page 3-23) and, therefore, would not be affected.

The rail corridor crosses 13 areas designated as game habitat and 8 areas designated as wild horse and burro management areas (see Chapter 3, Section 3.2.2.1.4). Construction activities would reduce habitat in these areas. Wild horses, burros, and game animals near these areas during construction would be disturbed and their migration routes could be disrupted.

At least one spring, one river, and three riparian areas are within the 0.4-kilometer (0.25-mile) corridor (Table 6-18). Although formal delineations have not been conducted, these springs and riparian areas may be jurisdictional wetlands or other waters of the United States. Construction could increase sedimentation in these areas. In addition, the corridor crosses a number of ephemeral streams that could be classified as waters of the United States. DOE would work with the U.S. Army Corps of Engineers to minimize impacts to these areas and would obtain individual or regional permits if necessary.

Construction activities would temporarily disturb about 18 square kilometers (4,500 acres) of soils in and adjacent to the corridor. The impacts to soils of disturbing 18 square kilometers along the 530-kilometer (329-mile)-long corridor would be transitory and small.

Operations. Impacts from operations would include periodic disturbances of wildlife from passing trains and from personnel servicing the corridor. Trains probably would kill individuals of some species but losses would be unlikely to affect regional populations of any species. No additional habitat loss would occur during operations.

Occupational and Public Health and Safety

Construction. Industrial safety impacts on workers from the construction and use of the Caliente branch rail line would be small. The analysis evaluated the potential for impacts in terms of total reportable cases of injury and illness, lost workday cases, and fatality risks to workers and the public from construction and operation activities. Table 6-20 lists these results.

The analysis also evaluated traffic fatality impacts that would occur during the moving of equipment and materials for construction, worker commutes to and from construction sites, and transport of water to construction sites if wells were not available. Table 6-21 lists these results.

Operations. Incident-free radiological impacts would occur during the routine transportation of spent nuclear fuel and high-level radioactive waste in the Caliente rail corridor. Table 6-22 lists the incident-free impacts, which include transportation along the Caliente corridor and along railways in Nevada leading to a Caliente branch line. The table includes the impacts of 2,600 legal-weight truck shipments from commercial sites that do not have the capability to load rail casks.

Socioeconomics

Construction. There would be socioeconomic impacts associated with construction of a branch rail line in the Caliente corridor. The projected length of the corridor—513 kilometers (319 miles)—is the most important factor for determining the number of workers that would be required. To construct a branch rail line in this corridor would require 560 workers (annual average) (TRW 1999d, Rail Files, Item 1) and 5 construction camps.

Table 6-20. Impacts to workers from industrial hazards during rail construction and operations in the Caliente corridor.

Group and industrial hazard category	Construction[a]	Operations[b]
Involved workers		
Total recordable cases[c]	110	120
Lost workday cases	56	68
Fatalities	1.1	0.2
Noninvolved workers		
Total recordable cases	7	6
Lost workday cases	4	3
Fatalities	0.01	0.01
Totals[d]		
Total recordable cases	120	130
Lost workday cases	60	71
Fatalities	1.1	0.23

a. Totals for 2.5 years of construction.
b. Totals for 24 years of operations.
c. Total recordable cases includes injury and illness.
d. Totals might differ from sums due to rounding.

Table 6-21. Estimated number of fatalities from construction material delivery vehicles and construction and operations worker commuting traffic for the Caliente rail corridor.

Activity	Kilometers[a]	Traffic fatalities	Emissions fatalities
Construction			
Material delivery vehicles	19,000,000	0.3	0.0014
Commuting workers	85,000,000	0.9	0.0061
Subtotals	*104,000,000*	*1.2*	*0.0075*
Operations			
Commuting workers	68,000,000	0.7	0.005
Totals	***172,000,000***	***1.9***	***0.013***

a. To convert kilometers to miles, multiply by 0.62137.

Table 6-22. Health impacts from incident-free Nevada transportation for the Caliente rail corridor implementing alternative.[a]

Category	Legal-weight truck shipments	Rail shipments	Totals[b]
Involved workers			
Collective dose (person-rem)	220	210	430
Estimated LCFs[c]	0.09	0.08	0.17
Public			
Collective dose (person-rem)	270	120	390
Estimated LCFs	0.14	0.06	0.20
Estimated vehicle emission-related fatalities	0.00014	0.0018	0.0019

a. Impacts are totals for 24 years (2010 to 2033).
b. Totals might differ due to rounding.
c. LCF = latent cancer fatality.

DOE anticipates that the total direct and indirect employment would peak in 2007 at about 1,200 for the corridor. Population increases in Nevada from the construction of a branch rail line, which would lag behind increases in employment, would peak in 2009 at about 900. Real disposable income, Gross Regional Product, and State and local government expenditures would rise. The expected peak changes due to the Caliente corridor would be increases of $27.7 million in real disposable income, $48.6 million in Gross Regional Product, and $2.5 million in state and local expenditures. (All dollar values reported in this section are in 1992 constant dollars unless otherwise stated.)

Impacts to employment, population, real disposable income, Gross Regional Product, and State and local government expenditures would be low for Clark and Nye Counties, as would increases in population and State and local government expenditures for Lincoln County. Impacts to employment, real disposable income, and Gross Regional Product in Lincoln County would be moderate compared to baseline values, increasing by about 4 percent, 2 percent, and 2 percent, respectively, in 2007. Although these impacts would be moderate for Lincoln County, they would not exceed historic short-term changes in growth.

Operations. The estimated direct employment for the Caliente branch line operations would be 47 workers. Total direct and indirect peak employment would be 130.

The greatest estimated real disposable income increase attributable to operation, which was projected to occur in 2033, the last year of operation, would be $5.4 million. The increase in Gross Regional Product in 2026, the year in which the increase would be greatest in comparison to the baseline, would be $9.1 million. Annual State and local government expenditures would be much lower than those reported above for construction.

Impacts to employment, population, real disposable income, Gross Regional Product, and State and local government expenditures from the operation of a Caliente branch rail line would be low for Clark and Nye Counties. Peak impacts to employment, population, real disposable income, Gross Regional Product, and State and local government expenditures in Lincoln Country would be moderate compared to baseline values, which would range from a 1.5- to 6.4-percent increase above the baseline. Although these impacts would be moderate for Lincoln County, they would be positive and would not exceed historic short-term changes in growth.

Noise

Most of the corridor would pass through undeveloped Bureau of Land Management land, where the only human inhabitants would be isolated ranchers or persons involved with outdoor recreation. Communities in the region of influence include Caliente, Panaca, Goldfield, and Beatty. Principally because of the populations in these communities, there would be a potential for noise impacts from both construction and operations.

Utilities, Energy, and Materials

Table 6-23 lists the use of fossil fuel and other materials for the construction of a Caliente branch rail line.

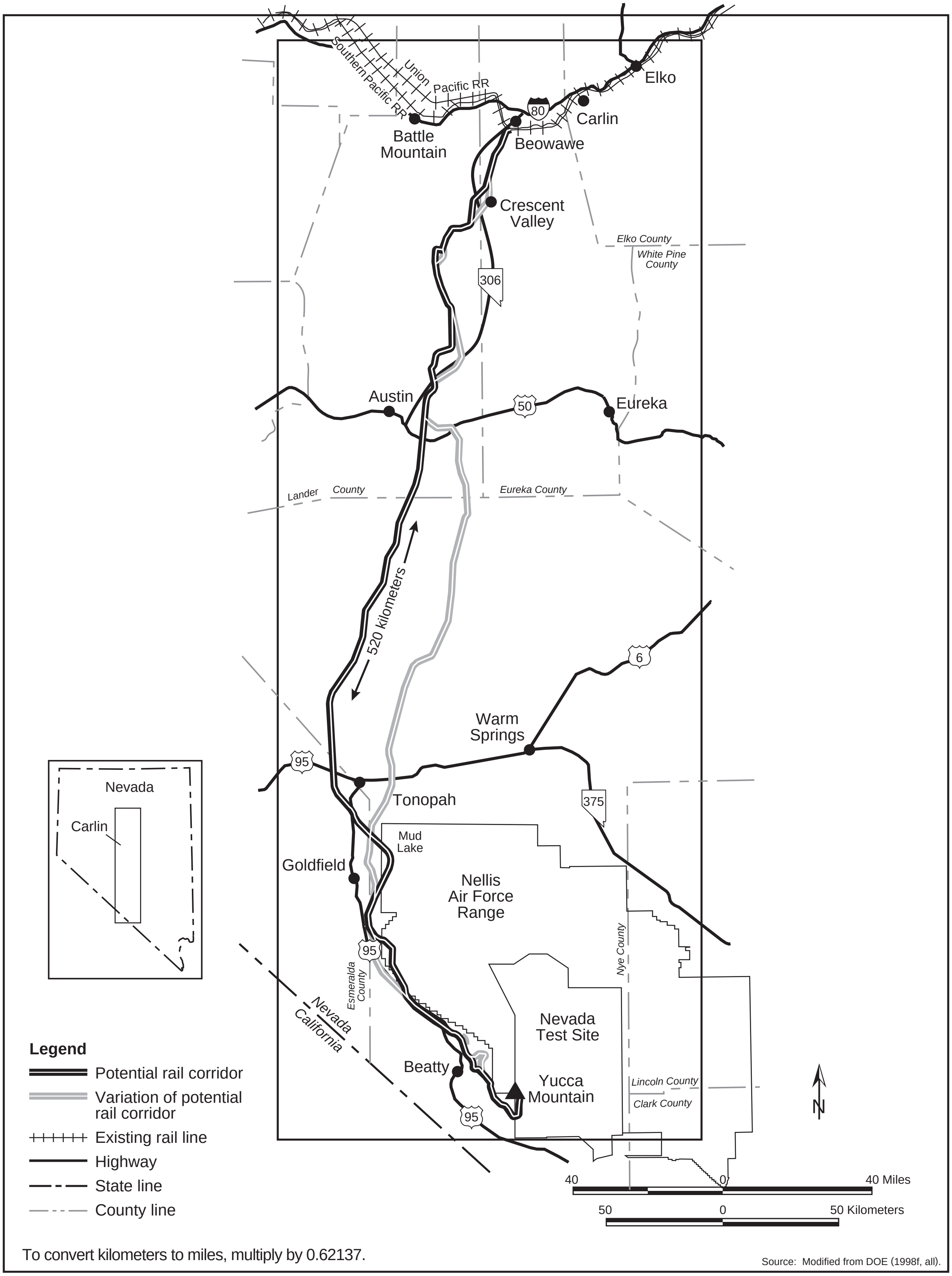
Table 6-23. Construction utilities, energy, and materials for a Caliente branch rail line used over 2.5 years.

Length (kilometers)[a]	Diesel fuel use (million liters)[b]	Gasoline use (thousand liters)	Steel (thousand metric tons)[c]	Concrete (thousand metric tons)[c]
513	42	870	71	420

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. To convert metric tons to tons, multiply by 1.1023.

6.3.2.2.2 *Carlin Rail Corridor Implementing Alternative*

The Carlin corridor originates at the Union Pacific main line railroad near Beowawe in north-central Nevada. Figure 6-12 shows the alignment of this corridor along with possible variations identified by engineering studies (TRW 1999d, Rail Files, Item 6). The alignment variations provide flexibility in addressing engineering, land-use, or environmental resource issues that could arise in a future, more detailed survey along the corridor. Appendix J assesses the attributes of these alignment variations. This section addresses impacts that would occur along the corridor alignment shown in Figure 6-12. With the



To convert kilometers to miles, multiply by 0.62137.

Source: Modified from DOE (1998f, all).

Figure 6-12. Carlin rail corridor.

exception of the differences identified in Appendix J, the impacts would be generally the same among the possible corridor alignments.

The corridor travels south through Crescent, Grass, and Big Smokey Valleys, passing west of the City of Tonopah and east of the City of Goldfield. The corridor then travels south following and periodically crossing the western boundary of the Nellis Air Force Range, passing through Oasis Valley and Beatty Wash. It travels along Fortymile Wash to the proposed repository location. The corridor is about 520 kilometers (323 miles) long from its link with the Union Pacific line to the Yucca Mountain site.

The construction of a branch rail line in the Carlin corridor would require approximately 2.5 years. Construction would take place simultaneously at multiple locations along the corridor. DOE would establish an estimated five construction camps at roughly equal distances along the corridor. These camps would provide temporary living accommodations for construction workers and construction support facilities.

The following sections address impacts that would occur to land use; biological resources and soils; hydrology including surface water and groundwater; occupational and public health and safety; socioeconomics; noise; and utilities, energy, and materials. Impacts that would occur to air quality, cultural resources, aesthetics, and waste management would be the same as those common impacts discussed in Section 6.3.2.1 and are, therefore, not repeated here. Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.

Land Use and Ownership

Construction. Table 6-24 summarizes the amount of land required for the Carlin corridor, its ownership, and the estimated amount of land that would be disturbed.

The corridor crosses several telephone, highway, and utility rights-of-way. It also crosses 12 Bureau of Land Management grazing allotments (Carico Lake, Dry Creek, Grass Valley, Kingston, Simpson Park, Wildcat Canyon, Smoky, Francisco, San Antone, Montezuma, Magruder Mountain, and Razorback) and 5 wild horse and burro herd management areas. Other areas crossed by the corridor include the Bates Mountain antelope release area, three designated riparian habitats, and the Simpson Park habitat management area. It does not cross any oil or gas exploration and extraction areas.

Table 6-24. Land use in the Carlin rail corridor.

Factor	Amount
Corridor length (kilometers)[a]	520
Land area in 400-meter[b]*-wide corridor (square kilometers)*[c]	210
Land ownership [square kilometers (percent)]	
Bureau of Land Management	180 (85)[d]
Air Force	19 (9)
DOE	4 (2)
Private	7 (3.4)
Other	None
Disturbed land (square kilometers)	
Inside corridor	17
Outside corridor	2

a. To convert kilometers to miles, multiply by 0.62137.

b. 400 meters = about 0.25 mile.

c. To convert square kilometers to acres, multiply by 247.1.

d. Percentages do not total 100 due to rounding.

If DOE decided to build and operate a branch rail line in the Carlin corridor, it would consult with the Bureau of Land Management, the U.S. Air Force, and other affected agencies to help ensure that it avoided or mitigated potential land-use conflicts associated with alignment of a right-of-way. Because Public Law 99-606 withdrew and reserved the Nellis Air Force Range for use by the Secretary of the Air Force, the Secretary would need to concur with a decision to build and operate a branch rail line through the Range before DOE could build and operate this line.

Based on currently available information, DOE is not aware of any conflicts with existing or planned land uses that would occur as a result of construction of a branch rail line in the Carlin corridor. Although there are no known community development plans that would conflict with the rail line, the presence of a rail line could influence future development and land use along the railroad in the communities of Austin, Beatty, Carver's Station, Cortez, Crescent Valley, Gold Acres, Goldfield, Manhattan, Round Mountain, Scotty's Junction, Tenabo, and Tonopah (that is, zoning and land use might differ depending on the presence or absence of a railroad). Construction of a branch rail line within the Carlin corridor would require conversion of land within existing grazing allotments and wild horse or wild horse and burro management areas; however, because the railroad would be unlikely to interfere with animal movements, the functionality of these areas would not be affected.

Operations. Rail corridor operations would involve the same land-use and ownership considerations discussed above for construction. The analysis identified no unique impacts for operations.

Hydrology

Surface Water

Surface-water resources along the Carlin rail corridor are discussed in Chapter 3, Section 3.2.2, and summarized in Table 6-25. As discussed in Section 6.3.2.1, impacts during construction or operations from the possible spread of construction-related materials by precipitation or intermittent runoff events, releases to surface waters, and the alteration of natural drainage patterns or runoff rates that could affect downgradient resources would be unlikely.

Table 6-25. Surface-water resources along Carlin rail corridor.[a,b]

Resources in 400-meter[c] corridor			Resources outside corridor within 1 kilometer[d]		
Spring	Stream/ riparian area	Reservoir	Spring	Stream/ riparian area	Reservoir
1	5	--[e]	10	2	1

a. Source: reduced from Table 3-35.
b. Water resources are the number of locations; that is, if a general location has more than one spring, it was counted as one water resource.
c. 400 meters = about 0.25 mile.
d. 1 kilometer = about 0.6 mile.
e. -- = none.

Groundwater

Construction. The water used during construction would come largely from groundwater resources. The annual demands would be a fraction of the perennial yields of most producing aquifers (see Chapter 3, Section 3.2.2.1.3, for estimated perennial yields for the hydrographic areas over which the Carlin rail corridor passes).

The estimated amount of water needed for the construction of a rail line in the Carlin corridor for soil compaction and dust control would be about 810,000 cubic meters (660 acre-feet) (LeFever 1998a, all). For planning purposes, DOE assumed that this water would come from 67 groundwater wells installed along the rail corridor. The average amount of water withdrawn from each well would be approximately 12,100 cubic meters (10 acre-feet).

Chapter 3, Section 3.2.2.1.3, discusses the hydrographic areas over which the corridor would pass, their perennial yields, and whether the State of Nevada considers each a Designated Groundwater Basin. If the hydrographic area is a Designated Groundwater Basin, permitted groundwater rights approach or exceed the estimated perennial yield, depleting water resources or requiring additional administration. Table 6-26 summarizes the status of the hydrographic areas associated with the Carlin rail corridor, and the approximate portion of the corridor that passes over Designated Groundwater Basins.

Table 6-26. Hydrographic areas along Carlin rail corridor.

	Designated Groundwater Basins	
Hydrographic areas	Number	Percent of corridor length
11	5	70

The withdrawal of about 12,000 cubic meters (10 acre-feet) a year from a well would have little impact on the hydrographic areas associated with the corridor based on their perennial yields (Chapter 3, Section 3.2.2.1.3). However, the installation of 67 wells along the corridor would mean that many hydrographic areas would have multiple wells. As indicated in Table 6-26, about 70 percent of the corridor length is in Designated Groundwater Basins, which the Nevada State Engineer's office watches carefully for groundwater depletion. This does not mean that DOE could not obtain water appropriations in these areas; the State Engineer would have the authority to approve such appropriations. Because the DOE requests would be for a short-term construction action, the State Engineer would have even more discretion. Rather than spacing the wells evenly along the corridor, DOE could use locations that would make maximum use of groundwater areas that are not Designated Groundwater Basins. With such a large portion of the corridor over these basins, however, this would mean that DOE would truck water for long distances. Another option would be to lease temporary water rights from individuals along the corridor. Obtaining a water appropriation from the State Engineer for short-term construction use or using an approved allocation would ensure no adverse effects to groundwater resources.

As an alternative, DOE could transport water by truck to meet construction needs. The construction of a branch rail line in the Carlin corridor would require about 43,000 tanker-truck loads of water or about 9 truckloads each day for each work camp along the corridor. Again, water obtained from permitted sources, which would be within allocations determined by the Nevada State Engineer, would not affect groundwater resources.

Operations. Operations along a completed rail line would have little impact on groundwater resources. Possible changes in recharge, if any, would be the same as those at the completion of construction.

Biological Resources and Soils

Construction. The construction of a rail line in the Carlin corridor would disturb approximately 19 square kilometers (4,700 acres) (Table 6-24). More than 50 kilometers (31 miles) of its length along the southern end of the corridor occurs in desert tortoise habitat. Construction activities would disturb about 3 square kilometers (740 acres) of this habitat, assuming the maximum rate of 0.06 square kilometer (15 acres) disturbed per linear kilometer of railroad. In addition, construction activities could kill individual desert tortoises; however, the abundance of this species is low in this area (Karl 1981, pages 76 to 92; Rautenstrauch and O'Farrell 1998, pages 407 to 411) so losses would be few. Three other special status species are found along this route but could be avoided during land-clearing activities and should not be affected.

This rail corridor would cross seven areas designated as game habitat and six areas designated as wild horse and burro management areas (see Chapter 3, Section 3.2.2.1.4). Construction activities would reduce habitat in these areas. Wild horses, burros, and game animals near these areas during construction would be disturbed, and their migration routes could be disrupted.

One spring, one river, and five riparian areas are within the 0.4-kilometer (0.25-mile)-wide corridor (Table 6-25). Although no formal delineations have been conducted, these areas may be jurisdictional wetlands or other waters of the United States. Construction could increase sedimentation in these areas. In addition, the corridor crosses a number of ephemeral streams that may be classified as waters of the United States. DOE would work with the U.S. Army Corps of Engineers to minimize impacts to these areas and would obtain individual or regional permits if necessary.

Construction activities would temporarily disturb about 19 square kilometers (4,700 acres) of soils in and adjacent to the corridor. The impacts to soils of disturbing 19 square kilometers (4,700 acres) along the 520-kilometer (323-mile)-long corridor would be transitory and small.

Operations. Impacts from operations would include periodic disturbance of wildlife from passing trains and from personnel servicing the corridor. Trains probably would kill individuals of some species but losses would be unlikely to affect regional populations of any species. No additional habitat loss would occur during operations. Impacts on soils would be small.

Occupational and Public Health and Safety

Construction. Industrial safety impacts on workers from the construction and use of the Carlin branch rail line would be small (see Table 6-27). The analysis evaluated the potential for impacts in terms of total reportable cases of injury, lost workday cases, and fatalities to workers from construction and operation activities.

Table 6-27. Impacts to workers from industrial hazards during rail construction and operations for the Carlin corridor.

Group and industrial hazard category	Construction[a]	Operations[b]
Involved workers		
Total recordable cases[c]	100	120
Lost workday cases	50	68
Fatalities	1	0.23
Noninvolved workers		
Total recordable cases	6	6
Lost workday cases	3	3
Fatalities	0.01	0.01
Totals[d]		
Total recordable cases	110	130
Lost workday cases	53	71
Fatalities	1	0.23

a. Totals for 2.5 years for construction.
b. Totals for 24 years for operations.
c. Total recordable cases includes injury and illness.
d. Totals might differ from sums due to rounding.

The analysis also evaluated traffic fatality impacts that would occur during the moving of equipment and materials for construction, worker commutes to and from construction sites, and transport of water to construction sites if wells were not available. Table 6-28 lists these results.

Operations. Incident-free radiological impacts would occur during the routine transportation of spent nuclear fuel and high-level radioactive waste in the Carlin rail corridor. Table 6-29 lists the incident-free impacts, which would include transportation along the Carlin corridor and transportation along railways in Nevada that led to a Carlin branch line. The table includes the impacts of 2,600 legal-weight truck shipments from commercial sites that do not have the capability to load rail casks.

Table 6-28. Estimated number of fatalities from construction material delivery vehicles and construction and operations worker commuting traffic for the Carlin rail corridor.

Activity	Kilometers[a]	Traffic fatalities	Emissions fatalities
Construction[b]			
Material delivery vehicles	19,000,000	0.3	0.0014
Commuting workers	76,000,000	0.8	0.0055
Subtotals	*95,000,000*	*1.1*	*0.0068*
Operations[c]			
Commuting workers	68,000,000	0.7	0.005
Totals	***163,000,000***	***1.8***	***0.012***

a. To convert kilometers to miles, multiply by 0.62137.
b. Totals for 2.5 years for construction.
c. Totals for 24 years for operations.

Socioeconomics

Construction. There would be socioeconomic impacts associated with the construction of a branch rail line in the Carlin corridor. The projected length of the corridor, 520 kilometers (323 miles), would determine the number of workers that would be required. The construction of a branch rail line in this corridor would require 500 workers (annual average) (TRW 1999d, Rail Files, Item 1) and 5 construction camps.

Table 6-29. Health impacts from incident-free Nevada transportation for the Carlin corridor implementing alternative.[a]

Category	Legal-weight truck shipments	Rail shipments	Totals[b]
Involved workers			
Collective dose (person-rem)	220	250	470
Estimated latent cancer fatalities	0.09	0.11	0.19
Public			
Collective dose (person-rem)	270	150	420
Estimated latent cancer fatalities	0.13	0.08	0.21
Estimated vehicle emission-related fatalities	0.00014	0.0024	0.0025

a. Impacts are totals for 24 years (2010 to 2033).
b. Totals might differ from sums due to rounding.

DOE anticipates that total direct and indirect construction employment would peak in 2007 at about 1,100. Population increases in Nevada from construction, which would lag behind increases in employment, would be likely to peak in 2009. The increase from constructing a Carlin branch rail line would be 790. In addition, real disposable income, Gross Regional Product, and State and local government expenditures would rise. The expected peak changes would be increases of $24.5 million in real disposable income, and $43.5 million in Gross Regional Product in 2007, and $2.2 million in State and local expenditures in 2009. (All dollar values reported in this section are in 1992 constant dollars unless otherwise stated.)

Impacts to employment, population, real disposable income, Gross Regional Product, and State and local government expenditures for construction of a branch rail line in the Carlin corridor would be low for all affected counties.

Operations. Estimated employment for operations in the Carlin corridor would be 47. The total estimated direct and indirect employment from these operations at its peak would be about 140.

The estimated increase in real disposable income in 2029 through 2033 compared to the baseline would be $6.0 million. The increase in Gross Regional Product in 2029 through 2033, the years when the analysis predicted the impacts would be greatest in comparison to the baseline, for the Carlin line would be about $9.4 million. This peak reflects the gradual increase in shipping that would occur over the 24 years of shipping. Annual State and local government expenditures would be much lower than those reported above for construction.

Impacts to employment, population, real disposable income, Gross Regional Product, and State and local government expenditures from operating a Carlin branch rail line would be low for all affected counties.

Noise

Most of the Carlin corridor would pass through undeveloped Bureau of Land Management land, where the only human inhabitants would be isolated ranchers or persons involved with outdoor recreation. There are small communities such as Crescent, Beowawe, and Hadley in the region of influence. For this corridor, noise impacts would be unlikely during construction and operation.

Utilities, Energy, and Materials

Table 6-30 lists the projected use of fossil fuels and other materials in the construction of a Carlin branch rail line.

Table 6-30. Construction utilities, energy, and materials for a Carlin branch rail line used during 2.5 years.

Length (kilometers)[a]	Diesel fuel use (million liters)[b]	Gasoline use (thousand liters)	Steel (thousand metric tons)[c]	Concrete (thousand metric tons)
520	39	800	72	400

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. To convert metric tons to tons, multiply by 1.1023.

6.3.2.2.3 *Caliente-Chalk Mountain Rail Corridor Implementing Alternative*

The Caliente-Chalk Mountain corridor is identical to the Caliente corridor until it reaches the northern boundary of the Nellis Air Force Range. At this point the Caliente-Chalk Mountain corridor turns south through the Nellis Air Force Range and the Nevada Test Site to the Yucca Mountain site. Figure 6-13 shows the alignment of this corridor along with possible variations identified by engineering studies (TRW 1999d, Page 1, Item 1). The alignment variations provide flexibility in addressing engineering, land-use, or environmental resource issues that could arise in a future, more detailed survey along the corridor. Appendix J assesses the attributes of these alignment variations. This section addresses impacts that would occur along the corridor alignment shown in Figure 6-13. With the exception of differences identified in Appendix J, the impacts would be generally the same among the possible corridor alignments. The corridor is 345 kilometers (214 miles) long from its link at the Union Pacific railroad near Caliente to Yucca Mountain.

The construction of a branch rail line in the corridor would require approximately 2.5 years. Construction would take place simultaneously at a number of locations. An estimated four construction camps would be established at roughly equal distances along the corridor. These camps would provide temporary living accommodations for construction workers and construction support facilities.

The following sections address impacts that would occur to land use; biological resources and soils; hydrology including surface water and groundwater; occupational and public health and safety; socioeconomics; noise; and utilities, energy, and materials. Impacts that would occur to air quality, cultural resources, aesthetics, and waste management would be the same as those discussed in Section 6.3.2.1 and are, therefore, not repeated here. Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.

Land Use and Ownership

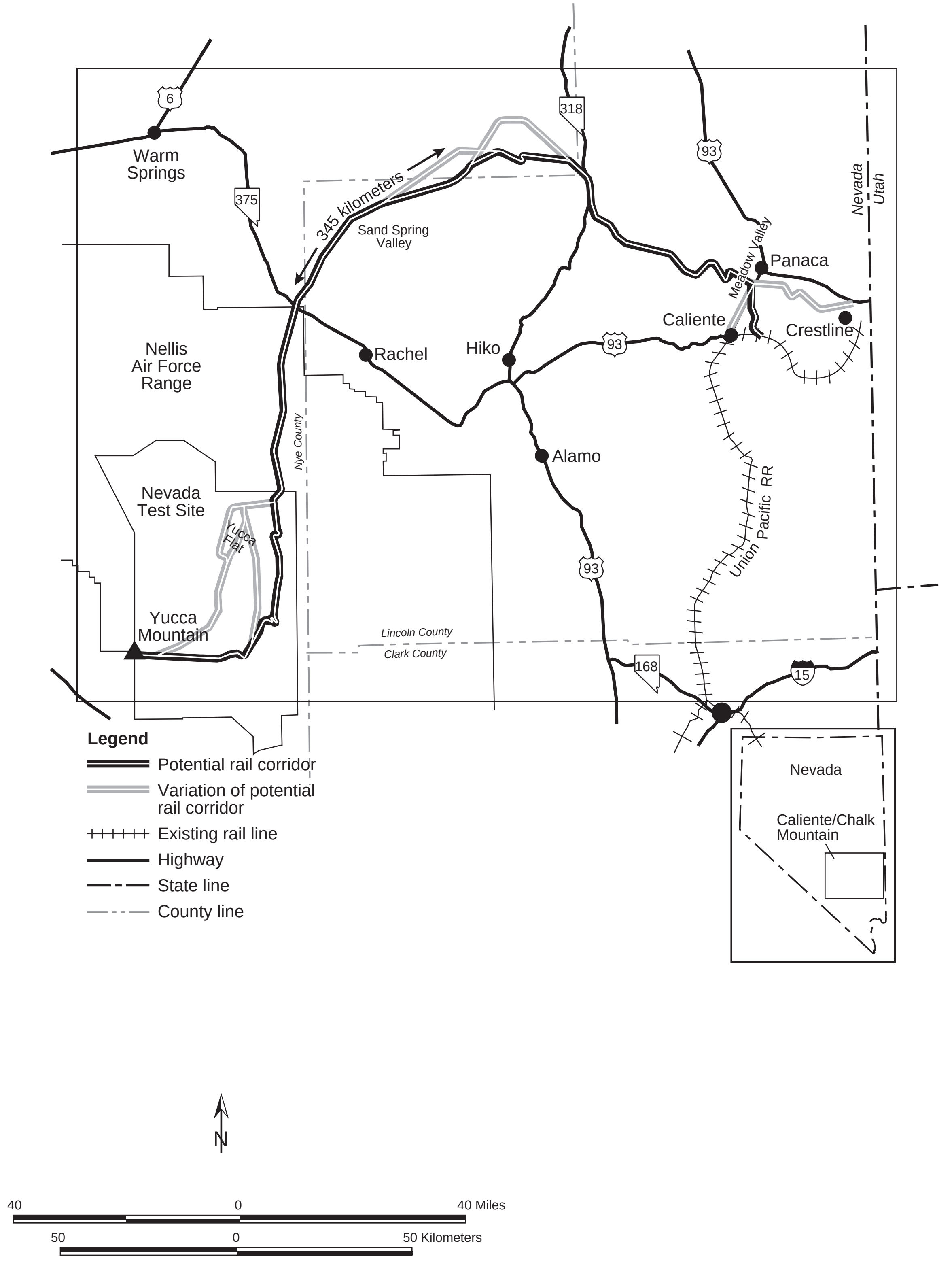
Construction. Table 6-31 summarizes the amount of land required for the Caliente-Chalk Mountain corridor, its ownership, and the estimated amount of land that would be disturbed.

The Caliente-Chalk Mountain corridor would involve several road, power line, and utility rights-of-way before it entered the Nellis Air Force Range and then the Nevada Test Site. Variations of the corridor alignment would provide flexibility to address engineering, land-use, or environmental constraints due to Nevada

Table 6-31. Land use in the Caliente-Chalk Mountain rail corridor.

Factor	Amount
Corridor length (kilometers)[a]	345
Land area in 400-meter[b]-wide corridor (square kilometers)[c]	140
Land ownership [square kilometers (percent)]	
BLM	76 (55)[d]
Air Force	22 (16)
DOE	40 (29)
Private	0.8 (0.6)
Other	None
Disturbed land (square kilometers)	
Inside corridor	10
Outside corridor	2

a. To convert kilometers to miles, multiply by 0.62137.
b. 400 meters = about 0.25 miles.
c. To convert square kilometers to acres, multiply by 247.1.
d. Percentages do not total 100 due to rounding.



To convert kilometers to miles, multiply by 0.62137.

Source: Modified from DOE (1998f, all).

Figure 6-13. Caliente-Chalk Mountain rail corridor.

Test Site surface areas and associated facilities and radiologically contaminated areas. The corridor would also cross five oil and gas leases.

The Caliente-Chalk Mountain corridor would involve the most land controlled by the Nellis Air Force Range, which, according to the Air Force, would affect Air Force operations. Because Public Law 99-606 withdrew and reserved the Nellis Air Force Range for use by the Secretary of the Air Force, the Secretary would need to concur with a decision to build and operate a branch rail line through the Range before DOE could build and operate this line. The Air Force has identified national security issues related to a Chalk Mountain route (Henderson 1997, all), citing interference with Nellis Air Force Range testing and training activities. In response to Air Force concerns, DOE regards the route as a "non-preferred alternative."

Hydrology

Surface Water

Chapter 3, Section 3.2.2, discusses surface-water resources along the Caliente-Chalk Mountain corridor; Table 6-32 summarizes these resources. As discussed in Section 6.3.2.1, impacts during construction or operations from the possible spread of construction-related materials by precipitation or intermittent runoff events, releases to surface waters, and the alteration of natural drainage patterns or runoff rates that could affect downgradient resources would be unlikely.

Table 6-32. Surface-water resources along Caliente-Chalk Mountain corridor.[a,b]

Resources in 400-meter[c] corridor			Resources outside corridor within 1 kilometer[d]		
Spring	Stream/ riparian area	Reservoir	Spring	Stream/ riparian area	Reservoir
--[e]	2	--	6	--	--

a. Source: reduced from Table 3-35.

b. Resources are the number of locations; that is, a general location with more than one spring was counted as one water resource.

c. 400 meters = about 0.25 mile.

d. 1 kilometer = about 0.6 mile.

e. -- = none.

Groundwater

Construction. The water used during construction would come largely from groundwater resources. The annual demands would be a fraction of the perennial yields of most producing aquifers (Chapter 3, Section 3.2.2.1.3, discusses estimated perennial yields for the hydrographic areas over which the Caliente-Chalk Mountain rail corridor passes).

The estimated amount of water needed for construction of a rail line in the corridor for soil compaction and dust control would be about 594,000 cubic meters (480 acre-feet) (LeFever 1998a, all). For planning purposes, DOE assumed that this water would come from 43 wells installed along the corridor. The average amount of water withdrawn from each well would be approximately 14,000 cubic meters (11 acre-feet).

Chapter 3, Section 3.2.2.1.3, discusses the hydrographic areas over which the corridor would pass, their perennial yields, and if the State of Nevada considers each a Designated Groundwater Basin. If the hydrographic area is a Designated Groundwater Basin, permitted groundwater rights approach or exceed the estimated perennial yield, depleting the basin and water resources or requiring additional administration. Table 6-33 summarizes the status of the hydrographic areas associated with the Caliente-Chalk Mountain rail corridor and the approximate portion of the corridor that passes over Designated Groundwater Basins.

Table 6-33. Hydrographic areas along Caliente-Chalk Mountain rail corridor.

	Designated Groundwater Basins	
Hydrographic areas	Number	Percent of corridor length
11	2	30

The withdrawal of about 14,000 cubic meters (11 acre-feet) a year from a well would have little impact on the hydrographic areas associated with the corridor based on their perennial yields (Chapter 3, Section 3.2.2.1.3). However, the installation of 43 wells along the corridor would mean that many hydrographic areas would have multiple wells. As listed in Table 6-33, about 30 percent of the corridor length is over Designated Groundwater Basins, which the Nevada State Engineer's office watches carefully for groundwater depletion. This does not mean that DOE could not obtain water appropriations in these areas; the State Engineer would have the authority to approve such appropriations. Because the DOE requests would be for a short-term construction action, the State Engineer would have even more discretion. Rather than spacing the wells evenly along the corridor, DOE could use well locations that would make maximum use of groundwater areas that are not Designated Groundwater Basins. Another option would be to lease temporary water rights from individuals along the corridor. Obtaining a water appropriation from the State Engineer for short-term construction use or using an approved allocation should ensure that groundwater resources did not receive adverse impacts.

As an alternative, DOE could transport water by truck to meet construction needs. The construction of a branch rail line in the Caliente-Chalk Mountain corridor would require about 32,000 tanker-truck loads of water or about eight truckloads each day for each work camp area along the corridor. Again, water obtained from permitted sources, which would provide water in allocations determined by the Nevada State Engineer, would not affect groundwater resources.

Operations. Operations along a completed rail line would have little impact on groundwater resources. Possible changes in recharge, if any, would be the same as those at the completion of construction.

Biological Resources and Soils

Construction. The construction of a rail line in the Caliente-Chalk Mountain corridor would disturb about 12 square kilometers (3,000 acres) of land (Table 6-31). About 40 kilometers (25 miles) of the corridor length at its southern end crosses desert tortoise habitat. Assuming that 0.06 square kilometer (15 acres) would be disturbed for each linear kilometer of railroad, construction activities would disturb about 2.4 square kilometers (590 acres) of desert tortoise habitat. Such activities could kill individual desert tortoises; however, their abundance is low in this area (Rautenstrauch and O'Farrell 1998, pages 407 to 411) so losses would be few. This corridor crosses a portion of the Meadow Valley Wash, which is habitat for an unnamed subspecies of the Meadow Valley Wash speckled dace and the Meadow Valley Wash desert sucker (see Chapter 3, Section 3.2.2.1.4). The construction of a branch rail line near Caliente could temporarily affect populations of these fish by increasing the sediment load in the wash during construction. Three special status plant species are found along this route but could be avoided during land-clearing activities and should not be affected.

This rail corridor would cross six areas designated as game habitat and two areas designated as wild horse or wild horse and burro management areas. Construction activities would reduce habitat in these areas. Game animals, burros, and horses near areas of active construction would be disturbed and their migration routes could be disrupted.

Two riparian areas are within the 0.4-kilometer (0.25-mile)-wide corridor (Table 6-32). Although no formal delineations have been conducted, these areas may be jurisdictional wetlands or other waters of the United States. Construction could increase sedimentation in these areas. The corridor also crosses a number of ephemeral streams that may be classified as waters of the United States. DOE would work with the U.S. Army Corps of Engineers to minimize impacts to these areas and would obtain individual or regional permits if necessary.

Soils in and adjacent to the corridor would be disturbed on approximately 12 square kilometers (3,000 acres) of land. The impacts of disturbing 12 square kilometers of soil along the 345-kilometer (214-mile)-long corridor would be transitory and small.

Operations. Impacts from operations would include periodic disturbances of wildlife from passing trains and from personnel servicing the corridor. Trains probably would kill individuals of some species but losses would be unlikely to affect regional populations of any species. No additional habitat loss would occur during operations. Impacts on soils would be small.

Occupational and Public Health and Safety

Construction. Industrial safety impacts on workers from the construction and use of the Caliente-Chalk Mountain branch rail line would be small (Table 6-34). The analysis evaluated the potential for impacts in terms of total reportable cases of injury, lost workday cases, and fatalities to workers and the public from construction and operation activities. The analysis also evaluated traffic fatality impacts that would occur in moving equipment and materials for construction, worker commutes to and from construction sites, and transport of water to construction sites if wells were not available. Table 6-35 lists these results.

Table 6-34. Impacts to workers from industrial hazards during rail construction and operations for the Caliente-Chalk Mountain corridor.

Group and industrial hazard category	Construction[a]	Operations[b]
Involved workers		
Total recordable cases[c]	80	120
Lost workday cases	40	68
Fatalities	0.8	0.23
Noninvolved workers		
Total recordable cases	5	6
Lost workday cases	3	3
Fatalities	0.01	0.01
Totals[d]		
Total recordable cases	85	130
Lost workday cases	43	71
Fatalities	0.8	0.23

a. Totals for 2.5 years for construction.
b. Totals for 24 years for operations.
c. Total recordable cases includes injury and illness.
d. Totals might differ from sums due to rounding.

Operations. Incident-free radiological impacts would occur during the routine transportation of spent nuclear fuel and high-level radioactive waste in the Caliente-Chalk Mountain rail corridor.

Table 6-36 lists the incident-free impacts, which include transportation along the corridor and along railways in Nevada leading to a Caliente-Chalk Mountain branch line. The table includes the impacts of 2,600 legal-weight truck shipments from commercial sites that do not have the capability to load rail casks.

Table 6-35. Estimated number of fatalities from construction material delivery vehicles and construction and operations worker commuting traffic for the Caliente-Chalk Mountain rail corridor.

Activity	Kilometers[a]	Traffic fatalities	Emissions fatalities
Construction[b]			
Material delivery vehicles	13,000,000	0.2	0.001
Commuting workers	61,000,000	0.6	0.0044
Subtotals	*74,000,000*	*0.8*	*0.0049*
Operations[c]			
Commuting workers	68,000,000	0.7	0.005
Totals	***142,000,000***	***1.5***	***0.01***

a. To convert kilometers to miles, multiply by 0.62137.
b. Totals for 2.5 years for construction.
c. Totals for 24 years for operations.

Table 6-36. Health impacts from incident-free Nevada transportation for the Caliente-Chalk Mountain implementing alternative.[a]

Category	Legal-weight truck shipments	Rail shipments	Totals[b]
Involved workers			
Collective dose (person-rem)	220	170	390
Estimated latent cancer fatalities	0.09	0.07	0.16
Public			
Collective dose (person-rem)	270	110	380
Estimated latent cancer fatalities	0.13	0.06	0.19
Estimated vehicle emission-related fatalities	0.00014	0.0016	0.0017

a. Impacts are totals for 24 years (2010 to 2033).

b. Totals might differ from sums of values due to rounding.

Socioeconomics

Construction. There would be socioeconomic impacts associated with the construction of a branch rail line in the Caliente-Chalk Mountain corridor. The length of the corridor, 345 kilometers (214 miles), determines the number of workers that would be required. The construction of a branch rail line in this corridor would require 400 workers and four construction camps (TRW 1999d, Rail Files, Item 1).

Based on analyses it conducted using the Regional Economic Models, Inc., system (REMI 1999, all), DOE anticipates that the total direct and indirect construction employment would peak in 2007 at about 910. Population increases in Nevada from construction, which would lag behind increases in employment, would be likely to peak two years later in 2009. The increase in population attributable to the Caliente-Chalk Mountain corridor would be about 640. Real disposable income, Gross Regional Product, and State and local government expenditures would rise. The expected peak year changes for a branch rail line in the Caliente-Chalk Mountain corridor would be increases of $19.2 million in real disposable income, $34.9 million in Gross Regional Product, and $1.9 million in State and local expenditures. (All dollar values reported in this section are in 1992 constant dollars unless otherwise stated.)

The impacts to employment, population, real disposable income, Gross Regional Product, and State and local government expenditures for constructing a branch rail line in the Caliente-Chalk Mountain corridor would be low for Clark and Nye Counties, as would increases in population in Lincoln County. Impacts to employment, real disposable income, and Gross Regional Product in Lincoln County would be moderate compared to baseline values ranging from 1 percent to 5.7 percent of the baseline. Although these impacts would be moderate in Lincoln County, they would not exceed historic short-term changes in growth.

Operations. Estimated employment for operations in the Caliente-Chalk Mountain corridor would be 47. The estimated peak total direct and indirect employment from these operations would be about 120.

The greatest estimated real disposable income increase attributable to the operation of the Caliente-Chalk Mountain branch line, which was projected to occur in 2033, would be $4.9 million. The increase in Gross Regional Product in 2029, the year in which increases would be greatest as a percentage of the baseline, would be $8.6 million. Annual State and local government expenditures would be much lower than those for construction.

The impacts to employment, population, real disposable income, Gross Regional Product, and State and local government expenditures from operating a Caliente-Chalk Mountain branch rail line would be low for Clark and Nye Counties. Impacts to employment, population, real disposable income, State and local government expenditures, and Gross Regional Product in Lincoln County would be moderate compared to baseline values ranging from about 1.5 percent to 6.4 percent of the baseline. These impacts would be moderate for Lincoln County; they would not exceed historic short-term changes in growth.

Noise

Almost half of the Caliente-Chalk Mountain corridor is on Nellis Air Force Range and Nevada Test Site land, where community response to noise would not be an issue. The communities of Caliente and Panaca could be affected. Because the corridor passes through or near these communities, it could have noise impacts from both construction and operation.

Utilities, Energy, and Materials

Table 6-37 lists the use of fossil fuels and other materials in the construction of a Caliente-Chalk Mountain branch rail line.

Table 6-37. Construction utilities, energy, and materials for a Caliente-Chalk Mountain branch rail line.

Length (kilometers)[a]	Diesel fuel use (million liters)[b]	Gasoline use (thousand liters)	Steel (thousand metric tons)[c]	Concrete thousand metric tons)
345	33	630	48	280

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. To convert metric tons to tons, multiply by 1.1023.

6.3.2.2.4 *Jean Rail Corridor Implementing Alternative*

The Jean corridor originates at the existing Union Pacific mainline railroad near Jean, Nevada. It travels northwest, passing near the Towns of Pahrump and Amargosa Valley before reaching the Yucca Mountain site. The corridor is about 181 kilometers (112 miles) long from its link at the Union Pacific line to the site. Figure 6-14 shows the alignment of this corridor along with possible variations identified by engineering studies (TRW 1999d, page 1, Item 6). The alignment variations provide flexibility in addressing engineering, land-use, or environmental resource issues that could arise in a future, more detailed survey along the corridor. Appendix J assesses the attributes of these alignment variations. This section addresses impacts that would occur along the corridor alignment shown in Figure 6-14. With the exception of differences identified in Appendix J, the impacts would be generally the same among the possible corridor alignments.

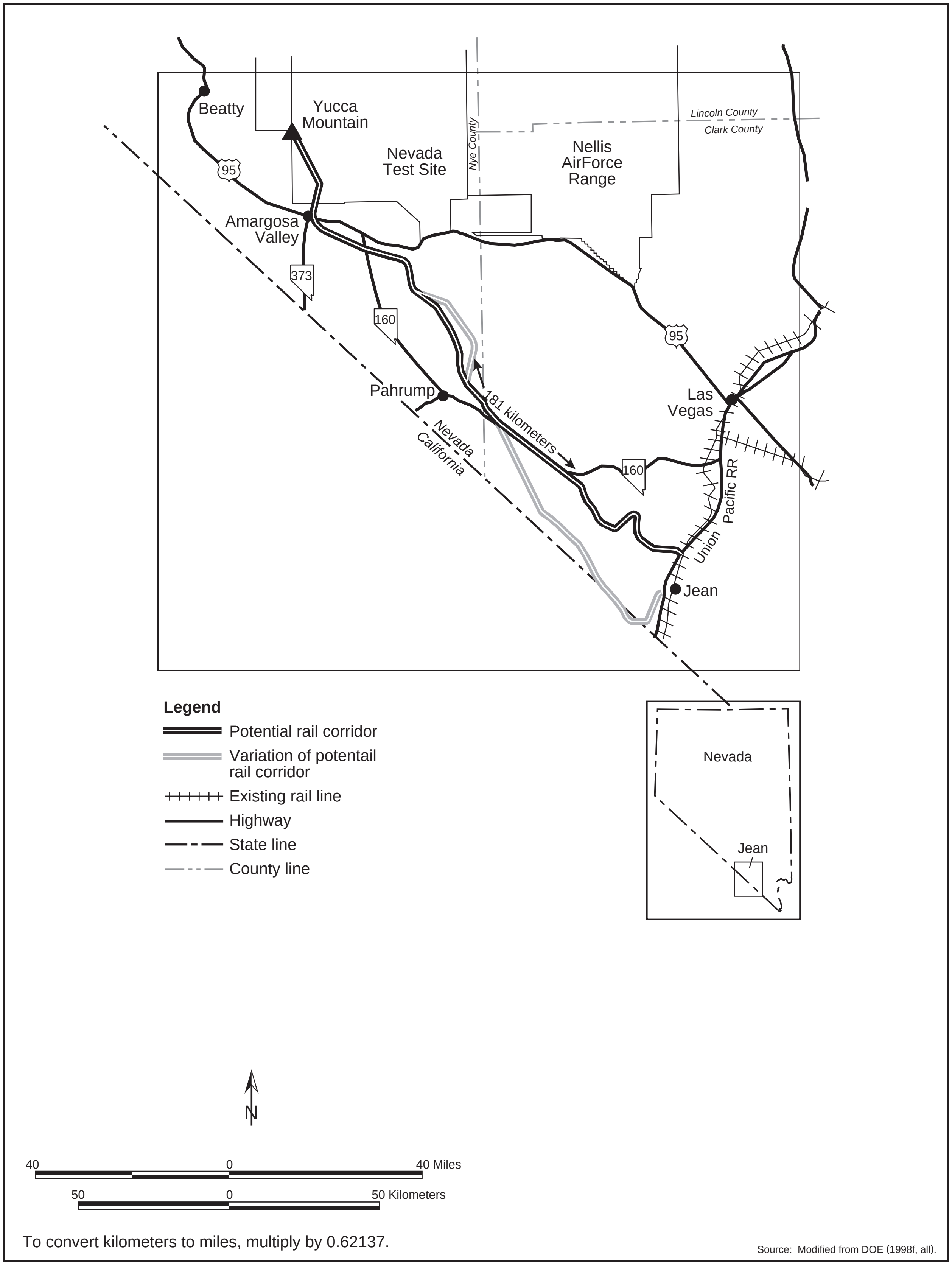
The construction of a branch rail line in the corridor would require approximately 2.5 years. Construction would take place simultaneously at a number of locations. An estimated two construction camps would be established at roughly equal distances along the corridor. These camps would provide temporary living accommodations for construction workers and construction support facilities.

The following sections address impacts that would occur to land use; biological resources and soils; hydrology, including surface water and groundwater; occupational and public health and safety; socioeconomics; noise; and utilities, energy, and materials. Impacts that would occur to air quality, cultural resources, aesthetics, and waste management would be the same as those discussed in Section 6.3.2.1 and are, therefore, not repeated here. Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.

Land Use and Ownership

Construction. Table 6-38 summarizes the amount of land required for the Jean corridor, its ownership, and the estimated amount of land that would be disturbed.

The corridor crosses eight Bureau of Land Management grazing allotments (Mount Stirling, Spring Mountain, Stump Springs, Table Mountain, Wheeler Wash, and three unnamed and unallotted areas); two wild horse and burro herd management areas (both in Pahrump Valley); the Old Spanish Trail/Mormon Road special recreation management area; and four areas designated as available for sale or transfer. It



To convert kilometers to miles, multiply by 0.62137.

Source: Modified from DOE (1998f, all).

Figure 6-14. Jean rail corridor.

Table 6-38. Land use in the Jean rail corridor.

Factor	Amount
Corridor length (kilometers)[a]	181
Land area in 400-meter[b]*-wide corridor (square kilometers)*[c]	72
Land ownership [square kilometers (percent)]	
Bureau of Land Management	60 (83)
Air Force	None
DOE	8.5 (12)
Private	3.6 (5)
Other	None
Disturbed land (square kilometers)	
Inside corridor	6.5
Outside corridor	2.5

a. To convert kilometers to miles, multiply by 0.62137.
b. 400 meters = about 0.25 mile.
c. To convert square kilometers to acres, multiply by 247.1.

also crosses several telephone, pipeline, highway, and power line rights-of-way. It is within 1.6 kilometers (1 mile) of the Toiyabe National Forest and three mines (Bluejay, Snowstorm, and Pilgram). In the vicinity of Pahrump, a rail line in the Jean corridor could conflict with town growth.

During the construction and operation and monitoring phases of the Proposed Action, there would be a potential for encroachment of the Jean rail corridor by private interest. If encroachment occurred, conflicts could result as impediments to the full use of the land. Areas most likely for use by private interests are those already privately owned and those that are currently designated for sale or transfer by the Bureau of Land Management.

If DOE decided to build and operate a branch rail line in the Jean corridor, it would consult with the Bureau of Land Management and other affected agencies to help ensure that it avoided or mitigated potential land-use conflicts associated with alignment of a right-of-way.

Based on currently available information, DOE is not aware of any conflicts with existing or planned land uses that would occur as a result of construction of a branch rail line in the Jean corridor. Although there are no known community development plans that would conflict with the rail line, the presence of a rail line could influence future development and land use along the railroad in the communities of Amargosa Valley, Goodsprings, Jean, Johnnie, and Pahrump (that is, zoning and land use might differ depending on the presence or absence of a railroad). Construction of a branch rail line within the Jean corridor would require conversion of land within existing grazing allotments and wild horse or wild horse and burro management areas; however, because the railroad would be unlikely to interfere with animal movements, the functionality of these areas would not be affected.

Operations. Rail corridor operations would involve the same land-use and ownership considerations discussed above for construction. No unique impacts for operations were identified.

Hydrology

Surface Water

Chapter 3, Section 3.2.2, notes that there are no surface-water resources along the Jean rail corridor.

Groundwater

Construction. The water used during construction would come largely from groundwater resources. The annual demands would be a fraction of the perennial yields of most producing aquifers (Chapter 3, Section 3.2.2.1.3, discusses estimated perennial yields for the hydrographic areas over which the Jean corridor passes).

The estimated amount of water needed for construction of a rail line in the corridor for soil compaction and dust control would be about 500,000 cubic meters (410 acre-feet) (LeFever 1998a, all). For planning purposes, DOE assumed that this water would come from 23 wells installed along the corridor. The average amount of water withdrawn from each well would be approximately 22,000 cubic meters (18 acre-feet).

Chapter 3, Section 3.2.2.1.3, discusses the hydrographic areas over which the corridor would pass, their perennial yields, and whether the State of Nevada considers each a Designated Groundwater Basin. If the hydrographic area is a Designated Groundwater Basin, permitted groundwater rights approach or exceed the estimated perennial yield, depleting the basin and water resources or requiring additional administration. Table 6-39 summarizes the status of the hydrographic areas associated with the Jean rail corridor and the approximate portion of the corridor that passes over Designated Groundwater Basins.

Table 6-39. Hydrographic areas along Jean rail corridor.

Hydrographic areas	Designated Groundwater Basins Number	 Percent of corridor length
6	5	90

The withdrawal of 22,000 cubic meters (18 acre-feet) a year from a well would have little impact on the hydrographic areas associated with the corridor based on their perennial yields (Chapter 3, Section 3.2.2.1.3). However, the installation of 23 wells along the corridor would mean that several of the hydrographic areas would have multiple wells. As indicated in Table 6-39, about 90 percent of the corridor length is over Designated Groundwater Basins, which the Nevada State Engineer's office watches carefully for groundwater depletion. This does not mean that DOE could not obtain water appropriations in these areas; the State Engineer would have the authority to approve such appropriations. Because the DOE requests would be for a short-term construction action, the State Engineer would have even more discretion. Rather than spacing the wells evenly along the corridor, DOE could use locations that would make maximum use of groundwater areas that are not Designated Groundwater basins. With such a large portion of the corridor over these basins, however, this would mean trucking water for long distances. Another option would be to lease temporary water rights from individuals along the corridor. Obtaining a water appropriation from the State Engineer for short-term construction use or using an approved allocation should ensure that groundwater resources are not adversely affected.

As an alternative, DOE could transport water by truck to meet construction needs. The construction of a branch rail line in the Jean corridor would require about 27,000 tanker-truck loads of water or about 14 truckloads each day for each work camp area along the corridor. Again, water obtained from permitted sources, which would provide water within allocations determined by the Nevada State Engineer, would not affect groundwater resources.

Operations. Operations along a completed rail line would have little impact on groundwater resources. Possible changes in recharge, if any, would be the same as those at the completion of construction.

Biological Resources and Soils

Construction. Approximately 9 square kilometers (2,200 acres) of land would be disturbed during the construction of a rail line in the Jean corridor (Table 6-38). This corridor passes through desert tortoise habitat along its entire length, so construction activities would disturb approximately 9 square kilometers of desert tortoise habitat. Construction activities could kill individual desert tortoises. Desert tortoise abundance is low along much of this corridor; however, some areas in the Ivanpah, Goodsprings, Mesquite, and Pahrump Valleys have higher abundance (BLM 1992, Map 3-13; Rautenstrauch and O'Farrell 1998, pages 407 to 411). Two other special status species are found along this route but could be avoided during land-clearing activities and should not be affected.

This rail corridor crosses ten areas designated as game habitat and three areas designated as wild horse and burro management areas (TRW 1999k, page 3-28). Construction activities would reduce habitat in these areas. Wild horses, burros, and game animals near these areas during construction would be disturbed and their migration routes could be disrupted.

No springs, perennial streams, or riparian areas occur along this corridor. The corridor crosses a number of ephemeral streams that may be waters of the United States, although no formal delineations have been conducted (TRW 1999k, page 3-29). DOE would work with the U.S. Army Corps of Engineers to minimize impacts to these areas and would obtain individual or regional permits if necessary.

Soils in and adjacent to the corridor would be disturbed on approximately 9 square kilometers (2,200 acres) during construction of a railroad. This impact to soils along the 181-kilometer (110-mile)-long corridor would be transitory and small.

Operations. Impacts from operations would include periodic disturbances of wildlife from passing trains and from personnel servicing the corridor. Trains probably would kill individuals of some species but losses would be unlikely to affect regional populations of any species. No additional habitat loss would occur during operations. Impacts on soils would be small.

Occupational and Public Health and Safety

Construction. Industrial safety impacts on workers from the construction and use of the Jean branch rail line would be small (Table 6-40). The analysis evaluated the potential for impacts in terms of total reportable cases of injury, lost workday cases, and fatalities to workers from construction and operation activities. The analysis also evaluated traffic fatality impacts that would occur during the moving of equipment and materials for construction, worker commutes to and from construction sites, and transport of water to construction sites if wells were not available. Table 6-41 lists these results.

Table 6-40. Impacts to workers from industrial hazards during rail construction and operations for the Jean corridor.

Group and industrial hazard category	Construction[a]	Operations[b]
Involved workers		
Total recordable cases[c]	68	95
Lost workday cases	34	52
Fatalities	0.7	0.2
Noninvolved workers		
Total recordable cases	4	4
Lost workday cases	2	2
Fatalities	0	0
Totals		
Total recordable cases	72	99
Lost workday cases	36	54
Fatalities	0.7	0.2

a. Totals for 2.5 years for construction.
b. Totals for 24 years for operations.
c. Total recordable cases includes injury and illness.

Operations. Incident-free radiological impacts would occur during the routine transportation of spent nuclear fuel and high-level radioactive waste in using the Jean rail corridor. Table 6-42 lists the incident-free impacts, which include transportation along the corridor and along railways in Nevada leading to a Jean branch line. The table includes the impacts of 2,600 legal-weight truck shipments from commercial sites that do not have the capability to load rail casks.

Table 6-41. Estimated number of fatalities from construction material delivery vehicles and construction and operations worker commuting traffic for the Jean rail corridor.

Jean	Kilometers[a]	Traffic fatalities	Emissions fatalities
Construction[b]			
Materials delivery vehicles	10,000,000	0.2	0.00072
Commuting workers	52,000,000	0.5	0.0038
Subtotals	*62,000,000*	*0.7*	*0.0045*
Operations[c]			
Commuting workers	52,000,000	0.5	0.0038
Totals	***114,000,000***	***1.2***	***0.0082***

a. To convert kilometers to miles, multiply by 0.62137.
b. Totals for 2.5 years for construction.
c. Totals for 24 years for operations.

Table 6-42. Health impacts from incident-free Nevada transportation for the Jean corridor implementing alternative.[a]

Category	Legal-weight truck shipments	Rail shipments	Totals[b]
Involved workers			
Collective dose (person-rem)	220	180	400
Estimated latent cancer fatalities	0.09	0.07	0.16
Public			
Collective dose (person-rem)	270	160	430
Estimated latent cancer fatalities	0.13	0.08	0.21
Estimated vehicle emission-related fatalities	0.00014	0.014	0.014

a. Impacts are totals for 24 years (2010 to 2033).

b. Totals might differ from sums of values due to rounding.

Socioeconomics

Construction. There would be socioeconomic impacts associated with the construction of a branch rail line in the Jean corridor. The projected length of the corridor, 181 kilometers (112 miles), determines the number of workers that would be required. The construction of a branch rail line in this corridor would require about 340 workers and 2 construction camps (TRW 1999d, Rail Files, Item 1).

DOE anticipates that the total direct and indirect employment would peak in 2007 at about 720. Population increases in Nevada, which would lag behind increases in employment, would be likely to peak in 2009. The estimated increase attributed to the Jean corridor would be about 530. Real disposable income, Gross Regional Product, and State and local government expenditures would also rise. The expected changes would be increases of about $16.3 million in real disposable income, about $29 million in Gross Regional Product, and about $1.4 million in State and local expenditures. (All dollar values reported in this section are in 1992 constant dollars unless otherwise stated.)

The impacts to employment, population, real disposable income, Gross Regional Product, and State and local government expenditures for constructing a branch rail line in the Jean corridor would be low for all counties affected.

Operations. Estimated employment for operations in the Jean corridor would be 36. The total estimated direct and indirect employment from these operations would be about 70.

The greatest estimated real disposable income increase attributable to the operation of a Jean branch line would occur in 2024 and would be about $3.1 million. The increase in Gross Regional Product in 2025, the year in which impacts would be greatest, would be about $6.0 million. Annual State and local government expenditures would be much lower than those reported for construction.

The impacts to employment, population, real disposable income, Gross Regional Product, and State and local government expenditures from operating a Jean branch rail line would be low for all counties affected.

Noise

The Jean corridor would pass the small communities of Amargosa Valley, Goodsprings, Jean, and Pahrump. In addition, the potential for development in the Las Vegas area and the fact that the corridor passes through private land could lead to noise impacts during both construction and operation because of the relatively large number of potential nearby inhabitants.

Utilities, Energy, and Materials

Table 6-43 lists the use of fossil fuels and other materials in the construction of a Jean branch rail line.

Table 6-43. Construction utilities, energy, and materials for a Jean branch rail line.

Route	Length (kilometers)[a]	Diesel fuel use (million liters)[b]	Gasoline use (thousand liters)	Steel (thousand metric tons)[c]	Concrete (thousand metric tons)
Jean	181	26	500	26	150

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. To convert metric tons to tons, multiply by 1.1023.

6.3.2.2.5 *Valley Modified Rail Corridor Implementing Alternative*

The Valley Modified corridor originates near the existing Apex rail siding off the Union Pacific mainline railroad. It travels northwest passing north of the City of Las Vegas, north of the Town of Indian Springs, parallel to U.S. 95 before entering the southwest corner of the Nevada Test Site and reaching the Yucca Mountain site. The corridor is about 159 kilometers (98 miles) long from its link with the Union Pacific line to the site. Figure 6-15 shows the alignment of this corridor along with possible variations identified by engineering studies (TRW 1999d, page 1, Item 6). The alignment variations provide flexibility in addressing engineering, land-use, or environmental resource issues that could arise in a future, more detailed survey along the corridor. Appendix J assesses the attributes of these alignment variations. This section addresses impacts that would occur along the corridor alignment shown in Figure 6-15. With the exception of differences identified in Appendix J, the impacts would be generally the same among the possible corridor alignments.

The construction of a branch rail line in the corridor would require approximately 2.5 years. Construction would take place simultaneously at a number of locations along the corridor. Two construction camps would be established to provide temporary living accommodations for construction workers and construction support facilities.

The following sections address impacts that would occur to land use; air quality; biological resources and soils; hydrology including surface water and groundwater; cultural resources; occupational and public health and safety; socioeconomics; noise; and utilities, energy, and materials. Impacts that would occur to aesthetics, and waste management would be the same as those discussed in Section 6.3.2.1 and are, therefore, not repeated here. Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.

Land Use and Ownership

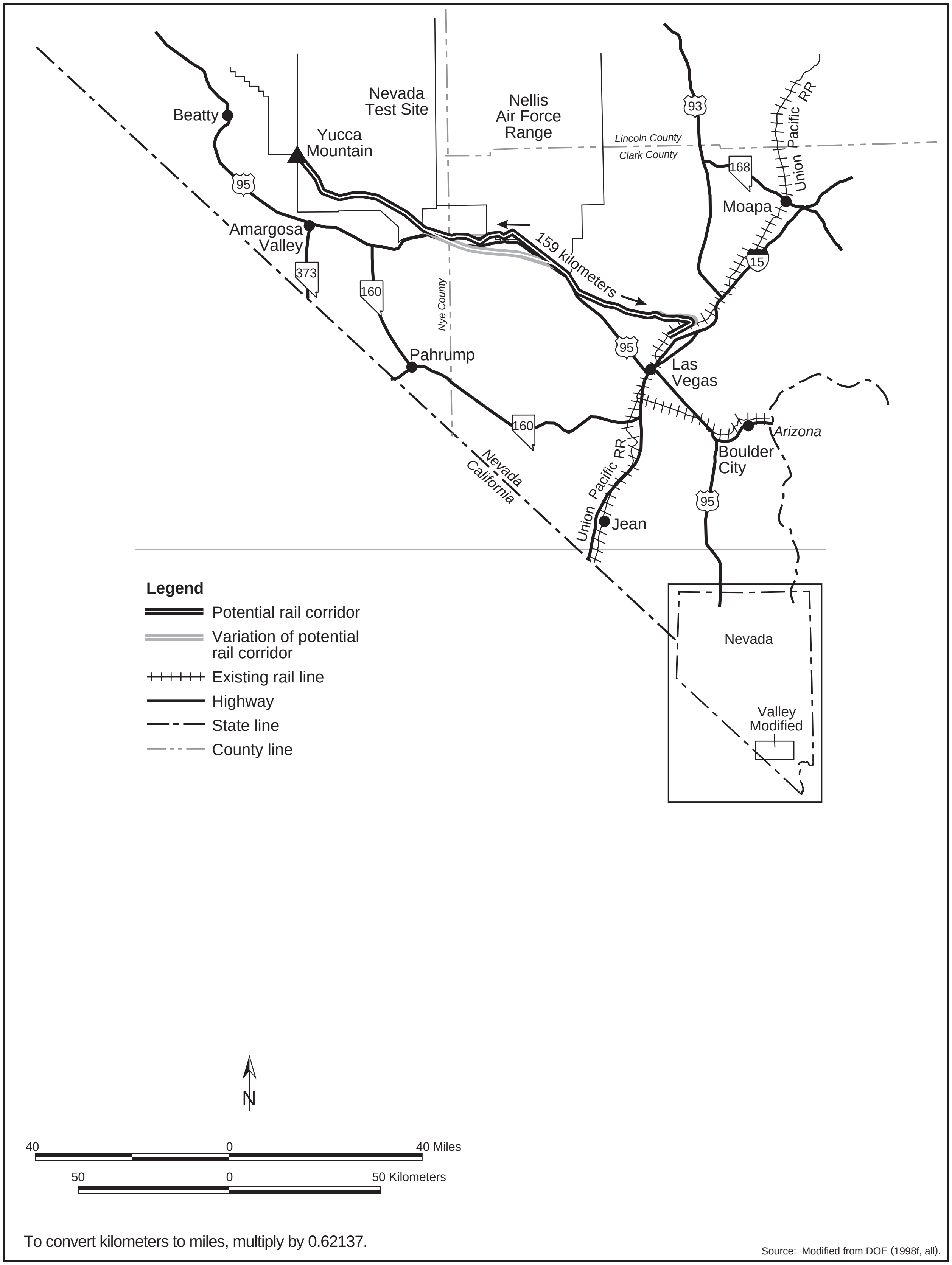
Construction. Table 6-44 summarizes the amount of land required for the Valley Modified corridor, its ownership, and the estimated amount of land that would be disturbed.

The corridor crosses three Bureau of Land Management grazing allotments (Wheeler Slope, Indian Springs, and Las Vegas Valley), two wilderness study areas (Nellis ABC and Quail Spring, both recommended by the Bureau as unsuitable for inclusion in the National Wilderness System), and one area designated as available for sale or transfer (TRW 1999f, Table 7). It also crosses several telephone, pipeline, highway, and power line rights-of-way, and the Nellis Air Force Base small arms range.

Table 6-44. Land use in the Valley Modified rail corridor.

Factor	Amount
Corridor length (kilometers)[a]	159
Land area in 400-meter[b]*-wide corridor (square kilometers)*[c]	64
Land ownership [square kilometers (percent)]	
Bureau of Land Management	32 (50)
Air Force	10 (15)
DOE	21 (35)
Private	None
Other	None
Disturbed land (square kilometers)	
Inside corridor	4.4
Outside corridor	0.6

a. To convert kilometers to miles, multiply by 0.62137.
b. 400 meters = about 0.25 mile.
c. To convert square kilometers to acres, multiply by 247.1.



To convert kilometers to miles, multiply by 0.62137.

Source: Modified from DOE (1998f, all).

Figure 6-15. Valley Modified rail corridor.

The corridor also passes along the Las Vegas metropolitan area's northern boundary, in an area that is currently undergoing growth and where future commercial and residential growth might occur. However, metropolitan area growth might not extend to the corridor area until after the operations phase of the repository when there would no longer be a need for a branch rail line. The corridor also passes within about 1.6 kilometers (1 mile) of the Las Vegas Paiute Indian Reservation north of Las Vegas.

During the construction and operation and monitoring phases of the Proposed Action, there would be a potential for encroachment of the Valley Modified rail corridor by private interests. If encroachment occurred, conflicts could result as impediments to the full use of lands. Areas most likely for use by private interests are those currently designated for sale or transfer by the Bureau of Land Management.

If DOE decided to build and operate a branch rail line in the Valley Modified corridor, it would consult with the Bureau of Land Management, U.S. Air Force, other affected agencies, and other DOE program operations on the Nevada Test Site to help ensure that it avoided or mitigated potential land-use conflicts associated with alignment of a right-of-way.

Based on currently available information, DOE is not aware of any conflicts with existing or planned land uses that would occur as a result of construction of a branch rail line in the Valley Modified corridor. Although there are no known community development plans that would conflict with the rail line, the presence of a rail line could influence future development and land use along the railroad in the communities of Indian Springs and North Las Vegas (that is, zoning and land use might differ depending on the presence or absence of a railroad). Construction of a branch rail line within the Valley Modified corridor would require conversion of land within existing grazing allotments and wild horse or wild horse and burro management areas; however, because the railroad would be unlikely to interfere with animal movements, the functionality of these areas would not be affected.

Operations. Rail corridor operations would involve the same land-use and ownership considerations discussed above for construction. No unique impacts for operations were identified.

Air Quality

Construction. The Valley Modified rail corridor would involve construction in the Las Vegas Valley airshed, which is in nonattainment for particulate matter (PM_{10}) and carbon monoxide (FHWA 1996, pages 3-53 and 3-54). To assess nonradiological air quality impacts from branch line construction in this airshed, DOE reviewed the environmental impact statement that Clark County prepared for the construction of the Northern and Western Las Vegas Beltway project.

An evaluation of environmental impacts of the construction of the Las Vegas Beltway observed that Federal air quality conformity criteria require that "[t]he project must not cause or contribute to new violations and/or increase the severity of existing carbon monoxide and PM_{10} violations" (FHWA 1996, page 4-38). The EIS for the Las Vegas Beltway project commented that "the study area is largely undeveloped at this time. Carbon monoxide Urban Airshed Modeling by the Clark County Department of Comprehensive Planning has shown that the area substantially affected by the project has low existing ambient carbon monoxide concentration levels."

In relation to PM_{10}, the Clark County EIS states (FHWA 1996, page 4-38):

> *[t]he Clark County Health District, Air Pollution Control division has an extensive array of particulate matter and fugitive dust control and mitigation regulations. Transportation facility construction in the Las Vegas Valley must comply with these Health District requirements. The Tier 2 EIS will address those dust control and mitigation measures appropriate to the facility's design concept and scope. The Health District's PM_{10} emissions control measures will be included in the final plans, specifications and estimates for the development of a facility within the selected corridor.*

The total amount of land disturbed by the construction of a branch rail line in the Valley Modified corridor would be approximately the same as that disturbed by the construction of the Northern and Western Las Vegas Beltway. As a consequence, air quality impacts from branch rail line construction activities in the Las Vegas Valley airshed would be less than those for the beltway project. If DOE selected the Valley Modified corridor for the construction and operation of a branch rail line, the final plans, specifications, and estimates would include the Clark County Health District PM_{10} emissions control measures.

Operations. Fuel consumption by diesel train engines operating along the rail corridor would emit carbon monoxide, nitrogen dioxide, and particulate matter (PM_{10} and $PM_{2.5}$). Based on the Federal standards for locomotives (EPA 1997a, page 3), there would be no significant emissions of sulfur dioxide.

In attainment areas, the pollutant concentrations in the air would increase slightly during the passage of a train, but the emissions from one or two trains a day would not exceed the ambient air quality standards. However, the Valley Modified rail corridor would include a route through the Las Vegas Valley airshed, which is in nonattainment for carbon monoxide and PM_{10}. The air quality impacts to this airshed from train operation along the Valley Modified rail corridor would be a small contribution in comparison to the amount of pollutants emitted by automotive travel in the basin. Thus, emissions from train operations in the Las Vegas Valley airshed would not produce further violations of the ambient air quality standards.

Hydrology

Surface Water

Chapter 3, Section 3.2.2, notes that there are no surface-water resources along the Valley Modified corridor.

Groundwater

Construction. The water used during construction would come largely from groundwater resources. The annual demands would be a fraction of the perennial yields of most producing aquifers (Chapter 3, Section 3.2.2.1.3, discusses estimated perennial yields for the hydrographic areas over which the Valley Modified corridor passes).

The estimated amount of water needed for construction of a rail line in the Valley Modified corridor for soil compaction and dust control would be about 395,000 cubic meters (320 acre-feet) (LeFever 1998a, all). For planning purposes, DOE assumed that this water would come from 20 groundwater wells installed along the corridor. The average amount of water withdrawn from each well would be approximately 20,000 cubic meters (16 acre-feet). Chapter 3, Section 3.2.2.1.3, discusses the hydrographic areas over which the Valley Modified rail corridor would pass, their perennial yields, and whether the State of Nevada considers each a Designated Groundwater Basin. If the hydrographic area is a Designated Groundwater Basin, permitted groundwater rights approach or exceed the estimated perennial yield, depleting the basin and water resources or requiring additional administration. Table 6-45 summarizes the designation status of the hydrographic areas associated with the Valley Modified rail corridor and the approximate portion of the corridor that passes over Designated Groundwater Basins.

Table 6-45. Hydrographic areas along Valley Modified rail corridor.

	Designated Groundwater Basins	
Hydrographic areas	Number	Percent of corridor length
6	3	70

The withdrawal of 20,000 cubic meters (16 acre-feet) a year from a well would have little impact on the hydrographic areas associated with the corridor based on their perennial yields (Chapter 3, Section 3.2.2.1.3). However, the installation of 20 wells along the corridor would mean that hydrographic areas would have multiple wells. As indicated in Table 6-45, about 70 percent of the corridor length is over Designated Groundwater Basins, which the Nevada State Engineer's office watches carefully for groundwater depletion. This does not mean that DOE could not obtain water appropriations in these areas; the State Engineer would have the authority to approve such appropriations. Because the DOE requests would be for a short-term construction action, the State Engineer would have even more discretion. Rather than spacing the wells evenly along the corridor, DOE could use locations that would make maximum use of groundwater areas that are not Designated Groundwater Basins. With such a large portion of the corridor over these basins, however, this would mean trucking water for long distances. Another option would be to lease temporary water rights from individuals along the corridor. Obtaining a water appropriation from the State Engineer for short-term construction use or using an approved allocation should ensure that groundwater resources are not adversely affected.

As an alternative, DOE could transport water by truck to meet construction needs. The construction of a branch rail line in the Valley Modified corridor would require about 21,000 tanker-truck loads of water or about 20 truckloads each day. Again, water obtained from permitted sources, which would provide water in allocations determined by the Nevada State Engineer, would not affect groundwater resources.

Operations. Operations along a completed rail line would have little impact on groundwater resources. Possible changes in recharge, if any, would be the same as those at the completion of construction.

Biological Resources and Soils

Construction. The construction of a rail line in the Valley Modified corridor would disturb approximately 5 square kilometers (1,200 acres) of land (Table 6-44). This corridor passes through desert tortoise habitat along its entire length, so construction activities would disturb approximately 5 square kilometers of desert tortoise habitat. Construction activities could kill individual desert tortoises. However, desert tortoise abundance is low along this corridor (BLM 1992, Map 3-13; Rautenstrauch and O'Farrell 1998, pages 407 to 411) so losses would be few. Populations of two special status plant species occur along the corridor but could be avoided during land-clearing activities and should not be affected.

There is one herd management area but no designated game habitat along this corridor (TRW 1999k, page 3-29). Construction activities would reduce habitat in this area. Wild horses and burros near this area during construction would be disturbed and their migration routes could be disrupted.

No springs, perennial streams, or riparian areas occur along this corridor. The corridor crosses a number of ephemeral streams that may be classified as waters of the United States, although no formal delineations have been conducted (TRW 1999k, page 3-29). DOE would work with the U.S. Army Corps of Engineers to minimize impacts to these areas and would obtain individual or regional permits, if necessary.

Soils in and adjacent to the corridor would be disturbed on approximately 5 square kilometers (1,200 acres) of land during construction of the railroad. Impacts to 5 square kilometers (1,200 acres) of soils along the 159-kilometer (99-mile)-long corridor would be transitory and small.

Operations. Impacts from operations would include periodic disturbance of wildlife from passing trains and from personnel servicing the corridor. Trains probably would kill individuals of some species but losses would be unlikely to affect regional populations of any species. No additional habitat loss would occur during operations. Impacts to soils would be small.

Cultural Resources

Construction. Because no systematic field studies have been completed for any of the rail corridors, specific impacts to culturally important sites, areas, or resources cannot be determined at this time.

The Valley Modified corridor would pass by the Las Vegas Paiute Indian Reservation in the northeastern part of the Las Vegas Valley. The corridor would not affect identified cultural resources on the reservation. If construction activities identified sites or resources important to Native Americans in the future, either in or near a right-of-way, adverse effects could occur. DOE would consult with Native American officials to develop appropriate mitigations for such impacts.

Operations. No additional direct or indirect impacts on archeological and historic sites or to Native American resources, traditional cultural properties, or ethnic cultural values from rail operation have been identified.

Occupational and Public Health and Safety

Construction. Industrial safety impacts on workers from the construction and use of the Valley Modified branch rail line would be small (Table 6-46). The analysis evaluated the potential for impacts in terms of total reportable cases of injury, lost workday cases, and fatalities to workers from construction and operation activities. The analysis also evaluated traffic fatality impacts that would occur during the moving of equipment and materials for construction, worker commutes to and from construction sites, and transport of water to construction sites if wells were not available (Table 6-47).

Operations. Incident-free radiological impacts would occur during the routine transportation of spent nuclear fuel and high-level radioactive waste in the Valley Modified rail corridor. Table 6-48 lists the incident-free impacts, which include transportation along the Valley Modified corridor and along railways in Nevada leading to a Valley Modified branch line. The table includes the impacts of 2,600 legal-weight truck shipments from commercial sites that do not have the capability to load rail casks.

Table 6-46. Impacts to workers from industrial hazards during rail construction and operations for the Valley Modified corridor.

Group and industrial hazard category	Construction[a]	Operations[b]
Involved worker		
Total recordable cases[c]	32	95
Lost workday cases	16	52
Fatalities	0.3	0.2
Noninvolved worker		
Total recordable cases	2	4
Lost workday cases	1	2
Fatalities	0	0
Totals		
Total recordable cases	34	99
Lost workday cases	17	54
Fatalities	0.3	0.2

a. Totals for 2.5 years for construction.
b. Totals for 24 years for operations.
c. Total recordable cases includes injuries and illness.

Table 6-47. Estimated number of fatalities from construction material delivery vehicles and construction and operations worker commuting traffic for the Valley Modified rail corridor.

Activity	Kilometers[a]	Traffic fatalities	Emissions fatalities
Construction[b]			
Material delivery vehicles	7,000,000	0.1	0.00054
Commuting workers	24,000,000	0.3	0.0017
Subtotals	*31,000,000*	*0.4*	*0.0022*
Operations[c]			
Commuting workers	52,000,000	0.5	0.004
Totals	***84,000,000***	***0.9***	***0.006***

a. To convert kilometers to miles, multiply by 0.62137.
b. Totals for 2.5 years for construction.
c. Totals for 24 years for operations.

Table 6-48. Health impacts from incident-free Nevada transportation for the Valley Modified corridor implementing alternative.[a]

Category	Legal-weight truck shipments	Rail shipments	Totals[b]
Involved workers			
Collective dose (person-rem)	220	160	380
Estimated latent cancer fatalities	0.09	0.06	0.15
Public			
Collective dose (person-rem)	270	110	380
Estimated latent cancer fatalities	0.13	0.06	0.19
Estimated vehicle emission-related fatalities	0.00014	0.0017	0.0018

a. Impacts are totals for 24 years (2010 to 2033).

b. Totals might differ from sums of values due to rounding.

Socioeconomics

Construction. There would be socioeconomic impacts associated with the construction of a branch rail line in the Valley Modified corridor. The length of the corridor, 159 kilometers (98 miles), determines the number of workers that would be required. The construction of a branch rail line in this corridor would require 160 workers and 2 construction camps (DOE 1999d, Rail Files, Item 1).

DOE anticipates that the total direct and indirect construction employment would peak in 2007 at about 335. Population increases in Nevada would be likely to peak two years later in 2009. The estimated peak increase attributed to building a Valley Modified branch rail line would be about 240. Real disposable income, Gross Regional Product, and State and local government expenditures would also rise. The expected changes for the Valley Modified corridor would be increases of about $8.1 million in real disposable income, $13.9 million in Gross National Product, and $600,000 in State and local expenditures. (All dollar values reported in this section are in 1992 constant dollars unless otherwise stated.)

The impacts to employment, population, real disposable income, Gross Regional Product, and State and local government expenditures for building a branch rail line in the Valley Modified corridor would be low for the affected counties.

Operations. Estimated employment for operation of a Valley Modified branch rail line would be 36. Total estimated direct and indirect employment from these operations would be about 57 at its peak.

Estimated real disposable income increase attributable to operations would be greatest in 2033, the last year of operation, and would be about $2.4 million. The increase in Gross Regional Product in 2029, when impacts would be greatest in comparison to the baseline, would be about $5.4 million. Annual State and local government expenditures would be lower than those reported above for construction.

The impacts to employment, population, real disposable income, gross regional product, and State and local government expenditures from operating a Valley Modified branch rail line would be low for the affected counties.

Noise

Because of the large population in the Las Vegas Valley, this corridor would have a potential for noise impacts in the region north of Las Vegas, particularly as urban growth moves in that direction. In addition, Indian Springs could receive noise impacts from this option.

Utilities, Energy, and Materials

Table 6-49 lists the use of fossil fuels and other materials in the construction of a Valley Modified branch rail line.

Table 6-49. Construction utilities, energy, and materials for a Valley Modified branch rail line.

Route	Length (kilometers)[a]	Diesel fuel use (million liters)[b]	Gasoline use (thousand liters)	Steel (thousand metric tons)[c]	Concrete (thousand metric tons)
Valley Modified	159	13	270	22	130

a. To convert kilometers to miles, multiply by 0.62137.

b. To convert liters to gallons, multiply by 0.26418.

c. To convert metric tons to tons, multiply by 1.1023.

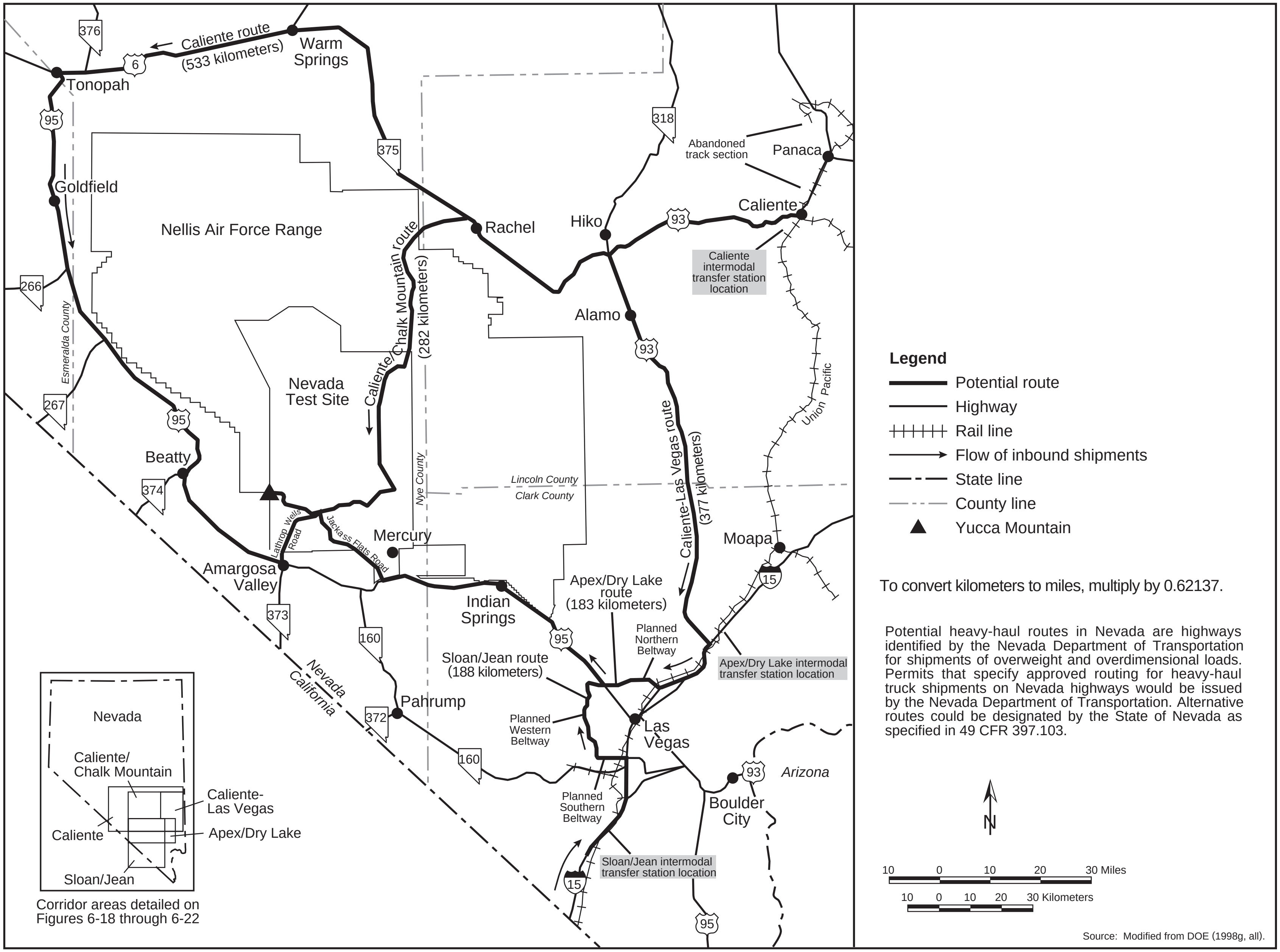
6.3.3 IMPACTS OF NEVADA HEAVY-HAUL TRUCK TRANSPORTATION IMPLEMENTING ALTERNATIVES

This section describes the analysis of human health and safety and environmental impacts for five implementing alternatives that would employ heavy-haul trucks to transport rail shipping casks containing spent nuclear fuel and high-level radioactive waste in Nevada. DOE has identified five highway routes in Nevada for potential use by the heavy-haul trucks to transport the casks. The casks would be transported to the repository from an intermodal transfer station along a mainline railroad where they would be loaded onto the heavy-haul trucks from railcars. The trucks would also transport empty casks from the repository back to the intermodal transfer station for loading back onto railcars. DOE would locate an intermodal transfer station at one of three potential locations in Nevada near existing rail lines and highways: (1) near Caliente, (2) northeast of Las Vegas (Apex/Dry Lake), or (3) southwest of Las Vegas (Sloan/Jean). Caliente is the originating location for three of the routes that heavy-haul trucks could use to ship spent nuclear fuel and high-level radioactive waste to the repository. There is one potential route each associated with the Apex/Dry Lake and Sloan/Jean locations (Figure 6-16).

For convenience and as shown in the figure, the five highway routes have been named the Caliente, Caliente-Chalk Mountain, Caliente-Las Vegas, Apex/Dry Lake, and Sloan/Jean routes. DOE considers these routes to be feasible for heavy-haul trucks to use in transporting large rail casks to and from the repository. The routes were compiled from a selection of highways in Nevada that the State has designated for use by heavy-haul trucks (TRW 1999d, Request #046). They include highways that were identified in a study by the College of Engineering at the University of Nevada, Reno, for the Nevada Department of Transportation (Ardila-Coulson 1989, all). This study provided a “preliminary identification of Nevada highway routes that could be used to transport current shipments of Highway Route-Controlled Quantities of Radioactive Materials and high-level radioactive waste.” They also include highways studied by the Transportation Research Center at the University of Nevada, Las Vegas, that characterized “rail and highway routes which may be used for shipments of high-level nuclear waste to a proposed repository at Yucca Mountain, Nevada” (Souleyrette, Sathisan, and di Bartolo 1991, all).

This section evaluates impacts in Nevada for each route and associated intermodal transfer station. The evaluation addresses (1) upgrading highways to accommodate frequent heavy-haul truck shipments, (2) constructing and operating an intermodal transfer station, and (3) making heavy-haul truck shipments. With the exception of Interstate System Highways, upgrades to existing Nevada highways would be necessary to accommodate the heavy-haul trucks.

The analysis of impacts for each of the five Nevada heavy-haul truck implementing alternatives assumed the national mostly rail transportation scenario. Therefore, the analysis included the impacts of legal-weight truck transportation from nine commercial generators that do not have the capability to handle or



To convert kilometers to miles, multiply by 0.62137.

Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. Permits that specify approved routing for heavy-haul truck shipments on Nevada highways would be issued by the Nevada Department of Transportation. Alternative routes could be designated by the State of Nevada as specified in 49 CFR 397.103.

Source: Modified from DOE (1998g, all).

Figure 6-16. Potential routes in Nevada for heavy-haul trucks.

load a large rail cask. About 2,600 legal-weight truck shipments would enter Nevada and travel to the repository. These trucks would use the same transport routes and carry about the same amounts of spent nuclear fuel per shipment as those for the mostly legal-weight truck scenario discussed in Section 6.3.1.

The analysis evaluates impacts for the following environmental resource areas: land use and ownership; air quality; hydrology; biological resources and soils; cultural resources; occupational and public health and safety; socioeconomics; noise; aesthetics; utilities, energy, and materials; and waste management.

Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.

6.3.3.1 Impacts Common to Nevada Heavy-Haul Truck Implementing Alternatives

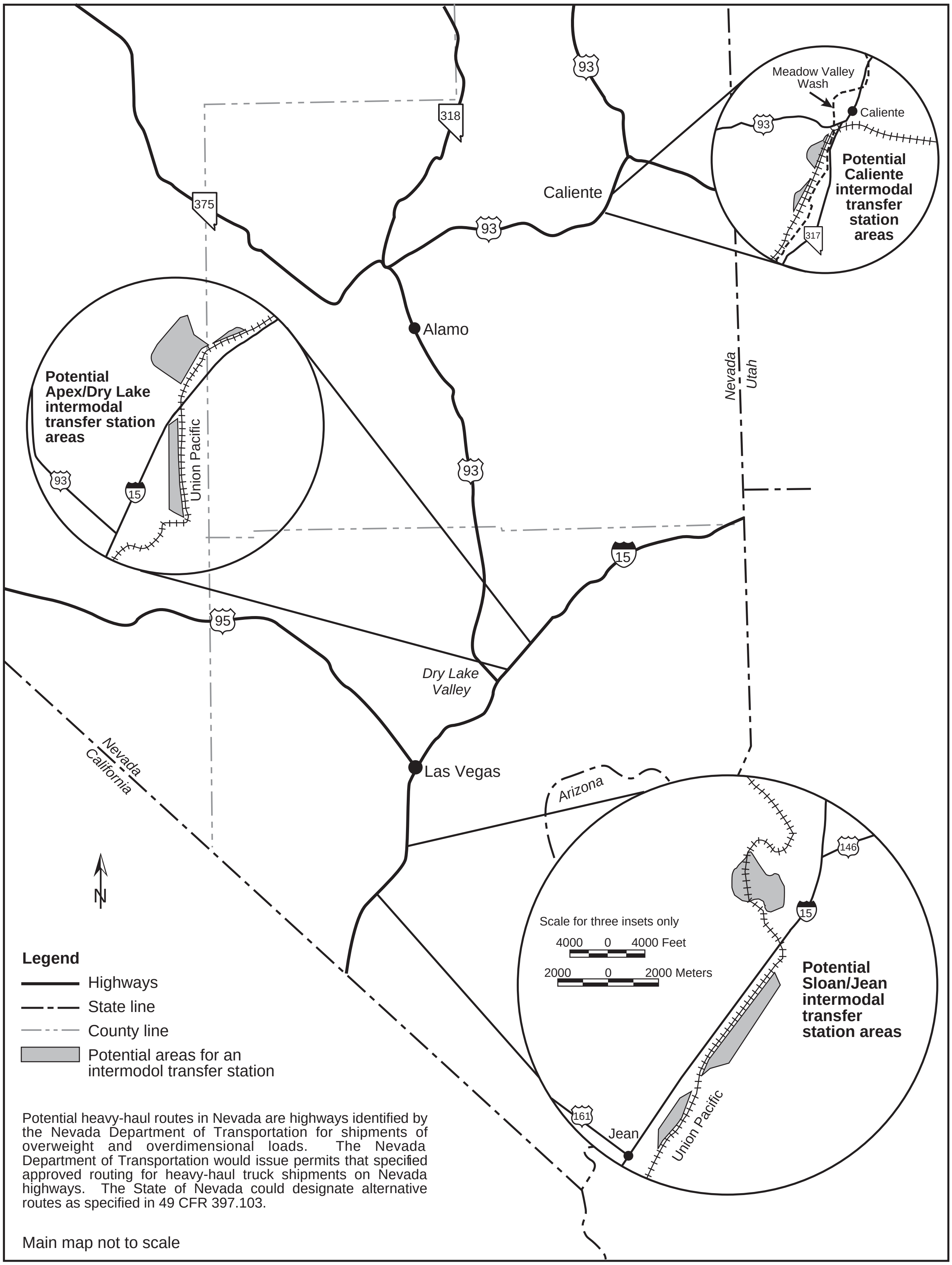
Nevada highways upgraded for heavy-haul truck use would allow routine, safe use in year-round operations. Upgrades would include reconstruction of some highway sections, especially in areas where spring and fall thaws and freezes make the highways susceptible to damage by heavy vehicles (frost-restricted areas). In addition, new turnout lanes at frequent intervals along two-lane highways would allow other traffic to pass the slower heavy-haul vehicles. Highway shoulders would be widened and road surfaces would be improved in many areas. Interstate highways would not be improved because they already meet standards that upgrades to other Nevada highways for heavy-haul truck shipments would follow.

Even with the highway upgrades, heavy-haul trucks would cause delays for other vehicles because of their size and slower travel speeds. On most of the highways in Nevada that heavy-haul shipments would use, traffic volumes are classified as *level of service Class A* (DOE 1998m, page 3-11), which means that traffic flows freely without delay (see Chapter 3, Section 3.2.2.2.11, for a description of all levels of service). The addition of 11 one-way trips each week to the traffic flow on these highways would not lead to a change in the average level of service. However, some traffic in lanes traveling with the vehicles would experience delays and short queues could form between turnout areas. In congested areas, such as the Las Vegas metropolitan area, where the level of service for the planned Las Vegas Beltway could be Class C or lower during non-rush-hour times, large slow-moving vehicles with their accompanying escort vehicles could present a temporary but large obstruction to traffic flow. Because disruptions on congested highways often continue after the removal of the cause, the duration of a traffic flow disruption would be longer than the time the vehicle would travel on the highway.

An intermodal transfer station would be common to all five heavy-haul truck implementing alternatives. Figure 6-17 shows the locations in Nevada that DOE is considering for such a station. Station construction would take about 1.5 years. The station would be a fenced area of about 250 by 250 meters (820 by 820 feet) and a rail siding that would be about 2 kilometers (1.25 miles) long. The estimated total area occupied by the facility and support areas would be 200,000 square meters (50 acres). It would

INTERMODAL TRANSFER STATION AND NAVAL SPENT NUCLEAR FUEL

Under the mostly legal-weight truck scenario, DOE would use the services of a commercial intermodal operator for the transfer of naval spent nuclear fuel shipments. This EIS assumed that DOE would not build an intermodal transfer station to handle those shipments. Because only 300 naval spent nuclear fuel casks would arrive in Nevada by rail over 24 years, the impacts of intermodal transfer operations would be considerably less than those for the mostly rail scenario. On average, the intermodal transfers would occur for about 2 weeks every 5 months to remove five casks from each train shipment. A staff of 20 would work only during these rail shipments.



Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. The Nevada Department of Transportation would issue permits that specified approved routing for heavy-haul truck shipments on Nevada highways. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

Figure 6-17. Potential locations for an intermodal transfer station.

include rail tracks, two shipping cask transfer cranes (one on a gantry rail and a backup rubber-tired vehicle), an office building, and a maintenance and security building. It would also have connecting tracks to an existing mainline railroad and storage and transfer tracks inside the station boundary. The maintenance building would provide space for routine service and minor repairs to the heavy-haul trailers and tractors. The station would have power, water, and other services. Diesel generators would provide a backup electric power source. The station would have the capacity to allow an intermodal transfer rate of 22 rail casks a week (11 loaded casks to the repository, 11 empty casks returned to the commercial and DOE sites).

Operations at an intermodal transfer station would include switching railcars carrying spent nuclear fuel and high-level radioactive waste casks from mainline railroad trains to the station's side track; queuing railcars on the side track for movement to the intermodal transfer area; moving railcars carrying loaded casks from the side track into position to transfer the casks to heavy-haul trucks; and using the facility crane to transfer loaded casks from railcars to heavy-haul trucks. The station would reverse this sequence of operations for empty casks returning from the repository.

This section discusses impacts for the analysis areas that would be common to all five heavy-haul truck implementing alternatives. It includes impacts for upgrading Nevada highways for use by heavy-haul trucks, constructing and operating an intermodal transfer station, and heavy-haul truck transportation of shipping casks, both loaded and empty. DOE evaluated these impacts as described in Section 6.3. Section 6.3.3.2 discusses impacts that would be unique to each heavy-haul truck transportation implementing alternative.

Land Use and Ownership

Highway Construction. With the exception of about 2 kilometers (1.2 miles) of new highway near Beatty, Nevada, for the Caliente route, upgrades to Nevada highways for use by heavy-haul trucks would involve improvements to existing roads and bridges. Areas disturbed by these activities would be adjacent to existing highway rights-of-way. Therefore, land disturbance would be limited to widening existing road shoulders by about 2 meters (6.6 feet), adding truck-lane pull-outs at intervals along the route, and increasing the height of overpasses. Borrow material (earth, gravel, and rock) to perform the initial upgrades would come largely from existing Nevada Department of Transportation facilities. Except for highways on the Nellis Air Force Range or Nevada Test Site, that Department would direct the highway improvements.

Intermodal Transfer Station Construction. Land-use impacts from an intermodal transfer station would center around the station because the railroad lines and the highways that DOE would use already exist and their intended use would not change. The construction of an intermodal transfer station would change the land uses and organizational control of about 0.2 square kilometer (50 acres) of property. This land would become the responsibility of DOE or possibly a transportation operating company. The rail line and station fencing could create barriers to wildlife and public access.

Heavy-Haul Truck and Intermodal Transfer Station Operations. Intermodal transfer station operations (arriving and departing trains, arriving and departing heavy-haul trucks, intermodal transfers, and maintenance and inspection activities) would be confined to the same areas that were disturbed during construction, so no additional disturbance would take place. Other land-use conflicts during the operation of an intermodal transfer station would be associated with fences that could create barriers to the movement of livestock and wildlife. Such restrictions would occur for any of the areas evaluated.

Only limited land-use impacts would result from heavy-haul truck operations on Nevada highways. Erosion along these highways would be managed as it is now. Because additional road construction would not be needed, additional land and soil disturbance would not occur.

Other land-use and ownership impacts differ among the implementing alternatives. These impacts are described in Section 6.3.3.2.

Air Quality

Highway Construction. Fuel consumption during construction activities would result in releases of criteria pollutants [carbon monoxide, nitrogen dioxide, sulfur dioxide, and particulate matter (PM_{10} and $PM_{2.5}$). Construction activities would also release particulate matter in the form of fugitive dust from such activities as excavation and truck traffic. Most of the road upgrades would occur in areas that are in attainment for all criteria pollutants. Road upgrade activities along the routes selected for heavy-haul truck use (including construction of a midroute stopover for routes originating in Caliente) would increase pollutant concentrations in the areas near the upgrade. However, because construction would be a moving source along various portions of the route, emissions would be transient and spread over a very large area.

Intermodal Transfer Station Construction. Table 6-50 lists estimated annual emissions from the construction of an intermodal transfer station. These estimates would apply to each of the three potential site areas. During station construction, fuel use by heavy equipment would emit carbon monoxide, nitrogen dioxide, sulfur dioxide, PM_{10}, and $PM_{2.5}$. Excavation and truck traffic would result in releases of particulate matter in the form of fugitive dust. The amount of fugitive dust would depend on the amount of disturbed land. Building the intermodal transfer station would disturb about 0.2 square kilometer (50 acres). The analysis assumed that construction activities would affect only 10 percent of the total disturbed land area at any time.

Table 6-50. Annual criteria pollutant releases from construction of an intermodal transfer station (kilograms per year).[a]

Pollutant	Construction emission (annual)	GCR[b] emission threshold	Percent of GCR emission threshold
Nitrogen dioxide	3,400	NA[c]	NA
Sulfur dioxide	320	NA	NA
Carbon monoxide	2,100	91,000	2.3
PM_{10}	31,000	64,000 (serious)	48

a. To convert kilograms to tons, multiply by 0.00110023.

b. GCR = General Conformity Rule (40 CFR 93). Applies for releases of pollutants in areas in nonattainment.

c. NA = not applicable.

Table 6-50 lists the percentage of each pollutant in relation to the General Conformity Rule emission threshold. The estimated annual releases from the construction of the intermodal transfer station would be 48 percent of the General Conformity Rule emission threshold (see 40 CFR 93) for PM_{10} and 2.3 percent for carbon monoxide.

Ozone would not be directly released during the construction of the intermodal transfer station. However, ozone precursors (nitrogen dioxide and volatile organic carbon compounds) would be released due to fuel use by construction equipment. The estimated annual emission rates of nitrogen dioxide and volatile organic carbon compounds would be small (40 CFR 52.21). The construction of the intermodal transfer facility, therefore, would not be a significant source of ozone.

Heavy-Haul Truck and Intermodal Transfer Station Operations. Fuel use by heavy-haul trucks would result in emissions of carbon monoxide, nitrogen dioxide, and PM_{10}. Based on the Federal standards for heavy-duty trucks (EPA 1997b, pages E-1 to E-3), emission of sulfur dioxide is not of concern. In attainment areas, the pollutant concentration in the area around the route would increase slightly during the passage of the trucks but would not exceed the standards.

Table 6-51 lists estimated annual emissions from the operation of an intermodal transfer station. These estimates would apply to each location. The station would emit carbon monoxide, nitrogen dioxide, and PM_{10} from the operation of a yard locomotive. Based on Federal standards for locomotives (EPA 1997b, page 73), emissions of sulfur dioxide are not included among emissions of greatest concern.

Table 6-51. Annual emissions of criteria pollutants from operation of an intermodal transfer station over 24 years (kilograms per year).[a]

Pollutant	Operation[b] emissions (annual)	PSD limit[c]	Percent of PSD limit	GCR[d] emission threshold	Percent of GCR emission threshold
Nitrogen dioxide	34,000	230,000	15	NA[e]	NA
Sulfur dioxide	(f)	230,000	(f)	NA	NA
Carbon monoxide	8,600	230,000	3.8	91,000	9.4
Particulate matter (PM_{10})	980	230,000	0.43	64,000	1.5

a. To convert kilograms to tons, multiply by 0.0011023.

b. Operations emissions from a switchyard locomotive and heavy-haul trucks.

c. PSD limit = Prevention of Signification Deterioration definition of a major stationary source (40 CFR 52.21); applies for releases of criteria pollutants during operation.

d. GCR = General Conformity Rule (40 CFR Part 93); applies for releases of pollutants in areas in nonattainment.

e. NA = not applicable.

f. Sulfur dioxide from locomotives is not included among emission constituents of greatest concern (EPA 1997b, page 73).

The estimated annual releases for the operation of the intermodal transfer station would be about 15 percent or less of the definition of a major stationary source (see Chapter 3, Section 3.1.2.1, or 40 CFR 52.21). The operation of a midroute stopover would result only in small releases of pollutants.

The operation of a yard locomotive would not emit ozone directly, but would emit ozone precursors (nitrogen dioxide and hydrocarbons). The estimated annual releases of the ozone precursors would be small; nitrogen dioxide would be about 15 percent of a major stationary source. Therefore, DOE does not expect the operation of the intermodal transfer facility to be a significant source of ozone.

Because the shipping casks would not be opened, there would be no radiological air quality impacts from normal operations at an intermodal transfer station.

Other air quality impacts would differ among the implementing alternatives (see Section 6.3.3.2).

Hydrology

This section describes impacts common to the five heavy-haul truck implementing alternatives (including upgrades to Nevada highways and construction of a midroute stopover and an intermodal transfer station at one of three locations) for surface water and groundwater.

Surface Water

Highway Construction. For road improvement work and construction of a midroute stopover, a contractor could place fuel tank trucks or trailers along the route to support equipment operations. Such a practice would present some potential for spills and releases. As long as the contractor met the regulatory requirements for reporting and remediating spills and properly disposing of or recycling used materials, the probability of unrecovered spills due to negligence or improper work practices would be low. If a release occurred, the potential for chemical contaminants (principally petroleum products) to enter flowing surface water before cleanup would be the largest risk.

A portable asphalt plant to support roadway improvement work would be located along the paving area. Aggregate crushing plants would be located in borrow areas. DOE assumes that the borrow areas would be those normally used by the Nevada Department of Transportation. Spills and releases of asphalt materials, which are predominantly petroleum products but include chemical additives, could occur in the course of operating an asphalt plant. Spill reporting and remediation requirements would be in place for these operations, as described above. Once asphalt was in place, it would be susceptible to minor leaching or bleeding while it cured, similar to the leaching or bleeding that occurs during road construction for other highway projects.

Intermodal Transfer Station Construction. Potential impacts to surface water would include (1) the possible spread of contamination by precipitation, intermittent runoff events, or, where present, releases to flowing water in the single perennial stream, and (2) the alteration of natural drainage patterns or runoff rates that could affect downgradient resources.

Materials that could contaminate surface water would be present during construction; these would consist primarily of petroleum products (fuels and lubricants) and coolants (antifreeze) to support equipment operations. There would not be much bulk storage of these materials. Fuel for vehicles would be purchased from nearby commercial vendors. Minor amounts of building materials such as paints, solvents, and thinners could be present during construction.

The construction of an intermodal transfer station would include stormwater runoff control, as necessary; the completed station would have a stormwater detention basin. These measures would minimize the potential for contaminated runoff to reach a stream.

Appendix L contains a floodplain/wetlands assessment that examines the effects of highway route construction, operation, and maintenance on the following floodplains in the vicinity of Yucca Mountain: Fortymile Wash, Busted Butte Wash, Drill Hole Wash, and Midway Valley Wash. There are no delineated wetlands at Yucca Mountain.

If DOE selected heavy-haul trucks to transport spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site, it would also select one of five routes (Figure 6-16) and one of three alternative intermodal transfer station sites (Figure 3-17). DOE would then prepare a more detailed floodplain/wetlands assessment of the selected alternatives. The assessment in Appendix L presents a comparison of what is known about the floodplains, springs, and riparian areas along the five alternative routes for heavy-haul trucks and at the three alternative intermodal transfer station sites. In general, wetlands have not been delineated along the alternative highway routes or at the three alternative intermodal transfer station sites.

Heavy-Haul Truck and Intermodal Transfer Station Operations. Surface-water impacts during operations would be limited to those from maintaining and resurfacing highways and parking areas at a midroute stopover that the heavy-haul trucks would use. As discussed above, good construction practices overseen by the Nevada Department of Transportation would limit impacts that could result from spills of chemical contaminants in the course of highway maintenance and resurfacing activities. Contamination of surface water caused by contaminants leached from new asphalt would be similar to that which occurs in the periodic resurfacing of asphalt highways.

Operations at a completed intermodal transfer station would have little impact on surface waters beyond any permanent drainage alterations that occurred during construction. The station area runoff rates would differ from those of the natural or existing terrain but, given the relatively small size [0.2 square kilometer (50 acres)] of the potentially affected area, they would add little to overall runoff quantities for the area.

The general design criteria for a station would consider the potential for a 100-year flood. Because the spent nuclear fuel and high-level radioactive waste shipping casks would not be opened or otherwise disassembled, the use of industrial design standards for this facility would be appropriate. The analysis assumes that the station would have a diesel-powered generator to provide standby electric power and an associated diesel storage tank. The diesel tank would present a minor potential for spills and releases. Runoff retention areas would limit impacts of potential oil and diesel spills in parking areas.

Groundwater

Highway Construction. For highway upgrades, the most likely impacts would be changes to infiltration rates and new sources of contamination that could migrate to groundwater during construction. In this case, however, the potential for impacts would be small due to the relatively small areas affected by upgrading and the fact that highway construction [with the exception of 2 kilometers (1.2 miles) of new highway near Beatty, Nevada, and a midroute stopover], would be a modification of existing roadways. In addition, there would be no large sources of contamination.

Construction activities would disturb and loosen the ground, which could produce greater infiltration rates. However, this impact would be minor and short-lived as contractors completed their work and stabilized the disturbed areas.

Intermodal Transfer Station Construction. Construction activities for an intermodal transfer station would disturb and loosen the ground for some time, which could cause higher infiltration rates. However, this impact would be minor and short-lived as contractors completed the facility and stabilized the disturbed areas.

Water needs for construction would be met by trucking water to the site, installing a well (which would also be used for operations), or possibly by connection to a local water distribution system. In any case, water demand would be small for construction.

Heavy-Haul Truck and Intermodal Transfer Station Operations. The use of highways by heavy-haul trucks would have little impact on groundwater resources. There would be no continued need for water along the route, and there would be no changes to recharge beyond those at the completion of construction.

The operation of a completed midroute stopover and an intermodal transfer station would have little impact on groundwater. Infiltration rates would be as described above for the completion of construction; the relatively small size of the facilities would minimize changes. Potential sources of contamination at the intermodal transfer station would consist primarily of a diesel fuel tank for the standby generator and heavy equipment. Water demand at the station and the midroute stopover would be small, consisting primarily of the needs of the operators, and would be obtained by the methods described above for construction. This demand would cause no noticeable change in water consumption rates for the area.

Other impacts to hydrology would differ among the implementing alternatives, as described in Section 6.3.3.2.

Biological Resources and Soils

Highway Construction. Highway upgrade activities would involve improving existing road surfaces and possibly building a bridge near Beatty, Nevada (Caliente route), a midroute stopover (Caliente routes), and about 2 kilometers (1.2 miles) of new highway to handle heavier vehicles (TRW 1999d, Request #048). Areas disturbed by these activities would be in, adjacent to, or near existing rights-of-way. These areas would consist of habitats previously degraded by human activities, which would limit impacts associated with the routes. Slight alterations of habitat immediately adjacent to existing roads would have only small impacts on desert tortoises because work would occur in the existing right-of-way. Tortoise populations are depleted for more than a kilometer on either side of roads having average daily traffic greater than 180 vehicles (Bury and Germano 1984, pages 57 to 72). The modification of bridges and culverts over perennial streams, if necessary, could temporarily disrupt stream flow and increase sedimentation in downstream aquatic environments. DOE anticipates that preconstruction surveys of potentially disturbed areas would identify and locate sensitive biological resources and best management practices would minimize the impacts of highway upgrades.

All of the heavy-haul truck implementing alternatives cross perennial or ephemeral streams that may be classified as jurisdictional waters of the Unites States. Discharge of dredged or fill material into those waters is regulated under Section 404 of the Clean Water Act. After the selection of a heavy-haul truck implementing alternative, if requested, DOE would assist the Nevada Department of Transportation to identify any jurisdictional waters of the United States that highway upgrades would affect; develop a plan to avoid when possible, and otherwise minimize, impacts to those waters; and obtain, as appropriate, an individual or regional permit from the U.S. Army Corps of Engineers for the discharge of dredged or fill material. By implementing the mitigation plan and complying with other permit requirements, the Nevada Department of Transportation would ensure that impacts to wetlands and other waters of the United States would be small.

The primary soil impacts from improvements to highways would be land disturbance. Road improvements would consist of widening existing roadways, constructing turnouts and truck lanes at designated stretches along the routes, and improving existing intersections. Water would be applied during construction to suppress dust and compact the soil; this would reduce the potential for erosion. Drainage control along the route probably would remain as it is now. These combined measures would minimize the potential for adverse impacts to soils.

Intermodal Transfer Station Construction. The biological settings of the three potential sites for an intermodal transfer station differ; Section 6.3.3.2 addresses impacts for each of the Nevada heavy-haul transportation implementing alternatives.

Soil impacts from the construction of an intermodal transfer station would arise primarily from the direct impacts of land disturbance and would apply to each station site and route. Table 3-41 lists estimates of land area required for an intermodal transfer station. The disturbed areas probably would be subject to increased erosion for at least some of the construction phase. Water would be applied during construction to suppress dust and compact the soil; this would reduce the potential for erosion. At the beginning of station construction, the topsoil would be stripped and stockpiled; during construction, temporary erosion control systems would minimize erosion impacts. At the completion of construction, the topsoil would be replaced over areas not used for station facilities, the area disturbed surrounding the station would be revegetated, and other permanent erosion control systems would be installed as appropriate.

Heavy-Haul Truck and Intermodal Transfer Station Operations. Impacts to biological resources from operations along any of the five possible routes would be very small. Because existing roadways would not be greatly altered, operations and maintenance would not lead to additional habitat losses. Heavy-haul truck operations could kill individuals of some species, but losses would be unlikely to have a detectable impacts on the regional population of any species and would be small in comparison to losses caused due to other traffic on the highways. Passing trucks could disrupt wildlife, but such effects would be transitory. The use of an upgraded highway would have only a small impact on soils.

Impacts to biological resources from operations at an intermodal transfer station and a midroute stopover would be very small. Operations would not lead to additional habitat losses. Individuals of some species could be disturbed or killed by human activities at the station and stopover, but such losses would be unlikely to have a detectable impacts on the regional population of any species.

The use of a completed intermodal transfer station and midroute stopover should have only small impacts on soils. The station and stopover would be maintained throughout the operations period, including the repair of erosion damage to the grounds around the station and the rail siding.

Other impacts to biological resources would differ among the heavy-haul truck implementing alternatives, as described in Section 6.3.3.2.

Cultural Resources

Highway and Intermodal Transfer Station Construction. Impacts could occur, primarily from surface-disturbing activities, to archaeological, historic, and traditional Native American cultural sites from upgrading highways, constructing a midroute stopover, and building an intermodal transfer station. Limited cultural resource inventories have been performed along the potential routes, and no systematic ethnographic field studies have been completed near the potential sites for an intermodal transfer station.

For example, there are four known archaeological sites near each of the Caliente and the Apex/Dry Lake intermodal station locations; none of these eight sites has been evaluated for eligibility for the *National Register of Historic Places*.

Therefore, specific impacts to culturally important sites, areas, or resources cannot be determined at this time. For the selected route and intermodal transfer station location, the Nevada Department of Transportation and DOE would perform specific archaeological surveys for proposed ground-disturbing activities. Such studies would occur during the development of the engineering design and before highway improvements or station construction began.

Heavy-Haul Truck and Intermodal Transfer Station Operations. No additional direct or indirect impacts would be likely to archaeological and historic sites from the operation of an intermodal transfer station or along highways from operations of heavy-haul trucks. Nonetheless, and although existing highways would be used, Native Americans have expressed great concern about the transport of spent nuclear fuel and high-level radioactive waste through tribal lands and through the larger region that comprises their traditional holy lands (AIWS 1998, all). Use of the Caliente-Las Vegas, Apex/Dry Lake, or Sloan/Jean route would include travel on U.S. 95 across a 1.6-kilometer (1-mile) section of the Las Vegas Paiute Indian Reservation. The Caliente-Las Vegas and Apex/Dry Lake routes pass near the Moapa Indian Reservation.

There are no known cultural resource impacts unique to any of the implementing alternatives.

Occupational and Public Health and Safety

Highway Construction. Approximately 2 traffic-related fatalities could occur among workers and members of the public during the upgrading of Nevada highways for heavy-haul truck use. There would be no other common impacts for highway construction under any of the implementing alternatives. Section 6.3.3.2 describes impacts for the implementing alternatives. The construction of a midroute stopover for routes originating in Caliente would not add much to the impacts of highway construction discussed in Section 6.3.3.2.

Intermodal Transfer Station Construction. Impacts to workers from industrial hazards during the construction of an intermodal transfer station would be the same for all three possible locations. These impacts would be small (see Table 6-52). The analysis estimated impacts to workers in terms of total recordable cases of injury or illness, lost workday cases, and fatalities to workers. In addition, it estimated that there would be less than 1 (0.01) construction and construction workforce traffic-related fatality.

Heavy-Haul Truck and Intermodal Transfer Station Operations. Section 6.3.3.2 discusses impacts for heavy-haul truck transportation and operations for each of the heavy-haul truck implementing alternatives. Common impacts for intermodal transfer station operations would include those to workers from industrial hazards and exposure to ionizing radiation (radiological impacts). DOE has determined that, because worker exposures to hazardous or toxic materials would be unlikely, workers at the station would incur no impacts from such materials. Table 6-53 lists potential impacts to workers from industrial hazards. In addition, there would be less than one (0.5) traffic-related fatality involving intermodal transfer station workers during operations.

Table 6-52. Health impacts to workers from industrial hazards during construction of an intermodal transfer station.

Group	Total recordable cases[a]	Lost workday cases	Fatalities
Involved	4	2	0.01
Noninvolved[b]	0.3	0.1	0
Totals[c]	**4.3**	**2.1**	**0.01**

a. Total recordable cases includes injuries and illness.
b. Noninvolved worker impacts based on 25 percent of the involved worker level of effort.
c. Impacts are totals for 1.5 years.

Table 6-53. Health impacts to workers from industrial hazards during operation of an intermodal transfer station.

Group	Total recordable cases[a]	Lost workday cases	Fatalities
Involved	69	37	0.1
Noninvolved[b]	3.1	1.0	0
Totals[c]	**72**	**38**	**0.1**

a. Total recordable cases includes injuries and illness.
b. Noninvolved worker impacts based on 25 percent of the involved worker level of effort.
c. Totals for 24 years of operations.

Intermodal transfer station workers would be exposed to direct radiation from the shipping casks the station would handle. Involved worker exposures would occur during both the inbound (to the proposed repository) and outbound (to the commercial and DOE sites) portions of the shipment campaign. The involved worker group would include as many as 20 personnel performing station operational tasks over a total shipment campaign of about 21,630 casks (10,815 inbound and 10,815 outbound). The analysis assumed that noninvolved workers would not be exposed to direct radiation during intermodal transfer station operations. Table 6-54 lists doses and radiological impacts to an individual worker and the involved worker population. The estimated doses are based on involved worker doses from Smith, Daling, and Faletti (1992, page 4.2).

Table 6-54. Doses and radiological impacts to involved workers from intermodal transfer station operations.[a]

Group	Dose	Latent cancer fatality
Maximum individual worker	12 rem[b]	0.005[c]
Involved worker population	260 person-rem	0.11[d]

a. Totals for 24 years of operations.
b. Assumes annual doses to intermodal transfer station workers would be limited to 0.5 rem per year.
c. The estimated probability of a latent cancer fatality in an exposed individual.
d. The estimated number of latent cancer fatalities in an exposed involved worker population.

Table 6-54 indicates that the involved group of workers could incur a collective dose of about 260 person-rem over the operating period of the intermodal transfer station. The analysis estimated that about 0.1 latent cancer fatality would occur in the exposed worker population. The maximum individual dose accumulated by these workers was assumed to be 500 millirem per year or 12 rem for a worker who worked at the facility for the 24-year operating period. This dose would result in a 0.005 probability of a latent cancer fatality (about a 1-in-200 chance). The assumed annual average dose to an involved worker is the administrative limit on occupational dose that DOE established for its facilities (DOE 1994c, Article 211). Because vehicles would not be loaded or unloaded at a midroute stopover (Caliente routes), workers at the stopover would receive only small radiation doses.

Incident-Free Transportation. Incident-free impacts of heavy-haul truck transportation in Nevada would be unique for each of the five Nevada heavy-haul truck transportation implementing alternatives; these are discussed for each implementing alternative in Section 6.3.3.2. In addition, the incident-free impacts that would occur in Nevada from 2,600 legal-weight truck shipments, although common among the heavy-haul truck implementing alternatives, are reported along with the incident-free impacts for heavy-haul truck transportation in Section 6.3.3.2 for each heavy-haul truck implementing alternative.

Accidents. Accident risks and maximum reasonably foreseeable accidents for heavy-haul truck shipments of spent nuclear fuel and high-level radioactive waste would be the same among the Nevada heavy-haul truck transportation implementing alternatives, so this section discusses them.

Table 6-55 lists the accident risks from the transportation of spent nuclear fuel and high-level radioactive waste for the five Nevada heavy-haul truck transportation implementing alternatives. The data show that the risks, which are for 24 years of operations, are low for all five alternatives. These risks include those associated with transporting 2,600 legal-weight truck shipments from the commercial sites that do not have the capability to load rail casks. Small variations in the risk values, principally evident for a Sloan/Jean route, are in part a result of the risks associated with transporting rail casks arriving from the east on the Union Pacific Railroad's mainline through the Las Vegas metropolitan area to a Sloan/Jean intermodal transfer station. The values that would apply for a Caliente-Chalk Mountain or Apex/Dry Lake route are lower because of a shorter route (Apex/Dry Lake), or a more remote and mid-length route (Caliente-Chalk Mountain).

Table 6-55. Health impacts[a] to the public from accidents for Nevada heavy-haul truck implementing alternatives.

Risk	Caliente	Caliente-Chalk Mountain	Caliente-Las Vegas	Apex/Dry Lake	Sloan/Jean
Radiological accident risk					
Dose-risk (person-rem)	0.29	0.26	0.72	0.67	4.1
LCF[b]	0.0001	0.0001	0.0004	0.0003	0.002
Traffic fatalities	0.73	0.42	0.54	0.31	0.33

a. Impacts are reported for 24 years of operations.
b. LCF = latent cancer fatality.

Consequences of Maximum Reasonably Foreseeable Accident Scenarios. DOE evaluated the impacts of maximum reasonably foreseeable accident scenarios for national transportation (see Section 6.2).

Socioeconomics

DOE analyzed the socioeconomic impacts of Nevada heavy-haul truck transportation for impacts from expenditures to upgrade and maintain Nevada highways, operate heavy-haul trucks, construct and operate a midroute stopover for routes originating in Caliente, and construct and operate an intermodal transfer station.

Highway Construction. Socioeconomic impacts from upgrading highways in Nevada (including constructing a midroute stopover) would be transient, occurring over short periods. For the most part, the projected impacts of highway upgrade work would occur in Clark County, which the analysis assumed would be the home county for construction workforces. Section 6.3.3.2 discusses impacts to communities and counties along the five potential routes. The construction time and employment required to complete road upgrades would depend on the route.

Intermodal Transfer Station Construction. If a decision was made to construct an intermodal transfer station, DOE anticipates that preliminary architecture and engineering work would begin in 2007, followed by the start of construction at the selected site in 2008. Construction would last about one and one-half years and would require 49 workers. For this analysis, DOE assumed that construction workers would probably come from Clark County.

The total increase in employment (direct and indirect) that would result from the project would peak in 2008 and would include about 130 workers. Population increases resulting from a net influx of new workers would peak in 2009 with about 70 additional residents. These employment and population increases, which would occur mostly in Clark County, would be small and temporary for the affected counties.

Increases in real disposable income from constructing an intermodal transfer station would peak in 2008 at between about $2.7 million and $3.1 million. The increase in Gross Regional Product would also peak in 2008 at between $7.5 million and $8.0 million. State and local government expenditures would peak in 2009 at about $200,000. These increases to real disposable income, Gross Regional Product, and government expenditures would be small for Clark County. (All dollar values reported in this section are in 1992 constant dollars unless otherwise stated.)

Highway Maintenance for Heavy-Haul Truck Operations. If DOE decided to use heavy-haul trucks, annual maintenance would be required after the completion of the highway upgrades. In addition, the routes would be resurfaced approximately every 8 years. Thus, highway expenditures for resurfacing a selected route would occur in approximately 2017, 2025, and 2033. The employment required for road maintenance would depend on the selected route. Section 6.3.3.2 discusses route-specific impacts.

Heavy-Haul Truck and Intermodal Transfer Station Operations. The socioeconomic impacts of operating heavy-haul trucks (including operating a midroute stopover for routes originating in Caliente) and an intermodal transfer station largely would occur in the county in which the station was located. Section 6.3.3.2 discusses these impacts.

Noise

Highway and Intermodal Transfer Station Construction. Impacts would occur from construction noise associated with upgrading road surfaces, constructing a midroute stopover, and constructing an intermodal transfer station. The upgrades and construction would include the use of earth-moving equipment (bulldozers, graders, loaders, dump trucks) and asphalt-laying equipment. The potential for noise impacts from construction would depend on the presence of humans along the routes and near the intermodal transfer station location. These persons would live in communities and possibly individual residences. Noise impacts from road upgrades and general construction would be transient and would move with the construction or end when the construction ended. The impacts, therefore, would be temporary for any location along affected highways. Construction noise, which would not occur at night, would be discernible (45 dBA) at distances as far as about 2,000 meters (6,600 feet).

The American Indian Writers Subgroup (AIWS 1998, page 2-19) has identified noise generated along transportation routes as a concern because it may affect ceremonies and the solitude necessary for healing and praying. Areas or sites of interest to Native Americans have not been identified along these routes.

Heavy-Haul Truck and Intermodal Transfer Station Operations. Heavy-haul trucks would be double-tractor vehicles that this analysis assumed would travel at speeds of 32 to 80 kilometers (20 to 50 miles) an hour. Noise levels probably would be greatest when loaded heavy-haul trucks were moving up grades at speeds as slow as 8 kilometers (5 miles) an hour. This would occur as the trucks approached the proposed repository site and on portions of the Caliente route (see Chapter 2, Section 2.1.3.3). At 48 kilometers (30 miles) an hour, the estimated noise from a single heavy-haul truck moving up a 5-percent grade would be 45 dBA at a distance of 630 meters (about 2,100 feet) from the road with no background traffic. Elevated truck noise would not be a consideration on the Nevada Test Site, the Nellis Air Force Range, or the repository site. Transportation workers would use hearing protection as required by Occupational Safety and Health Administration regulations.

During operations, DOE would transport 11 shipments a week of spent nuclear fuel and high-level radioactive waste to the proposed repository and 11 empty casks from the repository. Because the heavy-haul trucks probably would travel individually, elevated noise would occur during the brief time when a vehicle passed through communities. There would be no nighttime noise because trucks of this size would be restricted to operating during daylight hours. Truck noise at a midroute stopover would be similar to noise along the adjacent route. Therefore, the potential for adverse noise impacts from heavy-haul trucks would be low.

Noise associated with operations at an intermodal transfer station would occur as it received shipments and transferred them from railcars to heavy-haul trucks for transport to the proposed repository site. However, the baseline noise level is already elevated because of existing rail line operations at the potential station locations. Additional sources of noise at a station would include transferring railcars from trains into the station, moving the railcars in the station, and receiving returning empty transportation casks. Railcars could come to the station at night, so there would be a potential for nighttime sources of noise. However, shipments in the station could be handled during daylight hours, minimizing the potential for noise impacts.

Other noise impacts would differ among the implementing alternatives, as described in Section 6.3.3.2.

Aesthetics

Highway and Intermodal Transfer Station Construction. There could be impacts on visual resources during these activities because of the presence of workers, camps, vehicles, large earth-moving equipment, laydown yards, and dust generation. However, this phase would be of limited duration (approximately 18 months for an intermodal transfer station and up to 30 months for highway improvements). Dust generation would be controlled by implementing best management practices such as misting or spraying disturbed areas. Construction activities would not exceed the Bureau of Land Management Visual Resources Management guidelines (BLM 1986, all). If the route crosses Class II lands, more stringent management requirements would be necessary to retain the existing character of the landscape. However, the short duration of highway modification or construction activities, combined with the use of best management practices, would mitigate the impacts of activities, which could exceed the management requirements on any Class II lands.

Heavy-Haul Truck and Intermodal Transfer Station Operations. As many as 22 shipments would leave or arrive at the intermodal transfer station each week. Visual impacts would result from the presence of the station, increased worker activity in the area, the arrival and departure of trains, loading and unloading operations, and the arrival and departure of heavy-haul trucks. Some noise would occur from activities at the station, which could draw attention to it. These impacts would not exceed Class III objectives, which require only the partial retention of the existing character of the landscape.

Other aesthetic impacts would differ among the implementing alternatives, as described in Section 6.3.3.2.

Utilities, Energy, and Materials

Highway Construction. The amounts of utilities, energy, and materials needed would depend on the amount of upgrading to be done, which would be specific to each route. The amount of utilities, energy, and materials for each route is given in the following sections. All of the required amounts are much less than current use rates in Nevada. For example, fossil-fuel consumption in Nevada was about 3.8 billion liters in 1996 and none of the routes would require more than 0.5 percent of the annual consumption (BTS 1999a, Table MF-21).

Intermodal Transfer Station Construction. Intermodal transfer station design would be the same for any of the three sites and would include a small railyard with several sidings, a 180-metric-ton (200-ton) bridge crane, two steel prefabricated buildings (one for administration and one for maintenance), and a large paved area for heavy-haul truck parking and maneuvering. The basic facility would be a light industrial site with moderate utility requirements. During construction the electrical requirements would be supplied by portable generating equipment. Table 6-56 lists the materials that would be consumed during construction. The quantities of concrete, asphalt, and steel listed in the table are not substantial in comparison to annual use rates and would not affect the regional supply system. For example, the concrete required for an intermodal transfer station would be less than 1 percent of the concrete used in Nevada in 1998 (Sherwood 1998, all). Similarly, the demand for electricity and fossil fuel during construction would not be great. The construction of a midroute stopover for heavy-haul trucks (routes originating in Caliente) is accounted for in the specific route data included in the following sections.

Table 6-56. Construction utilities, energy, and materials for an intermodal transfer station over 1.5 years.

Electrical demand (kilowatts)	Fossil fuel (liters)[a]	Concrete (thousand metric tons)[b]	Asphalt (thousand metric tons)	Steel (thousand metric tons)
Onsite generation	Small	7.9	18	1.4

a. To convert liters to gallons, multiply by 0.26418.
b. To convert metric tons to tons, multiply by 1.1023.

Highway Maintenance for Heavy-Haul Truck Operations. Highways used by heavy-haul trucks would be maintained annually and resurfaced, on average, every 8 years. The amounts of utilities, energy, and materials for the annual and 8-year maintenance activities would be less than the initial amounts for upgrading the highways.

Heavy-Haul Truck and Intermodal Transfer Station Operations. The current estimate of electrical demand during the operation of an intermodal transfer station would be 165 kilowatts (TRW 1999d, Heavy-Haul Truck Files, Item 11). This would include 30 kilowatts for lighting, 50 kilowatts for each of the two buildings, 5 kilowatts for the guard station, and 30 kilowatts for the crane. The actual rate would be substantially less than peak capacity because operations would be intermittent. Only small amounts of fossil fuel would be used at an intermodal transfer station. Chapter 10 discusses fossil-fuel use for heavy-haul truck operations.

Other impacts on utilities, energy, and materials would differ among the implementing alternatives, as described in Section 6.3.3.2.

Waste Management

Highway Construction. Most wastes from upgrading highways, including constructing a midroute stopover, would be nonhazardous industrial or construction wastes that a contractor would dispose of in permitted industrial landfills or a permitted construction debris landfill, respectively. Hazardous waste such as lubricants and solvents or other hazardous materials would be shipped to a permitted hazardous waste treatment and disposal facility for appropriate disposition. In addition to disposition, much of the residual material from construction activities would be saved for reuse or recycled. Excess excavated materials such as soil and rock would be placed in spoil areas created for that purpose. A commercial vendor would provide portable restroom facilities and would manage the sanitary sewage.

Intermodal Transfer Station Construction. Construction would require traditional materials such as steel, lumber, and concrete that would result in debris that would require disposal or recycling. Excess construction materials would be salvaged. Construction debris would be disposed of in a local construction debris landfill. In addition, construction could require paints and resins that could become a hazardous waste if discarded. Hazardous waste would be shipped to a permitted treatment and disposal facility. A commercial vendor would provide portable restroom facilities and manage sanitary sewage. Waste quantities from construction would be about the same for all sites. The small impacts from disposing of the construction debris, hazardous waste, and sanitary sewage would be consistent for all station locations.

Highway Maintenance for Heavy-Haul Truck Operations. Periodic maintenance of highways and resurfacing every 8 years would generate construction wastes such as those discussed above for the initial highway improvements. Asphalt would be recycled.

Heavy-Haul Truck Operations. Heavy-haul truck operations along any of the five routes, including the operation of a midroute stopover for routes originating in Caliente, would result in wastes from vehicle maintenance and operation. These would include waste lubricants; solvents, paints, and other hazardous materials; sanitary waste; and industrial wastes typical of trucking company operations. Management and disposition of the wastes from operations would comply with applicable environmental and occupational and public safety regulations.

Intermodal Transfer Station Operations. Operations, regardless of the location, would generate (1) sanitary solid waste such as waste paper from office and personnel activities, (2) a small amount of hazardous waste from maintenance activities, and (3) potentially a small amount of low-level radioactive waste such as the smear wipes for radiological surveys of shipping casks and vehicles. In addition, the intermodal transfer station would generate sanitary sewage that DOE would dispose of in an onsite septic system or through connection to a municipal sewage facility.

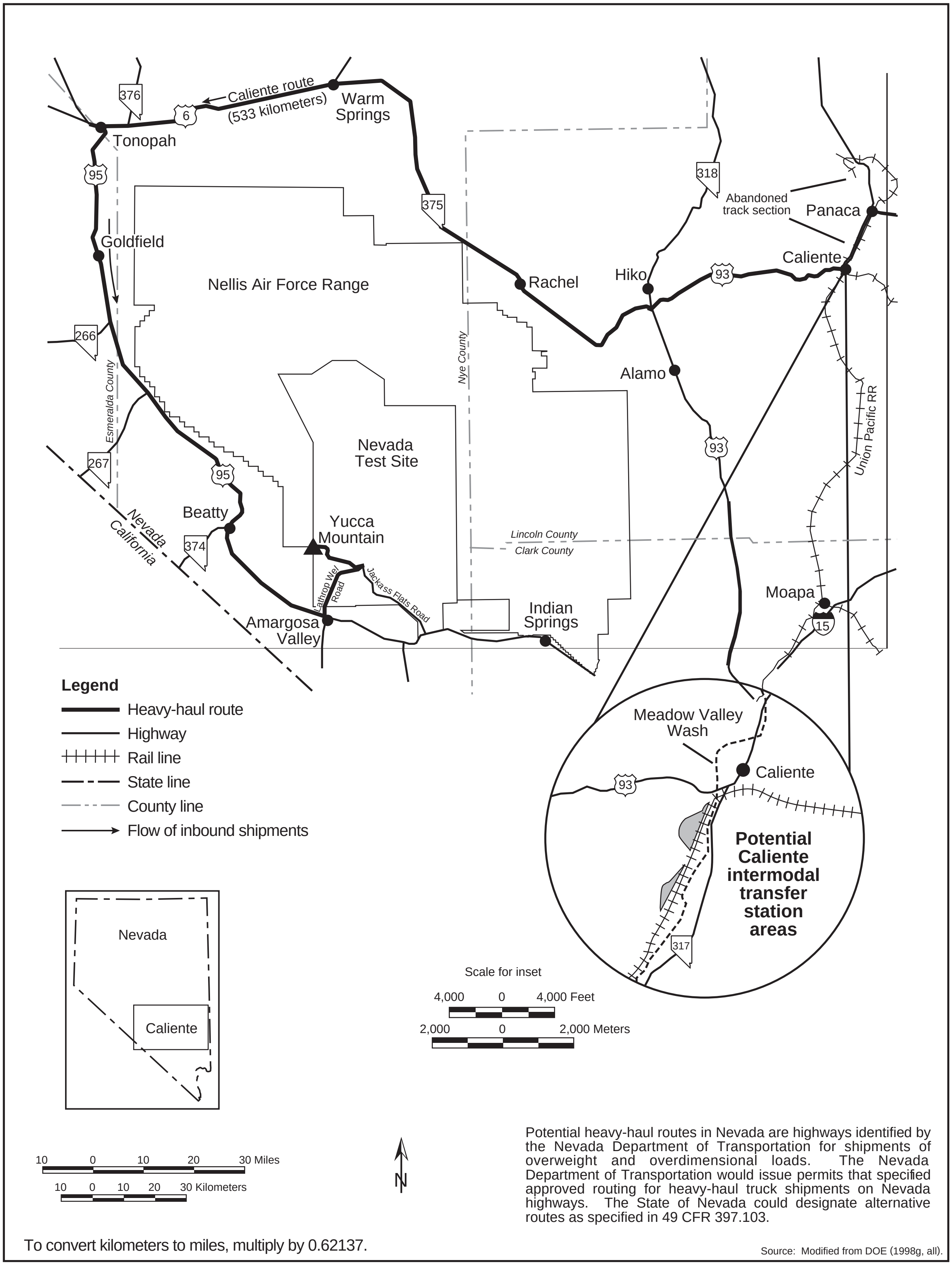
The intermodal transfer station operator would dispose of sanitary solid waste in a local permitted landfill with available capacity. Hazardous and low-level radioactive waste, if any, would be shipped to treatment and disposal facilities with appropriate permits. The small quantities would have very little impact to the treatment and disposal facilities. Treatment and disposal capacity for hazardous waste would be above the expected demand until 2013 (EPA 1996b, pages 32, 33, 36, 46, 47, and 50). Disposal capacity for a broad range of low-level radioactive wastes would be available at two currently licensed facilities, and three additional disposal facilities are under license review (NRC 1997a, section on U.S. Low-Level Radioactive Waste Disposal).

There are no waste management impacts unique to any of the heavy-haul truck implementing alternatives.

6.3.3.2 Specific Impacts from Nevada Heavy-Haul Truck Implementing Alternatives

6.3.3.2.1 *Caliente Route Implementing Alternative*

The Caliente route (Figure 6-18) would be approximately 533 kilometers (331 miles) long. Heavy-haul trucks and escorts leaving an intermodal transfer station in the Caliente area would travel directly from the intermodal transfer station to U.S. Highway 93. The trucks would travel west on U.S. 93 to State Route 375, then on State Route 375 to the intersection with U.S. 6. The trucks would travel on U.S. 6 to the intersection with U.S. 95 in Tonopah. The trucks would travel into Beatty on U.S. 95 where an alternative truck route would be built because an existing intersection is too constricted to allow a turn. Heavy-haul vehicles would then travel south on U.S. 95 to the Lathrop Wells Road exit, which would access the Yucca Mountain site.



Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. The Nevada Department of Transportation would issue permits that specified approved routing for heavy-haul truck shipments on Nevada highways. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

To convert kilometers to miles, multiply by 0.62137.

Source: Modified from DOE (1998g, all).

Figure 6-18. Caliente heavy-haul truck route.

Because of the estimated travel time associated with the Caliente route and the restrictions on nighttime travel for heavy-haul vehicles, DOE would construct a parking area along the route to enable these vehicles to park overnight. This parking area would be near U.S. 6 between Warm Springs and Tonopah.

The Caliente siting areas for an intermodal transfer station are south of the City of Caliente in the Meadow Valley Wash area. DOE has identified two areas along the west side of the canyon, with a combined area of 740,000 square meters (180 acres). Areas along the east side of the canyon would not be used to avoid disrupting Meadow Valley Wash and because of poor access to the Union Pacific rail line.

The following sections address impacts that would occur to land use; biological resources and soils; hydrology including surface water and groundwater; occupational and public health and safety; socioeconomics; noise; and utilities, energy, and materials. Impacts that would occur to air quality, cultural resources, aesthetics, and waste management would be the same as those discussed in Section 6.3.3.1 and are, therefore, not repeated here. Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.

Land Use and Ownership

This section describes land-use impacts that could occur from the construction and operation of a Caliente intermodal transfer station and upgrade of highways and heavy-haul truck operation over the Caliente route. Chapter 3, Section 3.2.2.2.1, describes the Caliente intermodal transfer station site and associated route.

With the exception of a small portion of the most northern part of the site area for an intermodal transfer station, the area is on patented land owned by the City of Caliente. The remaining part of the northern site is administered by the Bureau of Land Management. The northern site also includes an existing wastewater treatment plant (TRW 1999f, page 21).

Construction. There would be no unique land-use impacts for an intermodal transfer station in Caliente, Nevada. Land-use impacts that would be common to all locations are discussed in Section 6.3.3.1.

In addition to the impacts on land use discussed in Section 6.3.3.1 for upgrading Nevada highways, approximately 0.04 square kilometer (10 acres) of land near Beatty, Nevada, would be acquired to construct approximately 2 kilometers (1.2 miles) of new highway. This section of highway would be needed to avoid conflicts between the requirement of wide turning areas for heavy-haul trucks and existing land uses in Beatty where U.S. 95 makes a 90-degree turn. In addition, approximately 0.04 square kilometer (10 acres) of land in the vicinity of Tonopah would be acquired for a midroute stopping area for heavy-haul trucks.

Operations. There would be no direct land-use impacts associated with the operation of the Caliente intermodal transfer station or the Caliente route for heavy-haul trucks other than those described in Section 6.3.3.1.

Hydrology

DOE anticipates that limited impacts to surface water and groundwater would occur in the course of improving Nevada highways so they could accommodate daily use by heavy-haul trucks. This section discusses these potential impacts as well as those from the construction and operation of an intermodal transfer station and heavy-haul truck operations over the Caliente route. Section 6.3.3.1 discusses the hydrology impacts that would be common to all of the heavy-haul truck implementing alternatives. This section focuses on the hydrology impacts that are unique to the Caliente route.

Surface Water

Section 6.3.3.1 discusses impacts to surface water from the construction and operation of an intermodal transfer station and upgrades to highways. The common impacts discussed apply to surface water along the Caliente route.

Groundwater

Construction. Section 6.3.3.1 discusses the impacts to groundwater from the construction of an intermodal transfer station. Groundwater impacts from upgrading highways would be limited to those caused by the use of water from construction wells. The upgrades to the Caliente route would require about 126,000 cubic meters (100 acre-feet) (LeFever 1998b, all) of water which, for planning purposes, was assumed to come from 16 wells.

The average amount of water withdrawn from each well would be about 7,900 cubic meters (6 acre-feet). Chapter 3, Section 3.2.2.2.3, identifies the hydrographic areas over which the Caliente route would pass, their perennial yields, and whether the State considers each a Designated Groundwater Basin. Table 6-57 summarizes the status of the hydrographic areas associated with the Caliente route. It also identifies the approximate portion of the route that would pass over Designated Groundwater Basins.

Table 6-57. Hydrographic areas along Caliente route.

	Designated Groundwater Basins	
Hydrographic areas	Number	Percent of corridor length
19	8	45

The withdrawal of 7,900 cubic meters (6 acre-feet) a year from a well would have little impact on the hydrographic areas associated with the Caliente route based on their perennial yields (Chapter 3, Section 3.2.2.2.3), even if multiple wells were placed in the same hydrographic area. As indicated in Table 6-57, about 45 percent of the route's length would be in areas with Designated Groundwater Basins, where the Nevada State Engineer's office carefully watches the potential for groundwater depletion. This does not mean that a contractor could not obtain water appropriations in these areas; the State Engineer would have the authority to approve such appropriations. Requests for water appropriations under this action would be for minor amounts and for a short-term construction action, which should provide the State Engineer even more discretion. Other options would be to lease temporary water rights from individuals along the route, ship water from other permitted resources by truck to construction sites (about 7,000 truckloads), or use a combination of these two actions. Obtaining a water appropriation from the State Engineer for short-term construction use or using an approved allocation would ensure that groundwater resources would not be adversely affected.

Operations. Section 6.3.3.1 discusses the impacts to groundwater from the operation of an intermodal transfer station, highway maintenance, and heavy-haul truck operations.

Biological Resources

Section 6.3.3.1 discusses the impacts to biological resources from the construction and operation of an intermodal transfer station and upgrades to highways that would be common to all intermodal transfer stations and associated routes. This section discusses the construction- and operations-related impacts that are unique to the Caliente intermodal station and route.

Construction. Potential Caliente intermodal transfer station siting locations include two areas along the west side of the Meadow Valley Wash canyon. The land cover types are agriculture and salt desert scrub (TRW 1999k, page 3-30). The construction site would disturb approximately 0.2 square kilometer (50 acres). No special status species occur in the proposed location of the Caliente intermodal transfer station. However, two species classified as sensitive by the Bureau of Land Management—the Meadow Valley Wash speckled dace and the Meadow Valley Wash desert sucker—occur in the adjacent Meadow

Valley Wash (TRW 1999k, page 3-30). The construction of an intermodal transfer station could affect these fish by increasing the sediment load in the wash during construction. There is no designated game habitat at the proposed location for the intermodal transfer station, but the adjacent Meadow Valley Wash is classified as important habitat for water fowl and Gambel's quail (TRW 1999k, page 3-30). Impacts to this habitat would be small.

Moist areas in the proposed location and the adjacent perennial stream and riparian habitat along Meadow Valley Wash could be classified as jurisdictional wetlands or other waters of the United States, although no formal wetlands delineation of the area has been conducted. If this site was selected, DOE would delineate the boundaries of any jurisdictional wetlands, develop a plan to mitigate impacts, and consult with the U.S. Army Corps of Engineers regarding the need to obtain a regional or individual permit under Section 404 of the Clean Water Act.

The predominant land cover types along the Caliente route are salt desert scrub, sagebrush, and creosote-bursage (TRW 1999k, page 3-30). The regional area for each vegetation type is extensive (Utah State University 1996, GAP data). Because areas disturbed by upgrade activities would be in or adjacent to the existing rights-of-way, and have been previously degraded by human activities, impacts would be small.

Three threatened or endangered species occur along the Caliente route (TRW 1999k, page 3-30). The desert tortoise occurs along the southern part of the route along U.S. 95 from Beatty to Yucca Mountain. Construction activities could kill or injure some tortoises; however, their abundance is low in this area (Karl 1981, pages 76 to 92; Rautenstrauch and O'Farrell 1998, pages 407 to 411) so losses would be small. One endangered species—the Hiko White River springfish—occurs in Crystal Springs (50 CFR 17.95). The outflow of the spring comes within about 10 meters (33 feet) of State Route 375 near its intersection with State Route 318 near U.S. 93 (TRW 1999k, page 3-31). The construction or widening of the road would be unlikely to affect this species, because construction activities would avoid the spring outflow channel and because no sediment would enter the stream. An introduced population of the threatened Railroad Valley springfish occurs in Warm Springs (FWS 1996, page 20), the outflow of which crosses U.S. 6. If improvements to the highway in the vicinity of the Warm Springs outflow were necessary, there could be temporary adverse impacts to this introduced population due to habitat disturbance and siltation. Six other special status species occur along this route (TRW 1999k, pages 3-30 and 3-31) but, because construction activities would be limited to the road and adjacent areas and care would be taken to ensure no sediments would enter streams, species should not be affected.

This route would cross eight areas designated as game habitat (TRW 1999k, page 3-31). The amount of habitat in these areas would be reduced slightly due to construction activities alongside existing roads. Game animals in these areas during construction could be disturbed.

Nineteen springs occur near this route (TRW 1999k, page 3-31). Areas around these springs may be jurisdictional wetlands or waters of the United States. However, no formal delineation has occurred. Construction could increase sedimentation in these areas. The corridor crosses a number of ephemeral streams that may be classified as waters of the United States. DOE would work with the State of Nevada and the U.S. Army Corps of Engineers to minimize impacts to these areas, and obtain individual or regional permits, as appropriate.

Impacts on soils would be transitory and small and would occur only along the shoulders of existing roads.

Operations. Impacts from operations would include periodic disturbances of wildlife from activities at the intermodal transfer station and additional truck traffic along the route. Trucks probably would kill individuals of some species but losses would be few and unlikely to affect regional populations of any species. No additional habitat loss would occur during operations. Impacts to soils would be small.

Occupational and Public Health and Safety

This section addresses potential impacts to occupational and public health and safety from upgrading highways and heavy-haul truck operations on the Caliente route. Impacts of the associated intermodal transfer station are the same for each heavy-haul truck implementing alternative and are in Section 6.3.3.1.

Construction. Industrial safety impacts on workers from the upgrade of highways and use of the Caliente route would be small (see Table 6-58). The analysis evaluated the potential for impacts in terms of total reportable cases of injury, lost workday cases, fatality risks for workers, and traffic-related fatalities due to commuting workers and transporting construction materials and equipment. Table 6-59 lists the estimated fatalities from construction vehicle and commuter traffic.

Operations. The incident-free radiological impacts listed in Table 6-60 would occur during the routine transportation of spent nuclear fuel and high-level radioactive waste using the Caliente route. These impacts include transportation along the highway route as well as transportation along railways in Nevada to the Caliente intermodal transfer station. The table includes the impacts of 2,600 legal-weight truck shipments from commercial sites that do not have the capability to load rail casks.

Table 6-58. Impacts to workers from industrial hazards during the Caliente route construction upgrades.

Group and industrial hazard category	Construction[a]	Operations[b]
Involved workers		
Total recordable cases[c]	28	290
Lost workday cases	13	160
Fatalities	0.2	0.5
Noninvolved workers[d]		
Total recordable cases	5	13
Lost workday cases	2	7
Fatalities	0.01	0.01
Totals[e]		
Total recordable cases	33	300
Lost workday cases	15	170
Fatalities	0.2	0.5

a. Impacts are totals for about 2 years.
b. Includes impacts from periodic resurfacing and maintenance; impacts are totals for 24 years.
c. Total recordable cases includes injury and illness.
d. The noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
e. Totals might differ from sums due to rounding.

Socioeconomics

This section describes socioeconomic impacts that would occur from upgrading and using highways on the Caliente route and building an intermodal transfer station for heavy-haul truck transportation. It includes impacts from the operation of an intermodal transfer station at the Caliente site.

Construction. Socioeconomic impacts from upgrading highways for the Caliente route and building an intermodal transfer station would be transient, occurring over short periods and spread among the communities and counties along a route. Employment for route upgrades and intermodal transfer station construction would be about 250 workers. Upgrading the Caliente route would cost about $120 million (1998 dollars) and would require 36 months to complete. Constructing an intermodal transfer station would cost $24 million (1998 dollars) and require 1.5 years.

At its peak, increased employment for both construction workers (direct workers) and other workers who would be employed either because of highway upgrade and intermodal transfer station projects or as a result of the economic activity generated by the project (indirect workers) would be about 1,000. The change in employment for Clark, Nye, and the other Nevada counties except Lincoln County would be less than 1 percent of their employment bases. For Lincoln County, the increase in employment would be

Table 6-59. Estimated number of fatalities from construction material delivery vehicles and construction and operations worker commuting traffic for the Caliente route for heavy-haul trucks.

Activity	Kilometers[a]	Traffic fatalities	Vehicle emissions fatalities
Construction[b]			
Material delivery vehicles	180,000,000	3.1	0.013
Commuting workers	54,000,000	0.5	0.004
Subtotals[c]	*234,000,000*	*3.6*	*0.017*
Operations[d]			
Commuting workers	198,000,000	2.0	0.014
Totals	***432,000,000***	***5.6***	***0.031***

a. To convert kilometers to miles, multiply by 0.62137.
b. Impact totals are for about 2 years.
c. Totals might differ from sums due to rounding.
d. Impact totals are for 24 years.

Table 6-60. Health impacts from incident-free Nevada transportation for the Caliente route implementing alternative.[a]

Category	Legal-weight truck shipments[b]	Rail and heavy-haul truck shipments[c]	Totals[d]
Involved workers			
Collective dose (person-rem)	220	560	780
Estimated latent cancer fatalities	0.09	0.22	0.31
Public			
Collective dose (person-rem)	270	1,800	2,100
Estimated latent cancer fatalities	0.13	0.88	1.0
Estimated vehicle emission-related fatalities	0.00014	0.0052	0.0053

a. Impacts are totals for 24 years (2010 to 2033).
b. Impacts of 2,600 legal-weight truck shipments from nine commercial sites.
c. Includes impacts to workers at an intermodal transfer station and impacts to escorts.
d. Totals might differ from sums of values due to rounding.

as much as 2.3 percent of the county's employment base. The increase in employment in Lincoln County would be a moderate impact. However, it would be within historic short-term changes in employment for the county.

As a result of increased employment, population would be affected. The projected increases in population would reach a peak in 2009. During that year, the cumulative increase in population would be about 700. Population changes for Clark, Lincoln, or Nye County that would arise from increased employment would be less than 1 percent above the baseline. Thus, employment and population impacts arising from highway upgrade and intermodal transfer station construction projects would be small in comparison to existing employment and populations in the counties.

The increase in real disposable income of people in the affected counties would reach a peak in 2008 at $25.2 million. Gross Regional Product would peak in 2008 at $42.0 million. Increased State and local government expenditures resulting from highway upgrade and intermodal transfer station construction projects would reach their peak in 2009 at $2.0 million. (All dollar values reported in this section are in 1992 constant dollars unless otherwise stated.)

Changes to real disposable income and government expenditures would be small—less than 1 percent for Clark, Lincoln, Nye, and the other Nevada counties—as would changes to Gross Regional Product in Clark, Nye, and other counties. The change in Gross Regional Product in Lincoln County would be moderate, amounting to about 1.5 percent of the baseline but remaining within historic short-term changes in the county.

Operations. Operations at an intermodal transfer station and the use of heavy-haul trucks would begin in 2010 and last until 2033. An operations workforce of about 26 would be required for the intermodal transfer station. For the national mostly rail transportation scenario, the station would operate throughout the year. The workforce for heavy-haul truck operations over a Caliente route, including shipment escorts, would be about 120 workers. The analysis assumed that operations workers would reside in Clark, Lincoln, and Nye Counties.

Employment would be likely to remain relatively level throughout operations. Operations employment (direct and indirect) would average about 240 workers. About 90 of these workers would be in Lincoln County. The impact on population would be about 480 additional residents, with about 125 of these in Lincoln County. Employment and population increases for Lincoln County, which would experience the largest changes as a percentage of the baseline would be about 1.9 to 5.8 percent. These employment and population impacts during operations would be moderate in comparison to the existing employment and population levels for the county and would be within the range of historic changes in the county.

Real disposable income from operating an intermodal transfer station in Caliente and operating heavy-haul trucks based in Caliente would rise throughout operations, starting at $2.6 million in 2010 and rising to $11.7 million in 2033. Gross Regional Product would also rise during operations starting at $4.4 million in 2010 and increasing to $13.7 million in 2033. Annual State and local government expenditures would increase from $340,000 in 2010 to $2.6 million in 2033. Increases to real disposable income, Gross Regional Product, and government expenditures would be moderate in Lincoln County. Changes in real disposable income and government expenditures for the county would be about 2.7 and 1.7 percent, respectively. The projected change in Gross Regional Product for Lincoln County would be 4.0 percent; this would be within historic short-term changes for the county.

Because of the periodic need to resurface highways used by the heavy-haul trucks, employment would increase in the years these projects occurred. During those years, employment (direct and indirect) in the region would increase by about 250 for a Caliente route. Overall, employment changes from periodic (every 8 years) highway resurfacing projects would be less than 1 percent in Clark, Nye, and Lincoln Counties for the route. The impacts of the increases would be small.

Population increases would follow the increases in employment for highway resurfacing projects. Overall, the short-term increase in population in Nevada counties would be about 120 for a Caliente route. As a consequence, impacts to employment and population in affected counties in Nevada would be small and transient for highway resurfacing projects.

Noise

Section 6.3.3.1 discusses the noise impacts common to all heavy-haul truck implementing alternatives. This section focuses on noise impacts that would be unique to the Caliente heavy-haul truck implementing alternative.

Construction. The Caliente intermodal transfer station would border a wastewater treatment facility; there are no residences near the site. As a consequence, the potential for noise impacts from construction and operations would be nonexistent at this location.

Operations. For the Caliente route, the small rural communities of Amargosa Valley (at Lathrop Wells Road exit), Rachel, and Crystal Springs, and the Towns of Beatty, Goldfield, Tonopah, and Caliente would all fall within the 2,000-meter (6,560-foot) region of influence for construction noise. Noise impacts resulting from shipments along the Caliente route, based on community size and the number of affected communities, would be unlikely. Shipments would pass four established towns and three rural areas during transit to the Yucca Mountain site.

Utilities, Energy, and Materials

Section 6.3.3.1 discusses the utilities, energy, and materials impacts that would be common to the heavy-haul truck implementing alternatives. This section focuses on the utilities, energy, and materials impacts that would be unique to the Caliente heavy-haul truck implementing alternative.

Construction. The construction of the Caliente intermodal transfer station would have the same utilities, energy, and materials impacts as those discussed in Section 6.3.3.1.

Table 6-61 lists the estimated quantities of primary materials for the upgrade of Nevada highways for the Caliente route. These quantities are not likely to be very large in relation to the southern Nevada regional supply capacity (see Section 6.3.3.1).

Table 6-61. Utilities, energy, and materials required for upgrades along the Caliente route.

Route	Length (kilometers)[a]	Diesel fuel (million liters)[b]	Gasoline (thousand liters)	Asphalt (million metric tons)[c]	Concrete (thousand metric tons)	Steel[d] (metric tons)
Caliente	533	13.0	220	1.4	1.8	49.3

a. To convert kilometers to miles, multiply by 0.62137.

b. To convert liters to gallons, multiply by 0.26418.

c. To convert metric tons to tons, multiply by 1.1023.

d. Steel includes rebar only.

Operations. Section 6.3.3.1 discusses the utilities, energy, and material needs for operation of an intermodal transfer station.

Fossil fuel that would be consumed by heavy-haul trucks during operations is discussed in Chapter 10, which addresses irreversible commitments of resources.

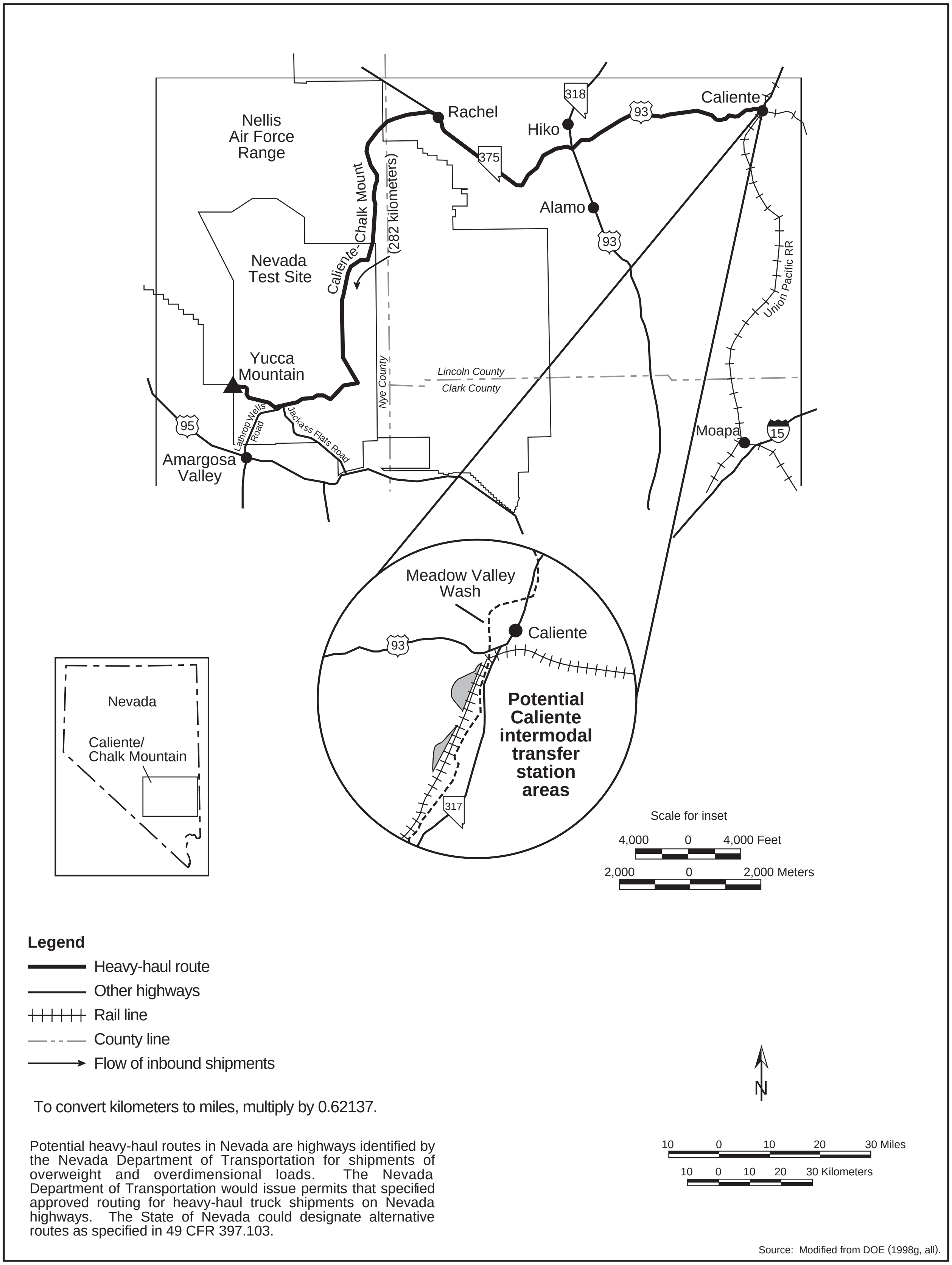
6.3.3.2.2 *Caliente-Chalk Mountain Route Implementing Alternative*

The Caliente-Chalk Mountain route (Figure 6-19) would be approximately 282 kilometers (175 miles) long. Heavy-haul trucks and escorts leaving an intermodal transfer station in the Caliente area would travel directly from the station to U.S. 93. The trucks would travel on U.S. 93 to State Route 375, then on State Route 375 to the Town of Rachel. Next they would head south on Valley Road through the Nellis Air Force Range past Chalk Mountain to the Groom Pass Gate to the Nevada Test Site.

Because of the estimated travel time associated with the Caliente-Chalk Mountain route and anticipated limits on travel on the Nellis Air Force Range, DOE would construct a parking area along the route near the northern boundary of the Nellis Air Force Range to enable these vehicles to park overnight.

Section 6.3.3.2.1 discusses the Caliente siting areas for an intermodal transfer station.

The following sections address impacts that would occur to land use; biological resources and soils; hydrology including surface water and groundwater; occupational and public health and safety; socioeconomics; noise; and utilities, energy, and materials. Impacts that would occur to air quality, cultural resources, aesthetics, and waste management would be the same as those discussed in Section 6.3.3.1 and are, therefore, not repeated here. Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.



To convert kilometers to miles, multiply by 0.62137.

Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. The Nevada Department of Transportation would issue permits that specified approved routing for heavy-haul truck shipments on Nevada highways. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

Source: Modified from DOE (1998g, all).

Figure 6-19. Caliente-Chalk Mountain heavy-haul truck route.

Land Use and Ownership

This section describes anticipated land-use impacts that could occur from the construction and operation of the Caliente intermodal transfer station, upgrades of highways, and heavy-haul truck operations over the Caliente-Chalk Mountain route. Chapter 3, Section 3.2.2.2.1, describes the Caliente intermodal transfer station site and the associated route.

Construction. Section 6.3.3.2.1 discusses Caliente intermodal transfer station impacts in relation to the current use of the land. Section 6.3.3.1 describes impacts on land use from upgrading highways for use by heavy-haul trucks.

In addition to the impacts on land use discussed in Section 6.3.3.1 for upgrading Nevada highways, approximately 0.04 square kilometer (10 acres) of land in the vicinity of the northern boundary of the Nellis Air Force Range would be acquired for a midroute stopping area for heavy-haul trucks.

The Caliente-Chalk Mountain route would involve land controlled by the Nellis Air Force Range, which, according to the Air Force, would affect Air Force operations. Because Public Law 99-606 withdrew and reserved the Nellis Air Force Range for use by the Secretary of the Air Force, the Secretary would need to concur with a decision to build and operate a branch rail line through the Range before DOE could build and operate this line. The Air Force has identified national security issues regarding a Caliente-Chalk Mountain route, citing interference with Nellis Air Force Range testing and training activities. In response to Air Force concerns, DOE has stated that it is acutely conscious of the security issues such a route would present and, because of the concerns expressed by the Air Force, regards the route as a "non-preferred alternative."

Operations. There would be no direct land-use impacts associated with the operation of the Caliente intermodal transfer station or the Caliente-Chalk Mountain route other than those described above and in Section 6.3.3.1.

Hydrology

DOE anticipates that limited impacts to surface water and groundwater would occur in the course of improving Nevada highways so that they could accommodate daily use by heavy-haul trucks. This section discusses these potential environmental impacts as well as those from the construction and operation of an intermodal transfer station and operation of the Caliente-Chalk Mountain route. Section 6.3.3.1 discusses the hydrological impacts that would be common to all the heavy-haul truck implementing alternatives. This section focuses on the hydrology impacts that would be unique to the Caliente-Chalk Mountain route.

Surface Water

Section 6.3.3.1 discusses the impacts to surface water from the construction and operation of an intermodal transfer station and upgrades to highways.

Groundwater

Construction. Section 6.3.3.1 discusses the impacts to groundwater from the construction of an intermodal transfer station. Groundwater impacts from upgrading highways would be limited to those caused by the use of water from construction wells. Upgrades to the Caliente-Chalk Mountain route would require about 75,000 cubic meters (60 acre-feet) of water (LeFever 1998b, all) that the analysis assumed would come from five wells.

The average amount of water withdrawn from each well would be about 15,000 cubic meters (12 acre-feet). Chapter 3, Section 3.2.2.2.3, identifies hydrographic areas over which the Caliente-Chalk Mountain route would pass, their perennial yields, and whether the State considers each a Designated Groundwater

Table 6-62. Hydrographic areas along Caliente-Chalk Mountain route.

	Designated Groundwater Basins	
Hydrographic areas	Number	Percent of corridor length
10	2	20

Basin. Table 6-62 summarizes the status of the hydrographic areas associated with the Caliente-Chalk Mountain heavy-haul route. It also identifies the approximate percentage of the route that would pass over Designated Groundwater Basins.

The withdrawal of 15,000 cubic meters (12 acre-feet) a year from a well would have little impact on the hydrographic areas associated with the Caliente-Chalk Mountain route based on their perennial yields (Chapter 3, Section 3.2.2.2.3), even if multiple wells were placed in the same hydrographic area. As indicated in Table 6-62, about 20 percent of the route's length would be in areas with Designated Groundwater Basins, which the Nevada State Engineer's office watches carefully for the potential for groundwater depletion. This does not mean that a contractor could not obtain water appropriations in these areas; the State Engineer would have the authority to approve such appropriations. The fact that requests for water appropriations under this action would be for minor amounts and for a short-term construction action should provide the State Engineer even more discretion. Other options would be to lease temporary water rights from individuals along the route, ship water from other permitted resources by truck (4,000 truckloads) to construction sites, or use a combination of these two actions. Obtaining a water appropriation from the State Engineer for short-term construction use or using an approved allocation should ensure that groundwater resources would not be adversely affected.

Operations. Section 6.3.3.1 discusses the impacts to groundwater from the operation of an intermodal transfer station, highway maintenance, and heavy-haul truck operations.

Biological Resources and Soils

Section 6.3.3.1 discusses impacts to biological resources from the construction and operation of an intermodal transfer station and upgrades to highways that would be common to all intermodal transfer stations and routes. This section discusses the construction- and operations-related impacts that would be unique to the Caliente intermodal station and Caliente-Chalk Mountain route.

Construction. Section 6.3.3.2.1 discusses potential Caliente intermodal transfer station siting locations and impacts to biological resources from station construction.

The predominant land cover types along the Caliente-Chalk Mountain route are salt desert scrub, blackbrush, sagebrush, and creosote-bursage (TRW 1999k, page 3-31). The regional area for each vegetation type is extensive (Utah State University 1996, GAP data). Because areas disturbed by highway upgrade activities would be in or adjacent to existing rights-of-way, and because these areas have been previously degraded by human activities, impacts would be small.

Two threatened or endangered species occur along the route (TRW 1999k, page 3-32). The desert tortoise occurs along the southern part of the route from the northern end of Frenchman Flat to Yucca Mountain. Construction activities could kill or injure desert tortoises; however, their abundance is low in this area (Rautenstrauch and O'Farrell 1998, pages 407 to 411), so losses would be few. One endangered species—the Hiko White River springfish—occurs in Crystal Springs (FWS 1998, page 16), which is about 10 meters (33 feet) south of State Route 375 near its intersection with Nevada 318 near U.S. 93. Construction or widening of the road is not likely to affect this species because construction activities would avoid the spring outflow channel and no sediment would enter the stream, which is critical habitat for this fish (50 CFR 17.95). Three other special status species occur along this route, but because construction activities would occur along existing roads, they should not be affected. Standard construction practices would be used to reduce erosion and runoff.

This route would cross six areas designated as game habitat (TRW 1999k, page 3-32). The amount of habitat in these areas would be reduced very slightly due to construction activities along existing roads. Game animals could be disturbed if they were in these areas during construction.

Three springs or riparian areas occur near this route (TRW 1999k, page 3-32). These springs and riparian areas may be jurisdictional wetlands or other waters of the United States; however, no formal delineation has occurred. Construction could increase sedimentation in these areas. The corridor crosses a number of ephemeral streams that may be classified as waters of the United States. DOE would work with the State of Nevada and the U.S. Army Corps of Engineers to minimize impacts to these areas and would obtain individual or regional permits, as appropriate.

Impacts to soils would be transitory and small and would occur only along the shoulders of existing roads.

Operations. Impacts from operations would include periodic disturbances of wildlife from additional truck traffic along this route. Trucks probably would kill individuals of some species but losses would be few and unlikely to affect regional populations of any species. No additional habitat loss would occur during operations. Impacts to soils would be small.

Occupational and Public Health and Safety

This section addresses potential impacts to occupational and public health and safety from upgrading highways and heavy-haul truck operations on the Caliente-Chalk Mountain route. Impacts of the associated intermodal transfer station in Caliente would be the same as those discussed in Section 6.3.3.1.

Construction. Industrial safety impacts to workers from upgrading highways for the Caliente-Chalk Mountain route would be small (Table 6-63). The analysis evaluated the potential for impacts in terms of total reportable cases of injury, lost workday cases, fatality risks for workers, and traffic-related fatalities related to commuting workers and the movement of construction materials and equipment. Table 6-64 lists the estimated fatalities from construction and commuter vehicle traffic.

Table 6-63. Impacts to workers from industrial hazards from upgrading highways along the Caliente-Chalk Mountain route.

Group and industrial hazard category	Construction[a]	Operations[b]
Involved workers		
Total recordable cases[c]	15	290
Lost workday cases	7	160
Fatalities	0.1	0.5
Noninvolved workers		
Total recordable cases	3	13
Lost workday cases	1	7
Fatalities	0.01	0.01
Totals[d]		
Total recordable cases	18	300
Lost workday cases	8	170
Fatalities	0.1	0.5

a. Impacts are totals over about 2 years.
b. Includes impacts from periodic maintenance and resurfacing. Impacts are totals over 24 years.
c. Total recordable cases includes injury and illness.
d. Totals might differ from sums due to rounding.

Operations. The incident-free radiological impacts listed in Table 6-65 would occur during the routine transportation of spent nuclear fuel and high-level radioactive waste using the Caliente-Chalk Mountain route. These impacts include transportation along the route and along railways in Nevada leading to an intermodal transfer station. The table includes the impacts of 2,600 legal-weight truck shipments from commercial sites that do not have the capability to load rail casks.

Socioeconomics

This section describes socioeconomic impacts that would occur from upgrading and using highways of the Caliente-Chalk Mountain route and building an intermodal transfer station for heavy-haul truck transportation. It includes the impacts from the operation of an intermodal transfer station at Caliente.

Table 6-64. Estimated number of fatalities from construction material delivery vehicles and construction and operations worker commuting traffic for the Caliente-Chalk Mountain route for heavy-haul trucks.

Activity	Kilometers[a]	Traffic fatalities	Vehicle emissions fatalities
Construction[b]			
Material delivery vehicles	45,000,000	0.8	0.0032
Commuting workers	30,000,000	0.3	0.0021
Subtotals	*75,000,000*	*1.1*	*0.0053*
Operations[c]			
Commuting workers	180,000,000	1.8	0.013
Totals[d]	***260,000,000***	***2.9***	***0.018***

a. To convert kilometers to miles, multiply by 0.62137.
b. Impacts are totals over about 2 years.
c. Impacts are totals over about 24 years.
d. Totals might differ from sums due to rounding.

Table 6-65. Impacts from incident-free transportation for the Caliente-Chalk Mountain heavy-haul truck implementing alternative.[a]

Category	Legal-weight truck shipments	Rail and heavy-haul truck shipments[b]	Totals[c]
Involved workers			
Collective dose (person-rem)	220	490	710
Estimated latent cancer fatalities	0.09	0.20	0.29
Public			
Collective dose (person-rem)	270	970	1,200
Estimated latent cancer fatalities	0.13	0.49	0.62
Estimated vehicle emission-related fatalities	0.00014	0.0032	0.0033

a. Impacts are totals for 24 years (2010 to 2033).
b. Includes impacts to workers at an intermodal transfer station and impacts to escorts.
c. Totals might differ from sums due to rounding.

Construction. Socioeconomic impacts from upgrading highways for the Caliente-Chalk Mountain route and building an intermodal transfer station would be transient, occurring over short periods and spread among the communities and counties along a route. Employment for route upgrades and intermodal transfer station construction would be about 240 workers. Upgrading this route would cost about $63 million (1998 dollars) and would require 26 months to complete. Constructing an intermodal transfer station would cost $24 million (1998 dollars) and require 1.5 years.

At its peak, increased employment for both construction workers (direct workers) and other workers who would be employed either because of highway upgrades and intermodal transfer station projects or as a result of the economic activity generated by the project (indirect workers) would be about 830. The change in employment for Clark, Nye, and the other Nevada counties except Lincoln County would be less than 1 percent of the counties' employment bases. For Lincoln County, the increase in employment would be as much as 2.6 percent of the employment base. The increase in employment in Lincoln County would be a moderate impact; however, it would be within historic short-term changes for the county.

As a result of increased employment, population would also be affected. Projected increases in population would reach a peak in 2009. During that year, the cumulative increase in population would be about 480. Population changes for Clark, Lincoln, or Nye County that would arise from increased employment would be less than 1 percent above the baseline. Thus, for the Caliente-Chalk Mountain route, employment and population impacts arising from highway upgrade and intermodal transfer station construction projects would be small in comparison to existing employment and populations in the counties.

The increase in real disposable income in the affected counties would peak at about $19.6 million in 2008. Gross Regional Product would peak in 2008 at $35.3 million. Increased State and local government expenditures resulting from highway improvement projects would reach their peak in 2009 at $1.3 million. Changes to government expenditures and real disposable income would be small—less than 1 percent for Clark, Lincoln, and Nye Counties. Changes to Gross Regional Product in the counties in Nevada except Lincoln County would also be small—less than 1 percent. Changes in Lincoln County of about 1.8 percent for Gross Regional Product would be moderate but within the range of historic short-term changes for the county. (All dollar values reported in this section are in 1992 constant dollars unless otherwise stated.)

Operations. Operations at an intermodal transfer station and the use of heavy-haul trucks would begin in 2010 and last until 2033. An operations workforce of 26 would be required for the intermodal transfer station. For the national mostly rail transportation scenario, the station would operate throughout the year. The workforce for heavy-haul truck operations over a Caliente-Chalk Mountain route, including shipment escorts, would be 110 workers. The analysis assumed that operations workers would reside in Lincoln County.

Employment would be likely to remain relatively level throughout operations. Operations employment (direct and indirect) would average about 230 workers. Under the assumptions of the analysis, about 135 workers would be employed in Lincoln County. The impact on population would be about 425 additional residents. Employment and population increases for Lincoln County, which would experience the largest changes, would be about 4.0 to 5.0 percent of the baseline. These employment and population impacts during operations would be moderate in comparison to the existing employment and population levels for the county and would be within the range of historic changes in the county.

Real disposable income from operating an intermodal transfer station in Caliente and operating heavy-haul trucks from it would rise throughout operations, starting at $2.4 million in 2010 and increasing to $10.5 million in 2033. Gross Regional Product would also rise during operations, starting at 4.3 million in 2010 and increasing to $12.9 million in 2033. Annual State and local government expenditures would increase from $350,000 in 2010 to $2.7 million in 2033. Increases to real disposable income, Gross Regional Product, and government expenditures would be moderate in Lincoln Country for the Caliente-Chalk Mountain route. Changes in real disposable income and government expenditure for the county would be about 3.2 and 2.4 percent, respectively. The projected change in Gross Regional Product for the county would be 5.8 percent.

Because of the periodic need to resurface the highways used by the heavy-haul trucks, employment would increase in the years during which these projects occurred. During those years, employment (direct and indirect) in the region would increase by about 130 for a Caliente-Chalk Mountain route. Overall, employment changes from periodic (every 8 years) highway-resurfacing projects would be less than 1 percent in Clark, Nye, Lincoln, and other Nevada counties for the route. The impact of these increases would be small.

Population increases would follow the increases in employment for highway resurfacing projects. Overall the short-term increase in population in Nevada counties would be about 320 for a Caliente-Chalk Mountain route. As a consequence, impacts to employment and population in affected counties in Nevada would be small and transient for highway resurfacing projects.

Noise

Section 6.3.3.1 discusses the noise impacts common to all the heavy-haul truck implementing alternatives. This section focuses on noise impacts that would be unique to the Caliente-Chalk Mountain heavy-haul truck implementing alternative.

Noise impacts of the Caliente intermodal transfer station would be the same as those discussed in Section 6.3.3.2.1. A large portion of the route would be inside the boundaries of the Nevada Test Site and the Nellis Air Force Range. The small rural communities of Crystal Spring and Rachel and the Town of Caliente would be within the 2,000-meter (6,560-foot) region of influence for construction noise.

Noise impacts resulting from shipments along the Caliente-Chalk Mountain route, based on community size and the number of affected communities, would be unlikely. The route passes one established town and two rural areas during transit to the Yucca Mountain site.

Utilities, Energy, and Materials

Section 6.3.3.1 discusses utilities, energy, and materials impacts that would be common to all the heavy-haul truck implementing alternatives. This section focuses on the utilities, energy and materials impacts that would be unique to the Caliente-Chalk Mountain heavy-haul truck implementing alternative.

Construction. The construction of the Caliente intermodal transfer station would have the same utilities, energy and materials impacts as those discussed in Section 6.3.3.1.

Table 6-66 lists the estimated quantities of primary materials for the upgrade of highways for the Caliente-Chalk Mountain route. These quantities are not likely to be very large in relation to the southern Nevada regional supply capacity (see Section 6.3.3.1).

Table 6-66. Utilities, energy, and materials required for upgrades along the Caliente-Chalk Mountain route.

Route	Length (kilometers)[a]	Diesel fuel (million liters)[b]	Gasoline (thousand liters)	Asphalt (million metric tons)[c]	Concrete (thousand metric tons)	Steel[d] (metric tons)
Caliente-Chalk Mountain	282	4.7	77	0.41	0.5	14.1

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. To convert metric tons to tons, multiply by 1.1023.
d. Steel includes rebar only.

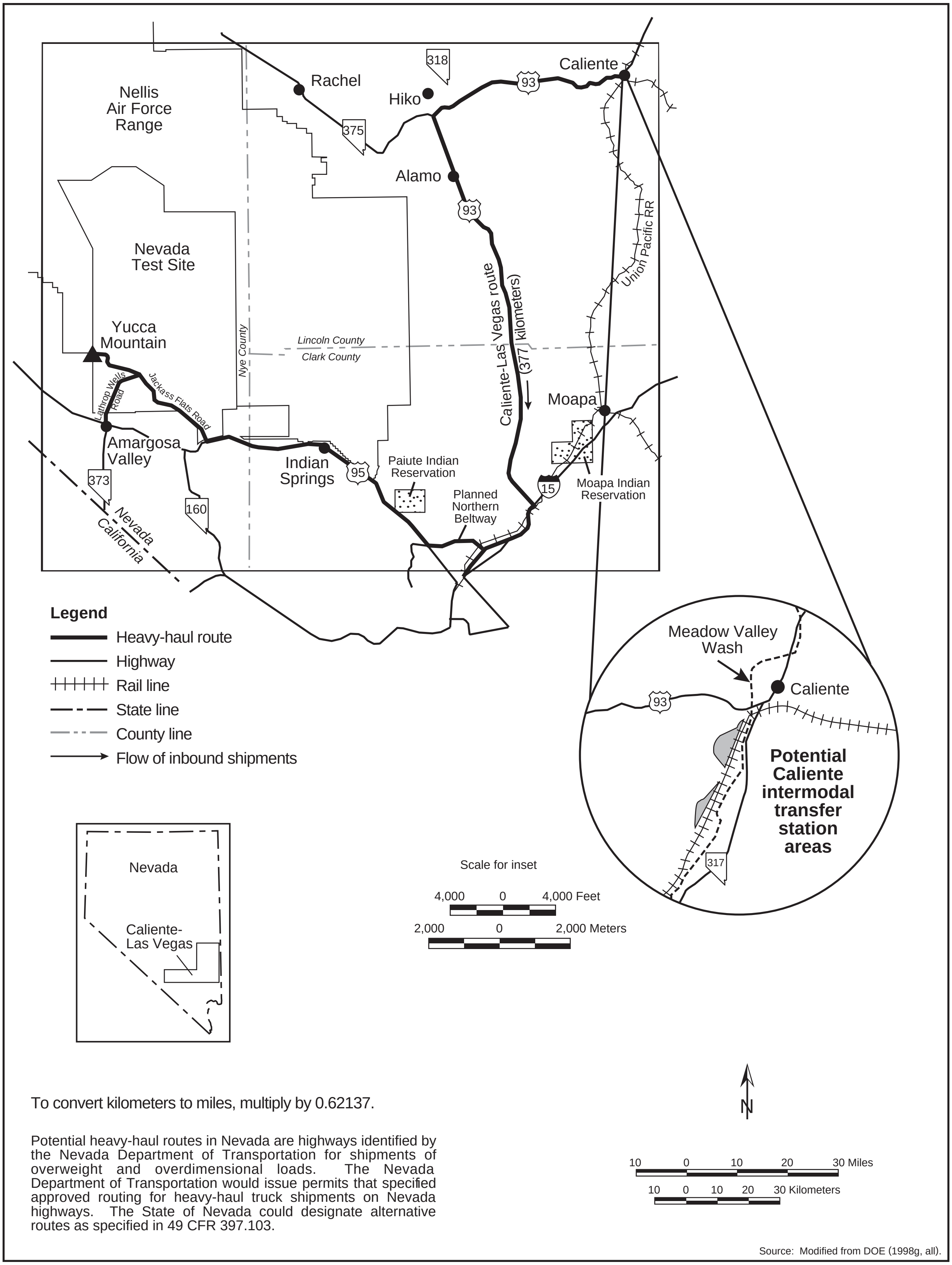
Fossil fuel that would be consumed by heavy-haul trucks during operations is discussed in Chapter 10, which addresses irreversible commitment of resources.

Operations. Section 6.3.3.1 discusses the utilities, energy, and materials needs for the operation of an intermodal transfer station.

6.3.3.2.3 *Caliente-Las Vegas Route Implementing Alternative*

The Caliente-Las Vegas route (Figure 6-20) would be approximately 377 kilometers (234 miles) long. Heavy-haul trucks and escorts leaving an intermodal transfer station in the Caliente area would travel directly from the station to U.S. 93. The trucks would travel south on U.S. 93 to the intersection with I-15 northeast of Las Vegas. The trucks would then travel south on I-15 to the exit for the proposed Las Vegas Beltway, and would travel west on the beltway. They would exit the beltway to U.S. 95, and travel north on U.S. 95 to the Mercury entrance to the Nevada Test Site. The trucks would travel on Jackass Flats Road on the Nevada Test Site to the Yucca Mountain site.

Because of the estimated travel time associated with the Caliente-Las Vegas route and the restrictions on nighttime travel for heavy-haul vehicles, DOE would construct a parking area along the route to enable



To convert kilometers to miles, multiply by 0.62137.

Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. The Nevada Department of Transportation would issue permits that specified approved routing for heavy-haul truck shipments on Nevada highways. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

Source: Modified from DOE (1998g, all).

Figure 6-20. Caliente-Las Vegas heavy-haul truck route.

these vehicles to park overnight. This parking area would be near the U.S. 93 and I-15 intersection at Apex.

Section 6.3.3.2.1 discusses the Caliente siting areas for an intermodal transfer station.

The following sections address impacts that would occur to land use; air quality; biological resources and soils; hydrology including surface water and groundwater; cultural resources; occupational and public health and safety; socioeconomics; noise; and utilities, energy, and materials. Impacts that would occur to aesthetics and waste management would be the same as those discussed in Section 6.3.3.1 and are, therefore, not repeated here. Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.

Land Use and Ownership

Chapter 3, Section 3.2.2.2.1, describes the Caliente intermodal transfer station site and associated truck route.

Construction. Section 6.3.3.2.1 discusses the Caliente intermodal station site area and impacts related to the current use of the land. Section 6.3.3.1.1 discusses the impacts on land use from upgrading Nevada highways for use by heavy-haul trucks.

In addition to the impacts on land use discussed in Section 6.3.3.1 for upgrading Nevada highways, approximately 0.04 square kilometer (10 acres) of land in the vicinity of Apex northeast of Las Vegas would be acquired for a midroute stopping area for heavy-haul trucks.

Operations. There would be no direct land-use impacts associated with the operation of the Caliente intermodal transfer station or use of the Caliente-Las Vegas route other than those described in Section 6.3.3.1.

Air Quality

This section describes anticipated nonradiological air quality impacts from the construction and operation of an intermodal transfer station and upgrades and heavy-haul truck operation along the Caliente-Las Vegas route. Such impacts would result from releases of criteria pollutants, including nitrogen dioxide, sulfur dioxide, carbon monoxide, and particulate matter (PM_{10} and $PM_{2.5}$).

Construction. Section 6.3.3.1 discusses air quality impacts for the construction of the Caliente intermodal transfer station, which would be a result of emissions from construction equipment and fugitive dust from earth excavation and construction vehicle traffic.

Section 6.3.3.1 also discusses air quality impacts likely to occur from upgrades of the Caliente-Las Vegas route for heavy-haul truck transport. These impacts would be a result of emissions from construction equipment and fugitive dust from earth excavation and construction vehicle traffic. Construction equipment design and controls would ensure that emissions did not exceed ambient air quality standards. Most of the road upgrades would occur in areas that are in attainment for all criteria pollutants. However, portions of the upgrades along the Caliente-Las Vegas route would occur in the Las Vegas Valley airshed, which is in nonattainment for carbon monoxide and PM_{10} (FHWA 1996, pages 3-53 and 3-54).

Operations. Section 6.3.3.1 discusses air quality impacts associated with the operation of the Caliente intermodal transfer station and from emissions of heavy-haul trucks. The Caliente-Las Vegas route would involve heavy-haul trucks passing through the Las Vegas Valley airshed. The air quality impacts to this airshed from the operation of four or five trucks a day would be very small in comparison to the amount of pollutants emitted by automobile travel and other commercial vehicles in the basin.

Hydrology

DOE anticipates that limited impacts to surface water and groundwater would occur in the course of improving Nevada highways so they could accommodate daily use by heavy-haul trucks. This section discusses these potential impacts as well as those from the construction and operation of an intermodal transfer station and operation of the Caliente-Las Vegas route. Section 6.3.3.1 discusses the hydrology impacts that would be common to all the heavy-haul truck implementing alternatives. This section focuses on the hydrology impacts that would be unique to the Caliente-Las Vegas heavy-haul truck implementing alternative.

Surface Water

Section 6.3.3.1 discusses impacts to surface water from the construction and operation of an intermodal transfer station and upgrades to highways. The common impacts discussed would apply to surface water along the Caliente-Las Vegas route.

Groundwater

Construction. Section 6.3.3.1 discusses impacts to groundwater from the construction of an intermodal transfer station. Groundwater impacts from upgrading highways would be limited to those caused by the use of water from construction wells. The upgrades to the Caliente-Las Vegas route would require about 54,000 cubic meters (44 acre-feet) of water (LeFever 1998b, all) that the analysis assumed would come from seven wells.

The average amount of water withdrawn from each well would be about 7,700 cubic meters (6 acre-feet). Chapter 3, Section 3.2.2.2.3, identifies the hydrographic areas over which the Caliente-Las Vegas route would pass, their perennial yields, and whether the State considers each a Designated Groundwater Basin. Table 6-67 summarizes the status of the hydrographic areas associated with the Caliente-Las Vegas route and identifies the approximate portion of the route that would pass over Designated Groundwater Basins.

Table 6-67. Hydrographic areas along Caliente-Las Vegas route.

	Designated Groundwater Basins	
Hydrographic areas crossed	Number	Percent corridor length represented
13	5	50

The withdrawal of 7,700 cubic meters (6 acre-feet) a year from a well would have little impact on the hydrographic areas associated with the Caliente-Las Vegas route based on their perennial yields (Chapter 3, Section 3.2.2.2.3), even if multiple wells were placed in the same hydrographic area. As indicated in Table 6-67, about 50 percent of the route's length would be in areas with Designated Groundwater Basins, where the potential for groundwater depletion is watched carefully by the Nevada State Engineer's office. This does not mean that a contractor could not obtain water appropriations in these areas; the State Engineer would have the authority to approve such appropriations. The fact that requests for water appropriations under this action would be for minor amounts and for a short-term construction action should provide the State Engineer even more discretion. Other options would be to lease temporary water rights from individuals along the route, ship water from other permitted resources by truck (about 3,000 truckloads) to construction sites, or use a combination of these two actions. Obtaining a water appropriation from the State Engineer for a short-term construction use or using an approved allocation should ensure that groundwater resources would not be adversely affected.

Operations. Section 6.3.3.1 discusses impacts to groundwater from the operation of an intermodal transfer station, highway maintenance, and heavy-haul truck operations.

Biological Resources and Soils

Section 6.3.3.1 discusses impacts to biological resources from the construction and operation of an intermodal transfer station and upgrades to highways that would be common to all intermodal transfer stations and routes. This section discusses construction- and operations-related impacts that would be unique to the Caliente intermodal station and Caliente-Las Vegas route.

Construction. Section 6.3.3.2.1 discusses potential Caliente intermodal transfer station siting locations and impacts to biological resources from construction of the station.

The predominant land cover types along the Caliente-Las Vegas route are creosote-bursage and Mojave mixed scrub (TRW 1999k, page 3-32). The regional area for each vegetation type is extensive (Utah State University 1996, GAP data). Because areas disturbed by upgrade activities would be in or adjacent to the existing rights-of-way and the areas have been previously degraded by human activities, impacts would be small.

Three threatened or endangered species occur along the route (TRW 1999k, page 3-33). The desert tortoise occurs along the southern part of the route from near Alamo to Yucca Mountain (Bury and Germano 1984, pages 57 to 72). An approximately 100-kilometer (62-mile) section of U.S. 93 from Maynard Lake to the junction with I-15 is critical habitat for the desert tortoise (50 CFR 17.95). Slight alterations of habitat immediately adjacent to existing roads would have only small impacts on desert tortoises because work would occur in the existing right-of-way. Tortoise populations are depleted for more than 1 kilometer (0.6 mile) on either side of roads with average daily traffic greater than 180 vehicles (Bury and Germano 1984, pages 57 to 72). Two endangered species—the Pahranagat roundtail chub and the White River springfish—occur in Ash Springs or its outflow. The route crosses the outflow of Ash Springs, which is designated critical habitat for the White River springfish (50 CFR 17.95). Because improvements would occur on the existing roadway and the Nevada Department of Transportation would use standard practices to reduce erosion and runoff, road improvements would not adversely affect the species living there. Nine other special status species occur within 100 meters (330 feet) of this route (TRW 1999k, page 3-33). Four of these species occur at Ash Springs or its outflow, and would not be affected for the reasons stated above for this site. The other five species would not be affected because construction activities would be restricted to the existing right-of-way, so occupied habitat would not be destroyed.

This route would cross eight areas designated as game habitat (TRW 1999k, page 3-33). Habitat in these areas would be reduced slightly due to construction activities along existing roads. Game animals could be disrupted if they were in these areas during construction.

Seven springs, riparian areas, or other wet areas occur near this route (TRW 1999k, page 3-33). These areas may be jurisdictional wetlands or other waters of the United States. However, no formal delineation has occurred. Construction could increase sedimentation in these areas. The corridor crosses a number of ephemeral streams that may be classified as waters of the United States. DOE will work with the State of Nevada and the U.S. Army Corps of Engineers to minimize impacts to these areas and would obtain individual or regional permits, as appropriate.

Impacts to soils would be transitory and small and would occur only along the shoulders of existing roads.

Operations. Impacts from operations would include periodic disturbances of wildlife by the additional truck traffic along this route. Trucks probably would kill individuals of some species but losses would be few and unlikely to affect regional populations of any species. No additional habitat loss would occur during operations. Impacts to soils would be small.

Cultural Resources

Section 6.3.3.1 discusses impacts to cultural resources that would be common to all the heavy-haul truck implementing alternatives.

There are four archaeological sites near the Caliente intermodal station locations, none of which has been evaluated for eligibility for the *National Register of Historic Places* (TRW 1999m, pages 2-19 to 2-47). Because no systematic ethnographic field studies have been completed for the Caliente-Las Vegas routes and the intermodal transfer station in Caliente, specific impacts to culturally important sites, areas, or resources cannot be determined at this time. The Caliente-Las Vegas route follows a portion of U.S. 95 that passes through approximately 1.6 kilometers (1 mile) of the Las Vegas Paiute Indian Reservation, and the U.S. 93 segment passes near the Moapa Indian Reservation.

Occupational and Public Health and Safety

This section addresses potential impacts to occupational and public health and safety from upgrading highways and heavy-haul truck operations on the Caliente-Las Vegas route. Impacts from the associated intermodal transfer station in Caliente would be the same as those discussed in Section 6.3.3.2.1.

Construction. Industrial safety impacts on workers from upgrading highways for the Caliente-Las Vegas route would be small (Table 6-68). The analysis evaluated the potential for impacts in terms of total reportable cases of injury, lost workday cases, fatality risks for workers, and traffic-related fatalities from commuting workers and the movement of construction materials and equipment. Table 6-69 lists the estimated fatalities from construction and commuter vehicle traffic.

Table 6-68. Impacts to workers from industrial hazards from upgrading highways along the Caliente-Las Vegas route.

Group and industrial hazard category	Construction[a]	Operations[b]
Involved workers		
Total recordable cases[c]	18	270
Lost workday cases	8	140
Fatalities	0.1	0.5
Noninvolved workers[d]		
Total recordable cases	4	12
Lost workday cases	2	6
Fatalities	0.01	0.01
Totals[e]		
Total recordable cases	22	280
Lost workday cases	10	150
Fatalities	0.1	0.5

a. Impacts are totals over about 2 years.
b. Includes impacts from periodic maintenance and resurfacing activities. Impacts are totals over 24 years.
c. Total recordable cases includes injury and illness.
d. The noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
e. Totals might differ from sums due to rounding.

Operations. Incident-free radiological impacts listed in Table 6-70 would occur during the routine transportation of spent nuclear fuel and high-level radioactive waste on the Caliente-Las Vegas route. These impacts would include those from transportation along the route and along railways in Nevada leading to the Caliente intermodal transfer station. The table includes the impacts of 2,600 legal-weight truck shipments from commercial sites that do not have the capability to load rail casks.

Socioeconomics

This section describes socioeconomic impacts that would occur from upgrading and using highways on the Caliente-Las Vegas route. It includes impacts from constructing and operating an intermodal transfer station in Caliente.

Construction. Socioeconomic impacts from upgrading highways for the Caliente-Las Vegas route and building an intermodal transfer station would be transient, occurring over short periods and be spread among the communities and counties along the route. Employment for route upgrades and intermodal transfer station construction would be about 290 workers. The highway upgrades would cost about $93

Table 6-69. Estimated number of fatalities from construction material delivery vehicles and construction and operations worker commuting traffic for the Caliente-Las Vegas route for heavy-haul trucks.

Activity	Kilometers[a]	Traffic fatalities	Vehicle emissions fatalities
Construction[b]			
Material delivery vehicles	61,000,000	1.1	0.0044
Commuting workers	37,000,000	0.4	0.0026
Subtotals	*98,000,000*	*1.5*	*0.007*
Operations[c]			
Commuting workers	200,000,000	2.0	0.014
Totals	***300,000,000***	***3.5***	***0.021***

a. To convert kilometers to miles, multiply by 0.62137.
b. Impacts are totals over about 2 years.
c. Impacts are totals over about 24 years.

Table 6-70. Health impacts from incident-free Nevada transportation for the Caliente-Las Vegas route heavy-haul truck implementing alternative.[a]

Category	Legal-weight truck shipments	Rail and heavy-haul truck shipments	Totals[b]
Involved workers			
Collective dose (person-rem)	220	520	740
Estimated latent cancer fatality	0.09	0.21	0.30
Public			
Collective dose (person-rem)	270	1,300	1,600
Estimated latent cancer fatality	0.13	0.64	0.77
Estimated vehicle emission-related fatalities	0.00014	0.0040	0.0041

a. Impacts are totals for 24 years (2010 to 2033).
b. Totals might differ from sums of values due to rounding.

million (1998 dollars) and would require 25 months to complete. Constructing an intermodal transfer station would cost $24 million and require 1.5 years.

At its peak, increased employment for both construction workers (direct workers) and other workers who would be employed either because of highway upgrade and intermodal transfer station construction projects or as a result of the economic activity generated by the projects (indirect workers) would be about 810. The change in employment for Clark, Nye, and other Nevada counties except Lincoln County would be less than 1 percent of the counties employment base. For Lincoln County, the increase in employment would be as much as 2 percent. This increase would be a moderate impact. However, it would be within historic short-term changes in employment for the county.

As a result of increased employment, population would be affected. The projected increases in population would reach a peak in 2009. During that year, the cumulative increase in population would be about 540. Population changes for Clark, Lincoln, and Nye Counties from increased employment would be less than 1 percent above the baseline. Thus, employment and population impacts from highway improvement and intermodal transfer station construction projects would be small in comparison to existing employment and populations in the affected counties.

The increased real disposable income in the affected counties would reach a peak in 2008 at $20.1 million. Gross Regional Product would peak in 2008 at $35.3 million. Increased State and local government expenditures from highway improvement and intermodal transfer station construction projects would reach their peak in 2009 at $1.5 million.

Changes to real disposable income, Gross Regional Product, and government expenditures would be small—less than 1 percent for Clark, Lincoln, Nye, and the other Nevada counties.

Operations. Operations at an intermodal transfer station and the use of heavy-haul trucks would begin in 2010 and last until 2033. An operations workforce of 26 would be required for the intermodal transfer station. For the national mostly rail transportation scenario, the station would operate throughout the year. The analysis assumed that operations workers would reside in Lincoln County. The workforce for heavy-haul truck operations, including escorts, would be 120 workers.

Employment would be likely to remain relatively level throughout operations. Operations employment (direct and indirect) would average about 250 workers. The analysis assumed that about 100 of these workers would be employed in Lincoln County. The impact on population would be about 460 additional residents, about 130 in Lincoln County. Employment and population increases for Lincoln County, which would experience the largest changes as a fraction of the baseline, would be about 3.5 percent. These employment and population impacts would be moderate in comparison to the existing employment and population levels for the county and would be within the range of historic changes in the county.

Real disposable income in the region of influence (Clark, Lincoln, and Nye Counties, and the remainder of Nevada) from operating an intermodal transfer station in Caliente and operating heavy-haul trucks based in Caliente would rise throughout operations, starting at $2.7 million in 2010 and increasing to $11.3 million in 2033. Gross Regional Product would also rise during operations, starting at $4.7 million in 2010 and increasing to $13.8 million in 2033. Annual State and local government expenditures would increase from $340,000 in 2010 to about $2.5 million in 2033. Increases to real disposable income, Gross Regional Product, and government expenditures would be moderate in Lincoln County for the Caliente-Las Vegas route. Changes in real disposable income and government expenditures for the county would be about 2.5 and 1.8 percent, respectively. The projected change in gross regional product for the county would be 4.3 percent. This change would be within historic short-term changes for Lincoln County.

Because of the periodic need to resurface highways used by the heavy-haul trucks, employment would increase in the years these projects occurred. During those years, employment (direct and indirect) in the region would increase by 190 for a Caliente-Las Vegas route. Overall, employment changes from periodic (every 8 years) highway-resurfacing projects would be less than 1 percent in Clark, Nye, and Lincoln counties for the route. The impacts of the increases would be small.

Population increases would follow the increases in employment for highway resurfacing projects. Overall, the short-term increase in population in Nevada would be about 100 for a Caliente-Las Vegas route. As a consequence, impacts to employment and population in affected counties in Nevada would be small and transient for highway resurfacing projects.

Noise

Section 6.3.3.1 discusses noise impacts common to all the heavy-haul truck implementing alternatives. This section focuses on the noise impacts that would be unique to the Caliente-Las Vegas heavy-haul truck implementing alternative.

Noise impacts of the Caliente intermodal transfer station would be the same as those discussed in Section 6.3.3.2.1.

Construction activities for upgrading highways along the Caliente-Las Vegas route would occur on all sections with the exception of the section of I-15 between its intersection with U.S. 93 and the planned Northern Las Vegas Beltway. Northern Las Vegas, the Towns of Caliente and Indian Springs, and the small rural communities of Crystal Springs and Alamo would fall within the 2000-meter (6,560-foot) region of influence for construction noise. The potential number of inhabitants would be highest for the route near the greater Las Vegas area. There are also small rural communities and towns along the route.

Because the shipments would pass through a large population area, there would be a potential for noise impacts along the route.

Utilities, Energy, and Materials

Section 6.3.3.1 discusses utilities, energy, and materials impacts that would be common to the heavy-haul truck implementing alternatives. This section focuses on the utilities, energy, and materials impacts that would be unique to the Caliente-Las Vegas heavy-haul truck implementing alternative.

Construction. The construction of the Caliente intermodal transfer station would produce the same utilities, energy, and materials impacts as those discussed in Section 6.3.3.1.

Table 6-71 lists the estimated quantities of primary materials for the upgrade of Nevada highways for the Caliente-Las Vegas route. These quantities would be unlikely to be large in relation to the southern Nevada regional supply capacity (see Section 6.3.3.1).

Table 6-71. Utilities, energy, and materials required for upgrades along the Caliente-Las Vegas route.

Route	Length (kilometers)[a]	Diesel fuel (million liters)[b]	Gasoline (thousand liters)	Asphalt (million metric tons)[c]	Concrete (thousand metric tons)	Steel[d] (metric tons)
Caliente-Las Vegas	377	5.5	110	0.55	0.80	21

a. To convert kilometers to miles, multiply by 0.62137.

b. To convert liters to gallons, multiply by 0.26418.

c. To convert metric tons to tons, multiply by 1.1023.

d. Steel includes rebar only.

Operations. Section 6.3.3.1 discusses the utilities, energy, and materials needs for the operation of an intermodal transfer station.

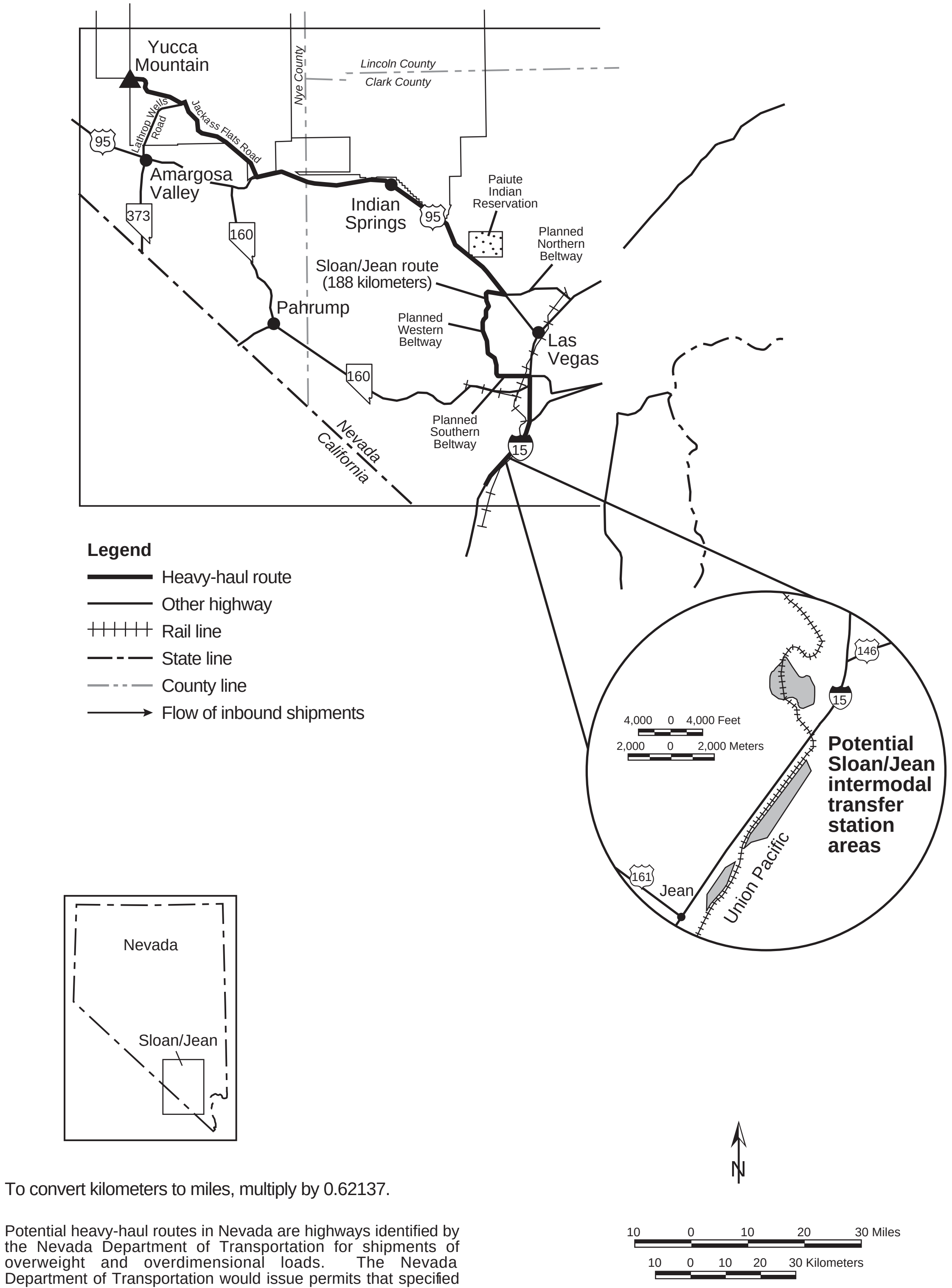
Fossil fuel that would be consumed by heavy-haul trucks during operations is discussed in Chapter 10, which addresses irreversible commitments of resources.

6.3.3.2.4 *Sloan/Jean Route Implementing Alternative*

The Sloan/Jean route (Figure 6-21) is about 188 kilometers (117 miles) long. Heavy-haul trucks and escorts leaving a Sloan/Jean intermodal transfer station would enter I-15 at the Sloan interchange. The trucks would travel on I-15 to the exit to the southern portion of the proposed Las Vegas Beltway, and then travel northwest on the beltway. They would leave the beltway at U.S. 95, and travel north on U.S. 95 to the Mercury entrance to the Nevada Test Site. The trucks would travel on Jackass Flats Road on the Nevada Test Site to the Yucca Mountain site.

The three potential areas for an intermodal transfer station southwest of Las Vegas are between the existing Union Pacific sidings at Sloan and Jean. One area is on the east side of I-15, south of the Union Pacific rail underpass at I-15, and has an area of 3.3 square kilometers (811 acres). The second, which has an area of 3.1 square kilometers (758 acres), is south of the Sloan rail siding along the east side of the rail line. A third area is south of the second, directly north of the Jean interchange on I-15, and has an area of 1.0 square kilometer (257 acres).

The following sections address impacts that would occur to land use; air quality; biological resources and soils; hydrology including surface water and groundwater; cultural resources; occupational and public health and safety; socioeconomics; noise; and utilities, energy, and materials. Impacts that would occur to aesthetics and waste management would be the same as those discussed in Section 6.3.3.1 and are,



To convert kilometers to miles, multiply by 0.62137.

Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. The Nevada Department of Transportation would issue permits that specified approved routing for heavy-haul truck shipments on Nevada highways. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

Source: Modified from DOE (1998g, all).

Figure 6-21. Sloan/Jean heavy-haul truck route.

therefore, not repeated here. Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.

Land Use and Ownership

This section describes anticipated land-use impacts that could occur from the construction and operation of the Sloan/Jean intermodal transfer station, upgrades of highways, and heavy-haul truck operations over the Sloan/Jean route. Chapter 3, Section 3.2.2.2.1, describes the Sloan/Jean intermodal transfer station site and the associated truck route.

Construction. At the Sloan/Jean intermodal station area there could be potential impacts related to the current use of the land. All three Sloan/Jean candidate sites are on land administered by the Bureau of Land Management. The northernmost area is in the Spring Mountain grazing allotment and the Ivanpah Valley desert tortoise area of critical environmental concern. The Bureau of Land Management has designated land east of the railroad as a gravel pit (community pit), but that land has not been worked; the area is open to fluid mineral leasing but closed to mining claims. The two southern areas are in the Jean Lake grazing allotment, a special recreation management area, and an area designated as available for sale or transfer. Both southern areas are open to fluid mineral leasing and mining claims (TRW 1999f, page 21).

The Sloan/Jean route would require considerable improvements at the interchange with I-15. These disturbed areas probably would be subject to increased erosion for at least some of the construction phase. Water would be applied during construction to suppress dust and compact the soil; this would reduce the potential for erosion. Drainage control along the route probably would remain as it is now. These combined measures would minimize the potential for adverse impacts to soils. Section 6.3.3.1 discusses other impacts on land use from upgrading Nevada highways for use by heavy-haul trucks.

Operations. There would be no direct land-use impacts associated with the operation of the Sloan/Jean intermodal transfer station or the Sloan/Jean route other than those described in Section 6.3.3.1.

Air Quality

This section describes anticipated nonradiological air quality impacts from the construction and operation of an intermodal transfer station and heavy-haul truck operation along the Sloan/Jean upgraded route. Such impacts would result from releases of criteria pollutants, including nitrogen dioxide, sulfur dioxide, carbon monoxide, and particulate matter (PM_{10} and $PM_{2.5}$).

Construction. Section 6.3.3.1 discusses air quality impacts for the construction of the Sloan/Jean intermodal transfer station. These impacts would be a result of emissions from construction equipment and fugitive dust from earth excavation and construction vehicle traffic. The Sloan/Jean intermodal transfer station locations are near or in the Las Vegas air basin, which is in nonattainment with national Ambient Air Quality Standards for carbon monoxide and PM_{10} (FHWA 1996, pages 3-53 and 3-54). Because the station could affect the air basin, DOE compared its estimated annual emission rates to the General Conformity Rule annual emission threshold levels for carbon monoxide and particulate matter. Based on the predicted annual rates, the construction of the Sloan/Jean intermodal transfer station would emit about 2 percent of the emission threshold level for carbon monoxide and 48 percent for PM_{10}. Based on this evaluation, a general conformity analysis would not be required for construction of the intermodal transfer station.

Section 6.3.3.1 also discusses the air quality impacts from upgrades of the Sloan/Jean route for heavy-haul truck transport. These impacts would be a result of emissions from construction equipment and fugitive dust from earth excavation and construction vehicle traffic. Construction equipment design and controls would ensure that emissions did not exceed ambient air quality standards. Most of the road upgrades would occur in areas that are in attainment for criteria pollutants. However, portions of the upgrades would occur in the Las Vegas Valley airshed, which is in nonattainment for carbon monoxide and PM_{10}.

Operations. Section 6.3.3.1 discusses the air quality impacts associated with the operation of the Sloan/Jean intermodal transfer station and from emissions of heavy-haul trucks. The potential station locations are near or in the Las Vegas air basin, which is in nonattainment for carbon monoxide and PM_{10}. Because the operation of a station could affect the air basin, DOE compared the estimated annual emission rates to the General Conformity Rule annual emission threshold levels for carbon monoxide and particulate matter. Based on the predicted annual emission rates, the operation of the Sloan/Jean intermodal transfer station would emit about 9 percent and 2 percent of the emission threshold levels for carbon monoxide and PM_{10}, respectively. Therefore, a general conformity analysis would not be required for operation of the intermodal transfer station.

The Sloan/Jean route would involve heavy-haul trucks passing through the Las Vegas Valley airshed, which is in nonattainment for carbon monoxide and PM_{10}. The air quality impacts to this airshed from the operation of four or five trucks a day would be very small in comparison to the amount of pollutants emitted from automobile travel and other commercial vehicles in the basin.

Hydrology

DOE anticipates limited impacts to surface water and groundwater during upgrades to Nevada highways so they could accommodate daily use by heavy-haul trucks. This section discusses these impacts as well as those from the construction and operation of an intermodal transfer station and operation of trucks on the Sloan/Jean route. Section 6.3.3.1 discusses the hydrology impacts that would be common to all of the heavy-haul truck implementing alternatives. This section focuses on the hydrology impacts that would be unique to the Sloan/Jean heavy-haul truck implementing alternative.

Surface Water

Section 6.3.3.1 discusses the impacts to surface water from the construction and operation of an intermodal transfer station and upgrades to highways. The common impacts discussed in that section apply to surface water along the Sloan/Jean route.

Groundwater

Construction. Section 6.3.3.1 discusses the impacts to groundwater from the construction of an intermodal transfer station. Upgrades to the Sloan/Jean route would not require any water wells. The road upgrades would require an estimated total of about 9,200 cubic meters (8 acre-feet) of water (LeFever 1998b, all). Options for obtaining this water would be to lease temporary water rights from individuals along the route, ship water from other permitted resources by truck (about 500 truckloads) to construction sites, or use a combination of these two actions.

Operations. Section 6.3.3.1 discusses impacts to groundwater from the operation of an intermodal transfer station, highway maintenance, and heavy-haul routes.

Biological Resources and Soils

Section 6.3.3.1 discusses impacts to biological resources from the construction and operation of an intermodal transfer station and upgrades to highways that would be common to all intermodal transfer stations and routes. This section discusses the construction- and operations-related impacts that would be unique to the Sloan/Jean intermodal station and route.

Construction. Potential Sloan/Jean intermodal transfer station site locations are between the existing Union Pacific rail sidings at Sloan and Jean. The dominant land cover type in these areas is creosote-bursage (TRW 1999k, page 3-36). The land cover type at the site is extensive in the region (Utah State University 1996, GAP data).

The three sites that DOE is considering for a Sloan/Jean intermodal transfer station are in the range of the desert tortoise, but none of the areas are critical habitat for the tortoise (50 CFR 17.95). The construction site would disturb approximately 0.2 square kilometer (50 acres) of tortoise habitat. The likelihood of tortoise death or injury due to construction activities would be small if DOE moved tortoises in the immediate area to a safe habitat. The pinto beardtongue (classed as sensitive by the Bureau of Land Management) occurs in two of the proposed locations of the Sloan/Jean intermodal transfer station (TRW 1999k, page 3-36). If one of these sites was selected, DOE would conduct pre-activity surveys for this plant species and would avoid disturbance of occupied areas if possible. There are no designated game habitats at the proposed location for the intermodal transfer station, and there are no springs or other areas that could be classified as wetlands (TRW 1999k, page 3-36).

Predominant land cover types in nonurban areas along the route are creosote-bursage and Mojave mixed scrub (TRW 1999k, page 3-36). The regional area for each vegetation type is extensive. Because areas disturbed by upgrade activities would be in or adjacent to existing rights-of-way and the areas have been previously degraded by human activities, impacts would be small.

The only threatened or endangered species that occurs along the route is the desert tortoise. Desert tortoise habitat occurs throughout the length of the route (Bury and Germano 1984, pages 57 to 72; 50 CFR 17.95). Construction activities could kill or injure desert tortoises; however, losses would be few because construction would occur only on the right-of-way and desert tortoises are uncommon along heavily traveled roads (Bury and Germano 1984, Appendix D, page D12). Four other special status species occur along this route (TRW 1999k, page 3-36), but construction activities would be limited to the road and adjacent areas; occupied habitat would not be destroyed and these species should not be affected.

This route would not cross any areas designated as game habitat and there are no springs or wetlands near the route. The corridor crosses a number of ephemeral streams that may be classified as waters of the United States. DOE would work with the State of Nevada and the U.S. Army Corps of Engineers to minimize impacts to these areas, and obtain individual or regional permits, as appropriate (TRW 1999k, page 3-36). Impacts to soils would be transitory and small and would occur only along the shoulders of existing roads.

Operations. Impacts from operations would include periodic disturbances of wildlife from activities at the intermodal transfer station and additional truck traffic along this route. Trucks probably would kill individuals of some species but losses would be few and unlikely to affect regional populations of any species. No additional habitat loss would occur during operations. Impacts to soils would be small.

Cultural Resources

Section 6.3.3.1 discusses the impacts to cultural resources that would be common to all the heavy-haul truck implementing alternatives.

There are seven archaeological sites near the Sloan/Jean intermodal transfer station locations, none of which has been evaluated for potential eligibility for the *National Register of Historical Places*.

The Sloan/Jean route follows a portion of U.S. 95 that passes through approximately 1.6 kilometers (1 mile) of the Las Vegas Paiute Indian Reservation. However, no field studies have been completed for the route. Therefore, specific impacts to culturally important sites, areas, or resources cannot be determined at this time.

Occupational and Public Health and Safety

This section addresses potential impacts to occupational and public health and safety from upgrading highways and heavy-haul truck operations on the Sloan/Jean route. Impacts from the associated intermodal transfer station in the Sloan/Jean area would be the same as those discussed in Section 6.3.3.1.

Construction. Industrial safety impacts on workers from upgrading highways for the Sloan/Jean route would be small (Table 6-72). The analysis evaluated the potential for impacts in terms of total reportable cases of injury, lost workday cases, fatality risks for workers, and traffic fatalities related to commuting workers and the movement of construction materials and equipment. Table 6-73 lists the estimated fatalities from construction and commuter vehicle traffic.

Operations. The incident-free radiological impacts listed in Table 6-74 would occur during the routine transportation of spent nuclear fuel and high-level radioactive waste on the Sloan/Jean route. These impacts would include transportation along the Sloan/Jean route as well as transportation along railways in Nevada leading to the Sloan/Jean intermodal transfer station. The table includes the impacts of 2,600 legal-weight truck shipments from commercial sites that do not have the capability to load rail casks.

Table 6-72. Health impacts to workers from industrial hazards from upgrading highways along the Sloan/Jean route.

Group and industrial impact category	Construction[a]	Operations[b]
Involved workers		
Total recordable cases[c]	10	160
Lost workday cases	4	90
Fatalities	0.07	0.3
Noninvolved workers[d]		
Total recordable cases	2	7
Lost workday cases	1	4
Fatalities	0	0.007
Totals[e]		
Total recordable cases	12	170
Lost workday cases	5	94
Fatalities	0.07	0.3

a. Impacts are totals over about 6 months.
b. Includes impacts for periodic maintenance and resurfacing. Impacts are totals over about 24 years.
c. Total recordable cases includes injury and illness.
d. The noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
e. Totals might differ from sums due to rounding.

Socioeconomics

This section describes socioeconomic impacts that would occur from upgrading and using highways along the Sloan/Jean route and building an intermodal transfer station for heavy-haul truck transportation. It includes the impacts of operating an intermodal transfer station near Sloan/Jean in southern Nevada.

Table 6-73. Estimated number of fatalities from construction material delivery vehicles and construction and operations worker commuting traffic for the Sloan/Jean route for heavy-haul trucks.

Activity	Kilometers[a]	Traffic fatalities	Vehicle emissions fatalities
Construction[b]			
Material delivery vehicles	32,000,000	0.6	0.0023
Commuting workers	21,000,000	0.2	0.0015
Subtotals	*53,000,000*	*0.8*	*0.0038*
Operations[c]			
Commuting workers	120,000,000	1.2	0.0089
Totals	***170,000,000***	***2.0***	***0.013***

a. To convert kilometers to miles, multiply by 0.62137.
b. Impacts are totals over about 6 months.
c. Impacts are totals over 24 years.

Construction. Socioeconomic impacts from upgrading highways for a Sloan/Jean route and building an intermodal transfer station would be transient, occur over short periods, and be spread among the communities and counties along the route. Employment for route upgrades and intermodal transfer station construction would be about 230 workers. Upgrading highways for the route would cost about

Table 6-74. Health impacts from incident-free Nevada transportation for the Sloan/Jean heavy-haul truck implementing alternative.[a]

Category	Legal-weight truck shipments	Rail and heavy-haul truck shipments[b]	Totals[c]
Involved workers			
Collective dose (person-rem)	220	490	710
Estimated latent cancer fatalities	0.09	0.2	0.29
Public			
Collective dose (person-rem)	270	750	1,000
Estimated latent cancer fatalities	0.13	0.38	0.51
Estimated vehicle emission-related fatalities	0.00014	0.015	0.015

a. Impacts are totals for 24 years (2010 to 2033).

b. Includes impacts to workers at an intermodal transfer station.

c. Totals might differ from sums of values due to rounding.

$20 million (1998 dollars) and would require 6 months to complete. Constructing an intermodal transfer station would cost $24 million (1998 dollars) and require 1.5 years.

Employment for both construction workers (direct workers) and other workers who would be employed either because of highway upgrade and intermodal transfer station projects or as a result of the economic activity generated by the project (indirect workers) would be about 720. The change in employment for Clark, Nye, and Lincoln Counties, and the remainder of Nevada would be much less than 1 percent of their employment bases.

Increased employment would affect population. The projected increases in population would reach a peak of about 560 in 2009. Population changes for Clark, Nye, and Lincoln Counties, and the remainder of Nevada that would arise from increased employment would be much less than 1 percent above the baseline. Thus, employment and population impacts would be small in comparison to existing employment and populations in the affected counties.

Increased real disposable income in Clark, Nye, and Lincoln Counties, and the remainder of Nevada for highway improvements and intermodal transfer station construction would peak in 2009 at $19.9 million. Gross Regional Product would peak in 2009 at $33.6 million. Increased State and local government expenditures resulting from highway upgrade and intermodal transfer station construction projects would reach their peak in 2009 at $1.5 million. Changes to real disposable income, Gross Regional Product, and government expenditures would be small—much less than 1 percent for Clark, Nye, and Lincoln Counties, and the remainder of Nevada. (All dollar values reported in this section are in 1992 constant dollars unless otherwise stated.)

Operations. Operations at an intermodal transfer station and the use of heavy-haul trucks would begin in 2010 and last until 2033. An operations workforce of about 26 would be required for the intermodal transfer station. For the national mostly rail transportation scenario, the station would operate throughout the year. The workforce for heavy-haul truck operations over a Sloan/Jean route, including shipment escorts, would be about 66 workers. The analysis assumed that operations workers would reside in Clark County.

Employment would be likely to remain relatively level throughout operations. Operations employment (direct and indirect) would be about 120 workers. The impact on population would be about 200 additional residents. Employment and population increases for Clark, Nye, and Lincoln Counties, and the remainder of Nevada would be small in comparison to existing employment and population levels.

Real disposable income from operating an intermodal transfer station in Sloan/Jean and operating heavy-haul trucks based at Sloan/Jean would rise throughout operations, starting at $1.6 million in 2010 and increasing to $5.4 million in 2033. Gross Regional Product would also rise during operations, starting at $2.3 million in 2010 and increasing to $4.7 million in 2033. Annual State and local government expenditures would increase from $240,000 in 2010 to $840,000 in 2033. Increases to real disposable income, Gross Regional Product, and government expenditures would be small—much less than 1 percent in Clark, Nye, and Lincoln Counties, and the remainder of Nevada for the Sloan/Jean route.

Because of the periodic need to resurface highways used by the heavy-haul trucks, employment would increase in the years these projects occurred. During those years, employment (direct and indirect) in the region would increase by about 100 for a Sloan/Jean route. Overall, employment changes from periodic (every 8 years) highway resurfacing projects would be small in Clark, Nye, and Lincoln Counties, and the remainder of Nevada for the route. As a consequence, impacts to employment and population in affected counties in Nevada would be small and transient for highway resurfacing projects.

Noise

Section 6.3.3.1 discusses noise impacts common to all the heavy-haul truck implementing alternatives. This section focuses on the noise impacts that would be unique to the Sloan/Jean heavy-haul truck implementing alternative.

Construction. There are residences and commercial businesses near the three potential sites for an intermodal transfer station in the Sloan/Jean area. Construction noise would occur during daylight hours and would be a temporary source of elevated noise in the area. Nighttime noise impacts would be unlikely because construction activities would not occur at night.

For the Sloan/Jean route, southern and western Las Vegas, the Town of Indian Springs, and the small rural community of Jean would be within the 2,000-meter (6,560-foot) region of influence for construction noise. Construction activities would occur on all sections of the route with the exception of I-15 between its interchange at Sloan and the planned Southern Las Vegas Beltway. Because the number of inhabitants of the region of influence would be high because the route passes around the greater Las Vegas area and includes other small rural communities and towns, there is a potential for construction noise impacts.

Operations. The presence of residences and commercial businesses near the Sloan/Jean location would make an intermodal transfer station a potential source of more noise complaints than the more remote locations. However, because operational noise in the vicinity of Sloan/Jean would not be much higher than the levels associated with most other light industrial areas, noise impacts would be unlikely. Railcar switching would be the greatest source of noise.

However, there would be a potential for noise impacts from heavy-haul truck operations along the Sloan/Jean route, based on community size and the number of affected communities. The route passes the City of Las Vegas, one established town, and one rural area on its way to the Yucca Mountain site.

Utilities, Energy, and Materials

Section 6.3.3.1 discusses utilities, energy, and materials impacts that would be common to all the heavy-haul truck implementing alternatives. This section focuses on the utilities, energy, and materials impacts that would be unique to the Sloan/Jean heavy-haul truck implementing alternative.

Construction. The construction of the Sloan/Jean intermodal transfer station would have the same utilities, energy and materials impacts as those discussed in Section 6.3.3.1.

Table 6-75 lists the estimated quantities of primary materials for the upgrade of Nevada highways for the Sloan/Jean route. These quantities are not likely to be very large in relation to the southern Nevada regional supply capacity (see Section 6.3.3.1).

Table 6-75. Utilities, energy, and materials required for upgrades along the Sloan/Jean route.

Route	Length (kilometers)[a]	Diesel fuel (million liters)[b]	Gasoline (thousand liters)	Asphalt (million metric tons)[c]	Concrete (thousand metric tons)	Steel[d] (metric tons)
Sloan/Jean	188	1.7	29	0.24	0.1	2.3

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. To convert metric tons to tons, multiply by 1.1023.
d. Steel includes rebar only.

Operations. Section 6.3.3.1 discusses utilities, energy, and materials needs for operation of an intermodal transfer station.

Fossil fuel that would be consumed by heavy-haul trucks during operations is discussed in Chapter 10, which addresses irreversible commitments of resources.

6.3.3.2.5 *Apex/Dry Lake Route Implementing Alternative*

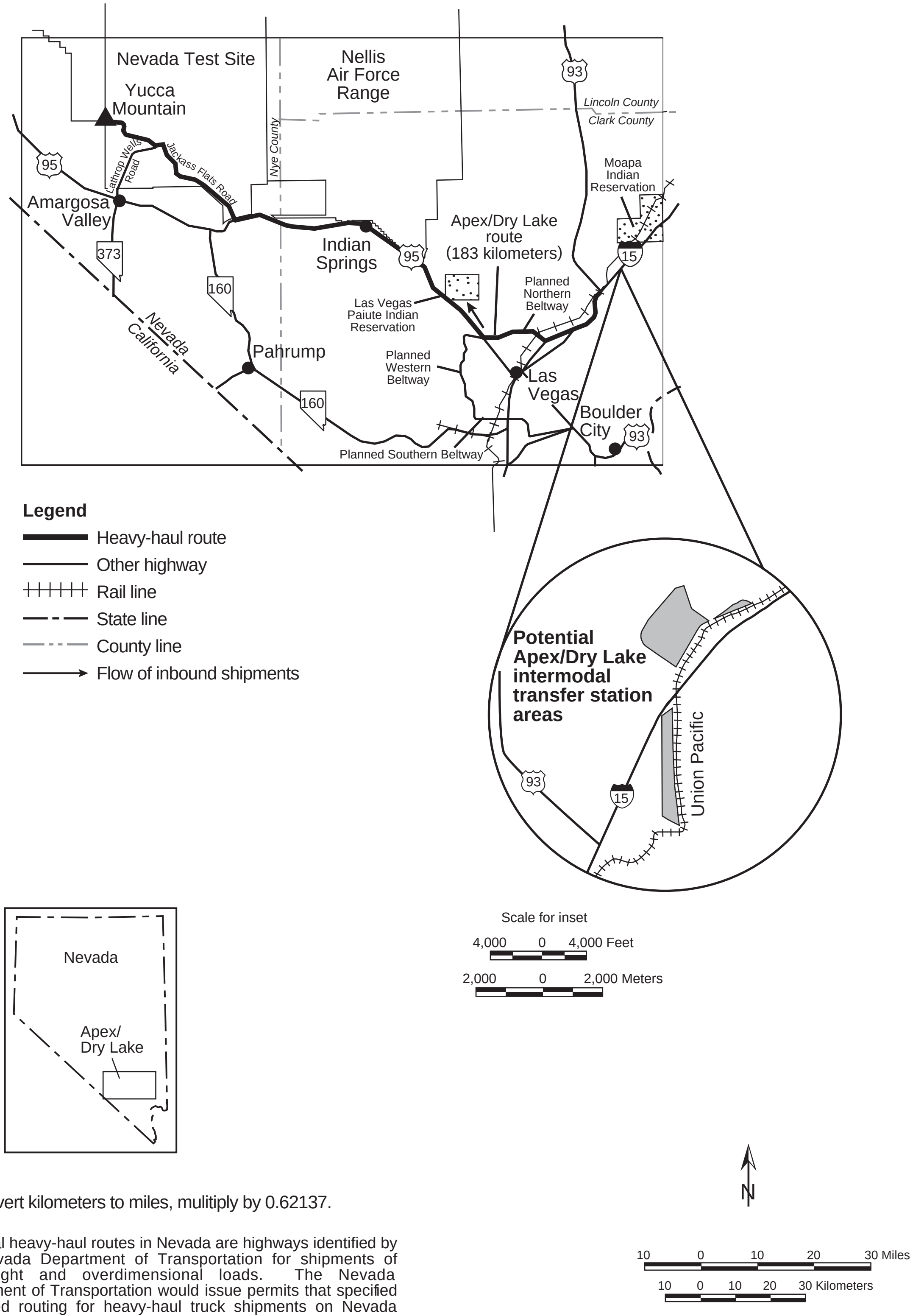
The Apex/Dry Lake route (Figure 6-22) is about 183 kilometers (114 miles) long. Heavy-haul trucks and escorts would leave the intermodal transfer station at the Apex/Dry Lake location and enter I-15 at the Apex interchange. The trucks would travel south on I-15 to the exit to the proposed northern Las Vegas Beltway and travel west on the beltway. They would leave the beltway at U.S. 95, and travel north on U.S. 95 to the Mercury entrance to the Nevada Test Site. The trucks would travel on Jackass Flats Road on the Nevada Test Site to the Yucca Mountain site.

The potential sites for the Apex/Dry Lake intermodal transfer station are in areas northeast of Las Vegas between the Union Pacific rail sidings at Dry Lake and at Apex. Two large contiguous areas are available for station siting. The first area is directly adjacent to the Dry Lake siding. The Dry Lake area is large [3.5 square kilometers (877 acres)] and has flat topography along the west side of the Union Pacific line. It is bounded by hills to the north and by a wash and private land to the south. The second area, which is on the east side of I-15 adjacent to the Union Pacific line and south of where the main Union Pacific line crosses I-15, has an area of 0.96 square kilometers (237 acres). Because this area is between the Dry Lake and Apex sidings, the construction of an additional rail siding would be necessary.

The following sections address impacts that would occur to land use; biological resources and soils; occupational and public health and safety; socioeconomics; and utilities, energy, and materials. Impacts to air quality, noise, and hydrology from the construction and operation of an intermodal transfer station, upgrading of highways, and operation of heavy-haul trucks on an Apex/Dry Lake route would be the same as those discussed in Section 6.3.3.2.4 for a Sloan/Jean route. Impacts to cultural resources, aesthetics, and waste management would be the same as those discussed in Section 6.3.3.1 and are, therefore, not repeated here. Section 6.3.4 discusses the potential for transportation activities to cause environmental justice impacts in Nevada.

Land Use and Ownership

This section describes estimated land-use impacts that could occur from the construction and operation of the Apex/Dry Lake intermodal transfer station, upgrades of highways, and heavy-haul truck operations on the Apex/Dry Lake route. Chapter 3, Section 3.2.2.2.1, describes the Apex/Dry Lake intermodal transfer station site and associated truck route.



To convert kilometers to miles, mulitiply by 0.62137.

Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. The Nevada Department of Transportation would issue permits that specified approved routing for heavy-haul truck shipments on Nevada highways. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

Source: Modified from DOE (1998g, all).

Figure 6-22. Apex/Dry Lake heavy-haul truck route.

Construction. The Apex/Dry Lake intermodal transfer station site could have potential impacts related to the current use of the land. Both potential Apex/Dry Lake site areas are on land administered by the Bureau of Land Management. The northern area has several infrastructure corridors (power line, telephone, and road rights-of-way). It is in the Dry Lake grazing allotment and a planned utility corridor. It is also open to mineral leasing and mining claims. One area has been designated as available for sale or transfer.

The Apex/Dry Lake route would require considerable improvements at the interchange at I-15. These disturbed areas probably would be subject to increased erosion for at least some of the construction phase. Water would be applied during construction to suppress dust and compact the soil; this would reduce the potential for erosion. Drainage control along the route probably would remain as it is now. These combined measures would minimize the potential for adverse impacts to soils. Section 6.3.3.1 discusses impacts on land use from upgrading Nevada highways for use by heavy-haul trucks.

Operations. There would be no direct land-use impacts associated with the operation of the Apex/Dry Lake intermodal transfer station or the Apex/Dry Lake route other than those described in Section 6.3.3.1.

Biological Resources and Soils

Section 6.3.3.1 discusses impacts to biological resources from the construction and operation of an intermodal transfer station and upgrades to highways that would be common to all intermodal transfer stations and routes. This section discusses the construction- and operations-related impacts that would be unique to the Apex/Dry Lake intermodal station and route.

Construction. DOE has identified three areas for the construction of an Apex/Dry Lake intermodal transfer station. The predominant land cover type at these sites (creosote-bursage) is extensively distributed in the region (TRW 1999k, page 3-36; Utah State University 1996, GAP data). Considerable industrial development has occurred near the potential sites. The three sites are in the range of the threatened desert tortoise, although none is in an area considered to be critical habitat for the tortoise (50 CFR 17.95). The construction site would disturb approximately 0.2 square kilometer (50 acres) of desert tortoise habitat. The likelihood of death or injury to tortoises due to construction activities would be small if DOE conducted surveys for tortoises in areas to be disturbed and moved tortoises in the immediate area out of harm’s way. Geyer’s milk vetch (BLM sensitive) occurs on the southern edge of one of the proposed locations of the Apex/Dry Lake intermodal transfer station (TRW 1999k, page 3-37). If this location for an intermodal transfer station was selected, DOE would conduct pre-activity surveys for this plant’s species and would avoid occupied habitat if possible. There are no designated game habitats at the proposed locations for the intermodal transfer station, or any springs or other areas that could be classified as wetlands (TRW 1999k, page 3-37).

The predominant land cover types along the Apex/Dry Lake heavy-haul route are creosote-bursage and Mojave mixed scrub, which are common throughout this region (TRW 1999k, page 3-34; Utah State University 1996, GAP data). Because areas disturbed by upgrade activities would be in or adjacent to the existing rights-of-way and the areas have been previously degraded by human activities, impacts would be small.

The only resident threatened or endangered species that occurs along the Apex/Dry Lake route is the desert tortoise. Desert tortoise habitat occurs along the entire length of the route (Bury and Germano 1984, pages 57 to 72; 50 CFR 17.95). Construction activities could kill or injure desert tortoises; however, losses would be few because construction would occur only on the right-of-way and desert tortoises are uncommon adjacent to heavily traveled roads (Bury and Germano 1984, Appendix D, page D12). Three other special status species occur along this route (TRW 1999k, page 3-35) but because construction activities would be limited to the road and adjacent areas, occupied habitat would not be destroyed and these species should not be affected.

This route would not cross any areas designated as game habitat or springs or possible wetlands (TRW 1999k, page 3-35). The corridor crosses a number of ephemeral streams that may be classified as waters of the United States. DOE would work with the State of Nevada and the U.S. Army Corps of Engineers to minimize impacts to these areas, and obtain individual, regional, or nationwide permits, as appropriate. Impacts to soils would be transitory and small and would occur only along the shoulders of existing roads.

Operations. Impacts from operations would include periodic disturbances of wildlife from activities at the intermodal transfer station and additional truck traffic along this route. Trucks probably would kill individuals of some species but losses would be few and unlikely to affect regional populations of any species. No additional habitat loss would occur during operations. Impact to soils would be small.

Occupational and Public Health and Safety

This section addresses potential impacts to occupational and public health and safety from upgrading highways and heavy-haul truck operations on the Apex/Dry Lake route. The impacts of the Apex/Dry Lake intermodal transfer station would be the same as those discussed in Section 6.3.3.1.

Construction. Industrial safety impacts on workers from upgrading highways for the Apex/Dry Lake route would be small (see Table 6-76). The analysis evaluated the potential for impacts in terms of total reportable cases of injury, lost workday cases, fatalities for workers, and traffic fatalities related to commuting workers and the movement of construction materials and equipment. Table 6-77 lists the estimated fatalities from construction and commuter vehicle traffic.

Operations. Incident-free radiological impacts listed in Table 6-78 would occur during the routine transportation of spent nuclear fuel and high-level radioactive waste on the route. These impacts would include transportation along the route as well as transportation along railways in Nevada leading to an Apex/Dry Lake intermodal transfer station. The table includes the impacts of 2,600 legal-weight truck shipments from commercial sites that do not have the capability to load rail casks.

Table 6-76. Impacts to workers from industrial hazards from upgrading highways along the Apex/Dry Lake route.

Group and trauma category	Construction[a]	Operations[b]
Involved workers		
Total recordable cases[c]	9	160
Lost workday cases	4	90
Fatalities	0.06	0.3
Noninvolved workers[d]		
Total recordable cases	2	7
Lost workday cases	1	4
Fatalities	0.004	0.007
Totals[e]		
Total recordable cases	11	170
Lost workday cases	5	94
Fatalities	0.06	0.3

a. Impacts are totals over about 6 months.
b. Includes periodic maintenance and resurfacing. Impacts are totals over about 24 years.
c. Total recordable cases includes injury and illness.
d. The noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
e. Totals might differ from sums due to rounding.

Socioeconomics

This section describes socioeconomic impacts that would occur from upgrading and using highways along the Apex/Dry Lake route and building an intermodal transfer station for heavy-haul truck transportation. It includes impacts from the operation of an intermodal transfer station at the Apex/Dry Lake site in Clark County.

Construction. Socioeconomic impacts from upgrading highways for an Apex/Dry Lake route and building an intermodal transfer station would be transient, occur over short periods, and be spread among

Table 6-77. Estimated number of fatalities from construction material delivery vehicles and construction and operations worker commuting traffic for the Apex/Dry Lake route for heavy-haul trucks.

Activity	Kilometers[a]	Traffic fatalities	Vehicle emissions fatalities
Construction[b]			
Material delivery vehicles	32,000,000	0.6	0.0023
Commuting workers	20,000,000	0.2	0.0014
Subtotals	*52,000,000*	*0.8*	*0.0037*
Operations[c]			
Commuting workers	120,000,000	1.2	0.0089
Totals	***170,000,000***	***2.0***	***0.013***

a. To convert kilometers to miles, multiply by 0.62137.
b. Impacts are totals over about 6 months.
c. Impacts are totals over 24 years.

Table 6-78. Health impacts[a] from incident-free Nevada transportation for the Apex/Dry Lake heavy-haul truck implementing alternative.

Category	Legal-weight truck shipments	Rail and heavy-haul truck shipments[b]	Totals[c]
Involved workers			
Collective dose (person-rem)	220	470	690
Estimated latent cancer fatalities	0.09	0.19	0.28
Public			
Collective dose (person-rem)	270	670	940
Estimated latent cancer fatalities	0.13	0.34	0.47
Estimated vehicle emission-related fatalities	0.00014	0.0029	0.0030

a. Impacts are totals for 24 years (2010 to 2033).
b. Includes impacts to workers at an intermodal transfer station.
c. Totals might differ from sums of values due to rounding.

the communities and counties along the route. Employment for route upgrades and intermodal transfer station construction would be about 230 workers.

Upgrading highways for the Apex/Dry Lake route would cost $20 million (1998 dollars) and would require 6 months to complete. Constructing an intermodal transfer station would cost $24 million (1998 dollars) and require 1.5 years.

At its peak, increased employment for both construction workers (direct workers) and other workers who would be employed either because of highway upgrade and intermodal transfer station projects or as a result of the economic activity generated by the projects (indirect workers) would reach about 540. The change in employment for Clark, Lincoln, and Nye Counties, and the remainder of Nevada would be much less than 1 percent of the counties' employment bases.

Increased employment would also affect population. The projected increases in population would reach a peak of about 360 in 2009. Population changes for Clark, Lincoln, and Nye Counties, and the remainder of Nevada from increased employment would be much less than 1 percent above the baseline. Thus, employment and population impacts from highway upgrade and intermodal transfer station construction projects would be small in comparison to the existing employment and populations in the affected counties.

The increased real disposable income of people in the affected counties would reach a peak in 2009 at less than $14.6 million. Gross Regional Product would peak in 2009 at less than $26 million. Increased State and local government expenditures resulting from highway upgrade projects would reach their peak in

2009 at less than $1 million. (All dollar values reported in this section are in 1992 constant dollars unless otherwise stated.)

Changes to real disposable income, Gross Regional Product, and government expenditures would be small—much less than 1 percent for Clark, Lincoln, and Nye Counties, and the remainder of Nevada.

Operations. Operations at an intermodal transfer station and the use of heavy-haul trucks would begin in 2010 and last until 2033. An operations workforce of about 26 would be required for the intermodal transfer station. For the national mostly rail transportation scenario, the station would operate throughout the year. The workforce for heavy-haul truck operations over an Apex/Dry Lake route, including shipment escorts, would be about 66 workers. The analysis assumed that operations workers would reside in Clark County.

Employment would be likely to remain relatively level throughout operations. Operations employment (direct and indirect) would be about 120 workers. The impact on population would be about 190 additional residents. Employment and population increases for Clark, Lincoln, and Nye Counties, and the remainder of Nevada would be small in comparison to existing employment and population levels.

Real disposable income from operating an intermodal transfer station at Apex/Dry Lake and operating heavy-haul trucks would rise throughout operations, starting at $1.6 million in 2010 and increasing to $5.4 million in 2033. Gross Regional Product would also rise during operations, starting at $2.3 million in 2010 and increasing to $4.7 million in 2033. Annual State and local government expenditures would increase from about $240,000 in 2010 to $840,000 in 2033. Increases to real disposable income, Gross Regional Product, and government expenditures would be small—much less than 1 percent in Clark, Lincoln, and Nye Counties, and the remainder of Nevada for the Apex/Dry Lake route.

Because of the periodic need to resurface highways used by the heavy-haul trucks, employment would increase in the years these projects occurred. During those years, employment (direct and indirect) in the region would increase by about 100 for an Apex/Dry Lake route. Overall, employment changes from periodic (every 8 years) highway resurfacing projects would be small in Clark, Lincoln, and Nye Counties, and the remainder of Nevada for the route.

Population increases would follow the increases in employment for highway resurfacing projects. Overall, the short-term increase in population would be about 100. As a consequence, impacts to employment and population in affected counties in Nevada would be small and transient for highway resurfacing projects.

Utilities, Energy, and Materials

Section 6.3.3.1 discusses the utilities, energy, and materials impacts that would be common to all the heavy-haul truck implementing alternatives. This section focuses on the utilities, energy and materials impacts that would be unique to the Apex/Dry Lake heavy-haul truck implementing alternative.

Construction. The construction of the Apex/Dry Lake intermodal transfer station would have the same utilities, energy, and materials impacts as those discussed in Section 6.3.3.1.

Table 6-79 lists the estimated quantities of primary materials for the upgrade of Nevada highways for the Apex/Dry Lake route. These quantities are not likely to be very large in relation to the southern Nevada regional supply capacity (see Section 6.3.3.1).

Operations. Section 6.3.3.1 discusses the utilities, energy, and materials needs for the operation of an intermodal transfer station.

Table 6-79. Utilities, energy, and materials required for upgrades along the Apex/Dry Lake route.

Route	Length (kilometers)[a]	Diesel fuel (million liters)[b]	Gasoline (thousand liters)	Asphalt (million metric tons)[c]	Concrete (thousand metric tons)	Steel[d] (metric tons)
Apex/Dry Lake	183	1.6	28	0.23	0.1	2.3

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. To convert metric tons to tons, multiply by 1.1023.
d. Steel includes rebar only.

Fossil fuel that would be consumed by heavy-haul trucks during operations is discussed in Chapter 10, which addresses irreversible commitments of resources.

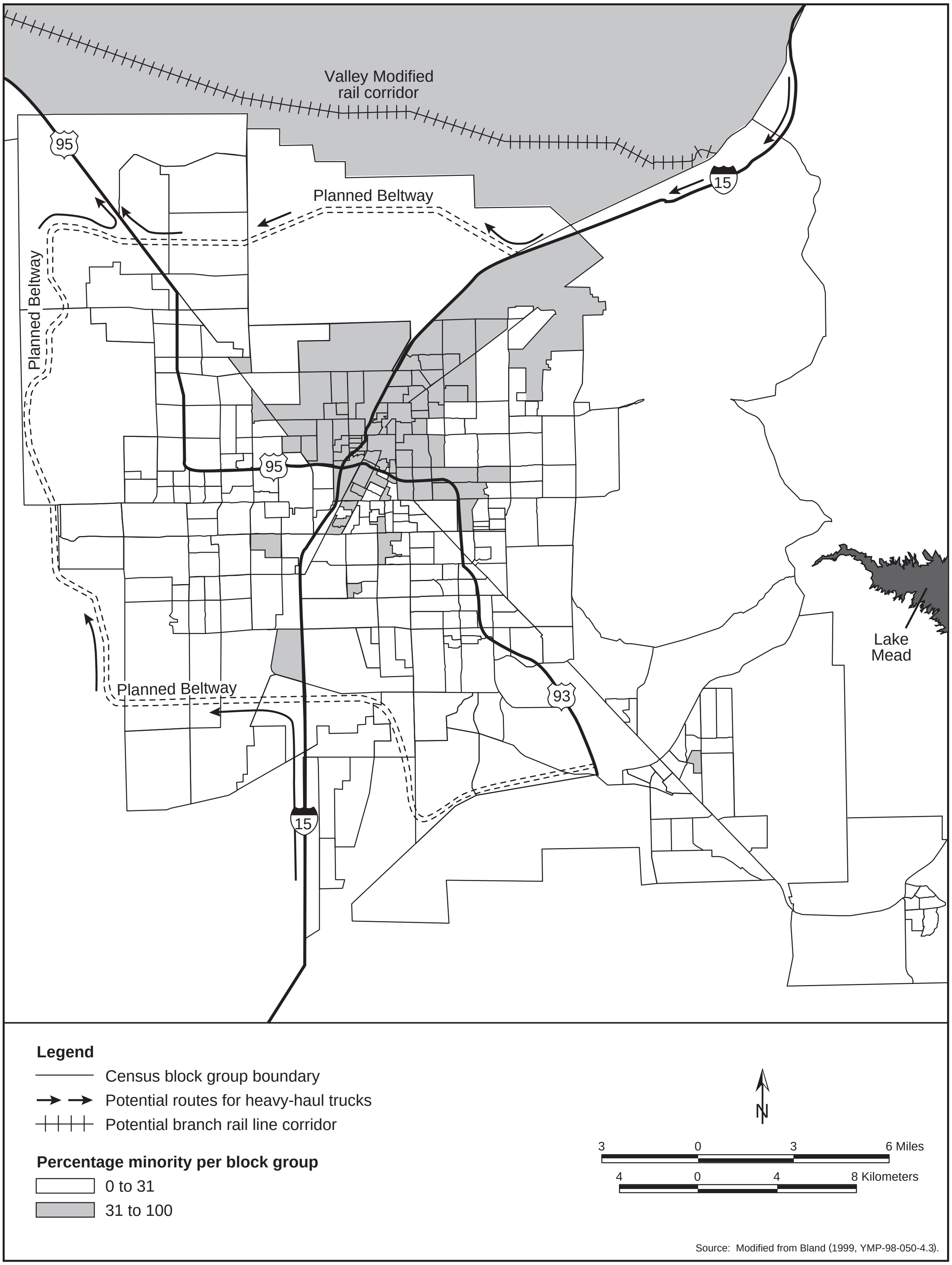
6.3.4 Environmental Justice Impacts in Nevada

The analysis considered existing highways and railroads that DOE would use in Nevada—I-15, the proposed Las Vegas Beltway; U.S. 95; five possible highway routes for heavy-haul trucks; the Union Pacific Railroad's mainlines in northern and southern Nevada; and alignments for a possible branch rail line in five rail corridors in the State. If DOE constructed and operated the repository, it would use combinations of these routes for shipments of spent nuclear fuel and high-level radioactive waste. DOE would use alternative preferred routes designated by the State of Nevada for highway shipments to the repository.

In general, the consequences of using a transportation route would occur close to the route. Thus, for transportation on a highway or railroad to affect a census block group for which environmental justice concerns could exist, the route would have to cross or be adjacent to the block group. Figure 3-23 shows the census block groups with minority percentages in Nevada. Figure 3-24 shows the census block groups with low-income percentages in Nevada. Figures 6-23 and 6-24 show the minority and low-income block groups, respectively, in the Las Vegas metropolitan area.

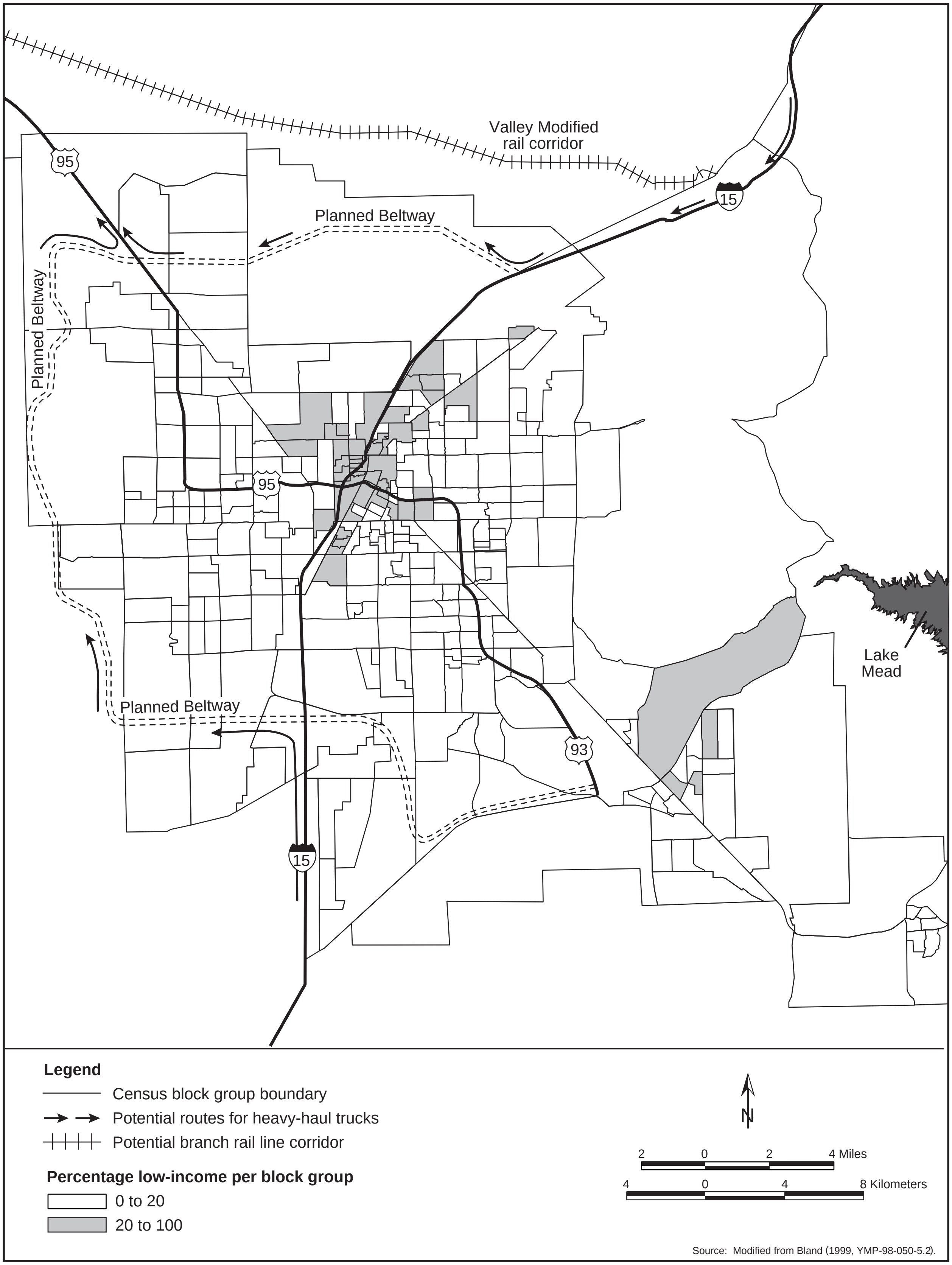
Portions of some routes would cross or be adjacent to Native American tribal lands. Highway routes avoid census block groups with high fractions of minority, low-income, or Native American populations with the exception of sections of I-15 that pass through the center of the Moapa Indian Reservation northeast of Las Vegas, Nevada; a 1.6-kilometer (1-mile) section of U.S. 95 across the southwest corner of the Las Vegas Paiute Indian Reservation; and sparsely populated areas of census block groups in the northern parts of Clark County. The Union Pacific Railroad's mainline tracks pass through the center of the Moapa Indian Reservation and through the center of Las Vegas, Nevada, crossing census block groups with high fractions of minority and low-income populations. Also, a branch rail line in the Valley Modified rail corridor would pass near the Las Vegas Paiute Indian Reservation, and the Caliente-Las Vegas and Apex/Dry Lake routes for heavy-haul trucks would pass near the Moapa Indian Reservation. None of the potential intermodal transfer station sites that DOE could use would be near a census block group with high minority or low-income populations, but an intermodal transfer station in the Apex/Dry Lake area could be as close as about 3 kilometers (2 miles) to the Moapa Indian Reservation.

Impacts along Nevada highways and railroads from the transportation of spent nuclear fuel and high-level radioactive waste would be small. The number of shipments in the mostly legal-weight truck and mostly rail scenarios would be small in comparison to the number of all other commercial shipments in southern Nevada. For comparison, under the mostly legal-weight truck scenario as many as five trucks carrying spent nuclear fuel would pass through the Moapa Indian Reservation on I-15 each day compared to daily traffic of more than 3,000 commercial trucks that use this section of highway (NDOT 1997, page 6; Cerocke 1998, all). Under the mostly rail scenario as many as 11 railcars per week carrying spent nuclear fuel could travel into southern Nevada compared to about 1,000 railcars each day for other



Source: Modified from Bland (1999, YMP-98-050-4.3).

Figure 6-23. Minority census block groups in the Las Vegas metropolitan area.



Source: Modified from Bland (1999, YMP-98-050-5.2).

Figure 6-24. Low-income census block groups in the Las Vegas metropolitan area.

commodities. Thus, impacts from truck and rail traffic and emissions would be small for these shipments. The potential for accidents that could result in injuries or fatalities involving the shipments would also be small in comparison to the overall risk of accidents that would occur from other commercial traffic.

Up to about 10 percent of travel in southern Nevada by legal-weight trucks or railcars carrying spent nuclear fuel would be through Native American reservations and census block groups with high fractions of minorities or low-income populations. Because public health and safety impacts to all populations in Nevada would be small (less than 1 latent cancer fatality for incident-free transportation and 0.0005 latent cancer fatality for accidents over 24 years), the impacts to populations along 10 percent of the routes of travel would also be small. Because the probability would be small at any single location, the risk of an accident at a specific location would also be small. Thus, impacts to minority or low-income populations or to Native Americans in small communities along the routes would also be small and, therefore, unlikely to be disproportionately high and adverse.

In addition, for existing highways and mainline railroads, the added traffic would be minimal and shipments of spent nuclear fuel and high-level radioactive waste would be unlikely to affect land use, air quality, hydrology, biological resources and soils, cultural resources, socioeconomics, noise, or aesthetics. The analyses discussed in the preceding sections also determined that impacts to these resource areas from construction and operation of a branch rail line in any of the five potential rail corridors or construction of an intermodal transfer station and upgrading of highways in Nevada would be low.

Because the analyses did not identify large impacts for railroad and highway transportation of spent nuclear fuel and high-level radioactive waste in Nevada that would constitute credible adverse impacts on populations, workers, or individuals, adverse effects would be unlikely for any specific segment of the population, including minorities, low-income groups, and Native American tribes. Thus, there would be no environmental justice impacts in Nevada unique to shipment by legal-weight truck, by rail using one of the branch rail line implementing alternatives, or by heavy-haul truck using an intermodal transfer station and one of the five highway routes evaluated. In addition, environmental justice impacts would be unlikely for the construction of an intermodal transfer station and upgrading of highways for one of the possible heavy-haul truck routes. Chapter 4, Section 4.1.13.4, contains an environmental justice discussion of a Native American perspective on the Proposed Action.

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7. ENVIRONMENTAL IMPACTS OF THE NO-ACTION ALTERNATIVE

This chapter describes the potential impacts associated with the No-Action Alternative described in Chapter 2. Under the No-Action Alternative and consistent with the Nuclear Waste Policy Act, as amended [NWPA, Section 113(c)(3)], the U.S. Department of Energy (DOE) would terminate activities at Yucca Mountain and undertake site reclamation to mitigate any significant adverse environmental impacts. Commercial utilities and DOE would continue to manage spent nuclear fuel and high-level radioactive waste at 77 sites in the United States. The No-Action Alternative provides a baseline for comparison with the Proposed Action.

Under the No-Action Alternative, if DOE decided not to proceed with the development of a repository at Yucca Mountain, it would prepare a report to Congress, as required by the Nuclear Waste Policy Act, with its recommendations for further action to ensure the safe, permanent disposal of spent nuclear fuel and high-level radioactive waste, including the need for new legislative authority. Under any future course that would include continued storage, both commercial and DOE sites would have an obligation to continue managing the spent nuclear fuel and high-level radioactive waste in a manner that protects public health and safety and the environment. Further, DOE intends to comply with the terms of existing consent orders and compliance agreements regarding the management of spent nuclear fuel and high-level radioactive waste. However, the future course that Congress, DOE, and the commercial utilities would take if Yucca Mountain did not receive a recommendation as a repository site remains highly uncertain. A number of possibilities could be pursued, including continued storage of the material at its present locations or at one or more centralized location(s); the study and selection of another location for a deep geologic repository (Chapter 1 identifies the process and alternative sites previously selected by DOE for technical study as potential geologic repository locations); development of new technologies (for example, transmutation); or reconsideration of other disposal alternatives to geologic disposal (as discussed in Section 2.3.1). Environmental considerations related to continued storage at current locations or at one or more centralized location(s) have been analyzed in other contexts for both commercial and DOE spent nuclear fuel and high-level radioactive waste in several documents. Table 7-1 lists representative studies related specifically to centralized or regionalized interim storage, including alternatives evaluated in DOE National Environmental Policy Act documents, and summarizes the relevant environmental considerations. Those studies contain more information on the potential environmental impacts of centralized or regional interim storage.

In light of the uncertainties described above, DOE decided to illustrate one set of possibilities by focusing the analysis of the No-Action Alternative on the potential impacts of two scenarios: long-term storage of spent nuclear fuel and high-level radioactive waste at the current sites with effective institutional control for at least 10,000 years (Scenario 1), and long-term storage with no institutional controls after approximately 100 years (Scenario 2). DOE recognizes that neither of these scenarios would be likely to occur if there was a decision not to develop a repository at Yucca Mountain. However, the Department selected these two scenarios for analysis because they provide a baseline for comparison to the impacts from the Proposed Action and because they reflect a range of the impacts that could occur. Scenario 1, which includes an analysis of impacts under effective institutional controls for at least 10,000 years, is consistent with the portion of the analysis of the Proposed Action that includes an analysis of effective institutional controls for the first 100 years after closure. Scenario 2, in which the analysis does not consider institutional controls after approximately 100 years, is parallel to the portion of the Proposed Action analysis in which long-term performance after 100 years also does not include institutional controls. Chapter 2 describes the scenarios more fully. Appendix K contains detailed descriptions of the assumptions for each scenario.

Table 7-1. Documents that address storage of spent nuclear fuel and high-level radioactive waste[a] (page 1 of 4).

Title and scope of storage analysis	Environmental and other considerations
Final Environmental Impact Statement, Management of Commercially Generated Radioactive Waste (DOE 1980, all)	
Evaluates a proposal to provide interim storage of spent nuclear fuel from U.S. power reactors before final disposal. The proposal would include acceptance of a limited amount of foreign spent fuel if such actions would contribute to U.S. nonproliferation goals. Evaluates several generic interim storage facility alternatives, including centralized storage at a few large ISFS facilities.	Analyses include a description of a *generic interim storage site environment* based primarily on data for the midwestern United States, and potential environmental effects of such a facility for ISFS facilities. Impacts evaluated include: natural resources, radiological impacts, land use, water use, ecological resources, air quality, traffic, noise, socioeconomics, waste management, utilities, aesthetics, transportation (including both to ISFS facilities and from ISFS facilities to the disposition facility), and safeguards and security.
Recommendations on the Proposed Monitored Retrievable Storage Facility (Clinch River 1985, all)	
Evaluates DOE proposal to consider the Clinch River Breeder Reactor and ORR sites in Tennessee for an MRS facility. Performed by the Clinch River MRS Task Force, which included three study groups: environmental, socioeconomic, and transportation. Public meetings and site visits were conducted by the study groups. Separate reports by each study group are summarized in findings, concerns, anticipated impacts, and recommended mitigations.	The Environmental Study Group's final report presented concerns and recommended mitigations for MRS construction impacts, damage to ecosystem from construction, special nuclear risks of construction, highway construction impacts, radiation protection of workers and the public, airborne effluents, aqueous releases, hazards from cask rupture, earthquakes, flooding, long-term radionuclide containment, secondary waste stream, local control, offsite emergency response, past contamination of the ORR, environmental data from the ORR, and MRS becoming a permanent waste storage site. The Socioeconomic Study Group's final report identified concerns or potentially negative impacts of an MRS and possible mitigations for business recruitment and expansion, residential recruitment and retention, institutional trust, pre- and postoperational impacts and costs, tourism and aesthetics, site neighbors, and legislative issues. The Transportation Study Group's final report defined areas of potential major impacts (for example, independent inspections, upgrades of railroad tracks, routing and upgrades to preferred highway truck routes, escorts, emergency response plans and training, and requirements applicable to private carriers), and presented findings and recommendations on accident probabilities, barge transport, cask safety and contents, prenotification, and safeguards.

Table 7-1. Documents that address storage of spent nuclear fuel and high-level radioactive waste[a] (page 2 of 4).

Title and scope of storage analysis	Environmental and other considerations
Monitored Retrievable Storage Submission to Congress, Volume 2: Environmental Assessment for a Monitored Retrievable Storage Facility (DOE 1986b, Volume 2, all)	
Evaluates a proposal for the construction of a facility for monitored retrievable storage. Evaluates two facility design concepts at each of three candidate sites in Tennessee (Clinch River Breeder Reactor, ORR, and TVA Hartsville Nuclear Power Plant).	Evaluates impacts common to all three sites and unique to each site, including radiological, air quality, water quality and use, ecological resources, land use, socioeconomics, resource requirements, aesthetics, and transportation. Also evaluates relative advantages and disadvantages of the six site design combinations.
MRS System Study Summary Report (DOE 1989b, all)	
Evaluates the role of the MRS facility in the waste management system.	Provides additional support to the general conclusion that an MRS facility provides tangible benefits to a waste management system, as articulated in the DOE 1986 MRS proposal to Congress (DOE 1986b, Volume 2, all). Examines various system configurations in a series of separate publications: • Scenario development and system logistics • Facility design/schedule/cost implications • Alternative MRS storage concepts • Location of high-level radioactive waste packaging • Waste package designs • Transportation impact analyses • Role of waste storage in operations of the waste management system • Licensing impacts of an MRS facility • System reliability
Nuclear Waste Management Systems Issues Related to Transportation Cask Design: At-Reactor Spent Fuel Storage, Monitored Retrievable Storage and Modal Mix (Hoskins 1990, all)	
Provides the State of Nevada evaluation of the DOE MRS proposal and the Tennessee studies and position in response.	Addresses the DOE MRS proposal, which evaluated the option of implementing an integral MRS facility as part of a waste management system and the option of “no-MRS facility” as part of the waste management system. The criteria for the evaluation included health and safety, economic, environmental, political (for example, acceptability, public confidence, local and state attitudes), social (for example, fears and anxieties), fairness (for example, equity, intergenerational, utilities/ratepayer, liability, geographic, interutility, and government-utility), repository scheduling, and flexibility (technical and institutional factors).

Table 7-1. Documents that address storage of spent nuclear fuel and high-level radioactive waste[a] (page 3 of 4).

Title and scope of storage analysis	Environmental and other considerations
Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement (DOE 1995a, all)	
Analyzes transportation and centralized interim storage of existing and projected inventories of DOE spent nuclear fuel (including naval spent nuclear fuel) at one site. Considers five interim storage sites (Hanford, INEEL, ORR, SRS, and the Nevada Test Site).	Focuses on key discriminator disciplines at each of the five sites, including socioeconomics, utilities (electricity), materials and waste management, occupational and public health and safety (radiation effects and accidents), transportation, and uncertainties and conservatism. Discusses cumulative impacts and impacts of no action. Does not provide detailed discussions of land use, cultural resources, aesthetic/scenic resources, geologic resources, air quality, water resources, ecological resources, noise, and utilities and energy because there would be small impacts for these areas that would be indistinguishable among the alternatives.
Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel (DOE 1996c, all)	
Evaluates a proposal to manage FRR spent nuclear fuel. Evaluates a management alternative for acceptance and management of FRR spent fuel in the United States that includes regionalized storage at SRS, INEEL, Hanford, ORR, and the Nevada Test Site. Basic implementation components of the proposal include policy duration, financing arrangements, amount of FRR spent fuel, location for taking title to FRR spent fuel, marine transport, ports of entry, ground transport, FRR spent fuel management sites, and storage technologies.	Analyzes impacts from policy considerations, marine transport, port activities, ground transport, and fuel management sites. More specifically, for fuel management sites, analyzes impacts for occupational and public health and safety, waste management, cumulative impacts, mitigation measures, and environmental justice. Covers impacts for land use, socioeconomics, cultural resources, aesthetics, scenic resources, geology, water resources, air quality, ecology, noise, utilities and energy, and waste management in general.
Final Waste Management Programmatic Environmental Impact Statement For Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste (DOE 1997b, all)	
Evaluates programmatic alternatives for managing various DOE wastes including HLW. Regionalized and centralized storage are among the management options evaluated. Under the regionalized alternatives, canisters from West Valley would be transported either to SRS or to Hanford, and HLW canisters would continue to be stored at Hanford, SRS, and INEEL until acceptance at the geologic repository. Under the centralized storage alternative, canisters would be transported from West Valley, INEEL, and SRS to Hanford, where they would be stored until acceptance at a geologic repository.	Describes regionalized and centralized sites based on available site-specific data and existing and planned storage facilities for HLW canisters. Impacts evaluated include health risks (includes transportation), air quality, water resources, ecological resources, economics, population, environmental justice, land use, infrastructure, cultural resources, and costs.

Table 7-1. Documents that address storage of spent nuclear fuel and high-level radioactive waste[a] (page 4 of 4).

Title and scope of storage analysis	Environmental and other considerations
Environmental Report for the Private Fuel Storage Limited Liability Company's (PFS) Proposed Independent Spent Fuel Storage Installation (ISFSI) License Application (NRC 1997b, all)	
Evaluates the impacts of a privately owned dry fuel storage facility proposed to be built in western Utah on the Skull Valley Goshute Indian Reservation. The facility would receive and store as much as 40,000 MTHM from several commercial nuclear reactor plants. The NRC has initiated development of a Draft EIS to support its licensing process for this facility. A scoping meeting was conducted on June 2, 1998, in Salt Lake City (transcripts of the meeting are available at the NRC web site: *http://www.nrc.gov/OPA/reports*).	Provides detailed descriptions and environmental impact analyses associated with construction and operation of the site and transportation corridors for geography, land use, and demography; ecological resources; climatology and meteorology (including air quality); hydrological resources; mineral resources; seismology; socioeconomics (including environmental justice analysis); noise and traffic; regional historic and cultural resources; scenic and natural resources; background radiological characteristics; and transportation (radiological and nonradiological impacts). Addresses installation siting and design alternatives based on several specific evaluation criteria (geography and demography; ecology; meteorology; hydrology; geology; regional historic/archaeological/architectural/scenic, cultural/natural features; noise; radiological characteristics).
Centralized Interim Storage Facility Topical Safety Analysis Report (DOE 1998p, all)	
Analyzes an above-ground temporary storage facility for up to 40,000 MTHM of commercial reactor spent nuclear fuel. The non-site-specific analysis concludes that DOE could construct and operate the commercial interim storage facility in a manner that protects public health and safety.	Describes generic site characteristics and design criteria developed to bound, to the extent possible, site-specific values once a CISF is selected. Generic site characteristics include meteorology, surface hydrology, geology, and seismology. Principal design parameters evaluated for normal and accident conditions include type of fuel, storage systems, fuel characteristics, tornado (wind and missile load), straight wind, floods, precipitation, snow and ice, seismicity (ground motion and surface faulting), volcanic eruption (ash fall), explosions, aircraft impact, proximity to uranium fuel cycle operations, ambient temperature, solar load, confinement, radiological protection, nuclear criticality, decommissioning, materials handling, and retrieval capability.

a. Abbreviations: ISFS = independent spent fuel storage; ORR = Oak Ridge Reservation; MRS = monitored retrievable storage; TVA = Tennessee Valley Authority; INEEL = Idaho National Engineering and Environmental Laboratory; SRS = Savannah River Site; FRR = Foreign Research Reactor; HLW = high-level radioactive waste; MTHM = metric tons of heavy metal; NRC = U.S. Nuclear Regulatory Commission; CISF = centralized interim storage facility.

INSTITUTIONAL CONTROL

Institutional control implemented by commercial utilities and DOE provides monitoring and maintenance of storage facilities to ensure that radiological releases to the environment and radiation doses to workers and the public remain within Federal limits and DOE Order requirements. Having attained this goal, institutional control ensures the maintenance of incurred doses as low as reasonably achievable, taking social and economic factors into account. Because the future course of action taken by the Nation and by commercial utilities would be uncertain if Yucca Mountain were not recommended as a repository site, the continued storage analysis evaluated two hypothetical scenarios with different assumptions about institutional control to bound potential environmental impacts.

The assumption for Scenario 1 is that DOE and commercial utilities would maintain institutional control of the storage facilities to ensure minimal releases of contaminants to the environment for at least 10,000 years.

Scenario 2 assumes no effective institutional control after approximately 100 years. DOE based the choice of 100 years on a review of generally applicable U.S. Environmental Protection Agency regulations for the disposal of spent nuclear fuel and high-level radioactive waste (40 CFR Part 191), U.S. Nuclear Regulatory Commission regulations for the disposal of low-level radioactive material (10 CFR Part 61), and the National Research Council report on standards for the proposed Yucca Mountain Repository (National Research Council 1995, page 106), which generally discount the consideration of institutional control for longer periods in performance assessments for geologic repositories. Assuming no effective institutional control after 100 years provides a consistent analytical basis for comparing the No-Action Alternative and the Proposed Action.

For consistency, the No-Action analysis considered the same spectrum of environmental impacts as the analysis of the Proposed Action. However, because of the DOE commitment to manage spent nuclear fuel and high-level radioactive waste safely and the uncertainties typical in predictions of the outcome of complex physical and biological phenomena over long periods, DOE decided to focus the No-Action analysis on the short- and long-term health and safety of workers and members of the public.

To ensure a consistent comparison with the Proposed Action for the cumulative effects analysis, the analysis included the impacts of the continued storage of spent nuclear fuel and high-level radioactive waste in excess of 70,000 metric tons of heavy metal (MTHM). This additional material, with the 70,000 MTHM under the Proposed Action (collectively called Module 1), includes 105,000 MTHM of commercial spent nuclear fuel, 2,500 MTHM of DOE spent nuclear fuel, and 22,280 canisters of high-level radioactive waste.

In view of the almost unlimited possible future states of society and the importance of these states to future risk and dose, the National Research Council recommended the use of a particular set of assumptions about the biosphere (for example, how people get their food and water and from where) for compliance calculations such as those performed to evaluate long-term repository performance. Further, the National Research Council recommended the use of assumptions that reflect current technologies and living patterns (National Research Council 1995, page 122). For consistency with the methods used to analyze environmental impacts from the proposed repository, the No-Action analysis selected current technologies and living patterns for the long-term impact evaluation, even though they might not represent an accurate prediction of future conditions.

The No-Action Alternative differs from the Proposed Action in that it would affect the 72 commercial and 5 DOE facilities and their surrounding environments as well as the Yucca Mountain site. The commercial and DOE sites would experience long-term impacts that the Yucca Mountain site would not.

Under Scenario 1, 77 sites around the country would store spent nuclear fuel and high-level radioactive waste. For this scenario, the analysis assumed that institutional control for at least 10,000 years would ensure regular maintenance and continuous monitoring at the facilities, which would safeguard the health and safety of facility employees, surrounding communities, and the environment. All maintenance, including routine industrial maintenance and maintenance unique to a nuclear materials storage facility, would be performed under standard operating procedures or best management practices to ensure minimal releases of contaminants (industrial and nuclear) to the environment and minimal exposures to workers and the public. With institutional control, the facilities would be maintained to ensure that workers and the public received adequate protection in accordance with current Federal regulations such as 10 CFR Part 20 and Part 835 and DOE Order requirements (see Chapter 11).

In addition, the Scenario 1 analysis assumed that storage facilities would undergo replacement every 100 years and would undergo major repairs halfway through the first 100-year cycle, because the storage facilities at any site would be built for a facility life of less than 100 years. (Federal regulations [10 CFR 72.42(a)] require license renewal every 20 years.) Figure 7-1 shows facility timelines for Scenarios 1 and 2.

DOE and commercial organizations intend to maintain control of the nuclear storage facilities as long as necessary to ensure public health and safety. However, to provide a basis for evaluating the upper limits of potential adverse human health impacts, Scenario 2 assumes no effective institutional control of the storage facilities after approximately the first 100 years. Therefore, after about 100 years and up to 10,000 years, the scenario assumes that spent nuclear fuel and high-level radioactive waste storage facilities at 72 commercial sites and 5 DOE sites would begin to deteriorate and that the radioactive materials in the spent nuclear fuel and high-level radioactive waste would eventually be released to the environment, contaminating the local soil, surface water, and groundwater. Appendix K contains the details of this long-term analysis.

For this environmental impact statement (EIS), DOE performed analyses to 10,000 years from the present. To parallel the repository analysis, the No-Action analysis considered both short- and long-term impacts. Short-term impacts would be those experienced during about the first 100 years, and long-term impacts would be those experienced during the remaining 9,900 years. Short-term impacts would be the same under Scenarios 1 and 2 because both scenarios assume institutional control during this period. The short-term No-Action Alternative impacts include those resulting from the termination of activities at Yucca Mountain and decommissioning and reclamation of the site, so there would be no long-term impacts at the Yucca Mountain site. In addition, the short-term No-Action Alternative impacts at Yucca Mountain would be the same for both scenarios.

Impacts at the 77 sites after approximately 100 years (long-term) under Scenario 1 primarily would affect facility workers. Long-term impacts at the storage sites after approximately 100 years under Scenario 2 would affect only members of the public because the facility would close and there would be no workers (Scenario 2 assumes no effective institutional control after about 100 years).

To permit a comparison of both short- and long-term impacts from the construction, operation and monitoring, and eventual closure of a proposed repository at Yucca Mountain and from the No-Action Alternative, DOE took care to maintain as much consistency as possible in the methods used to analyze

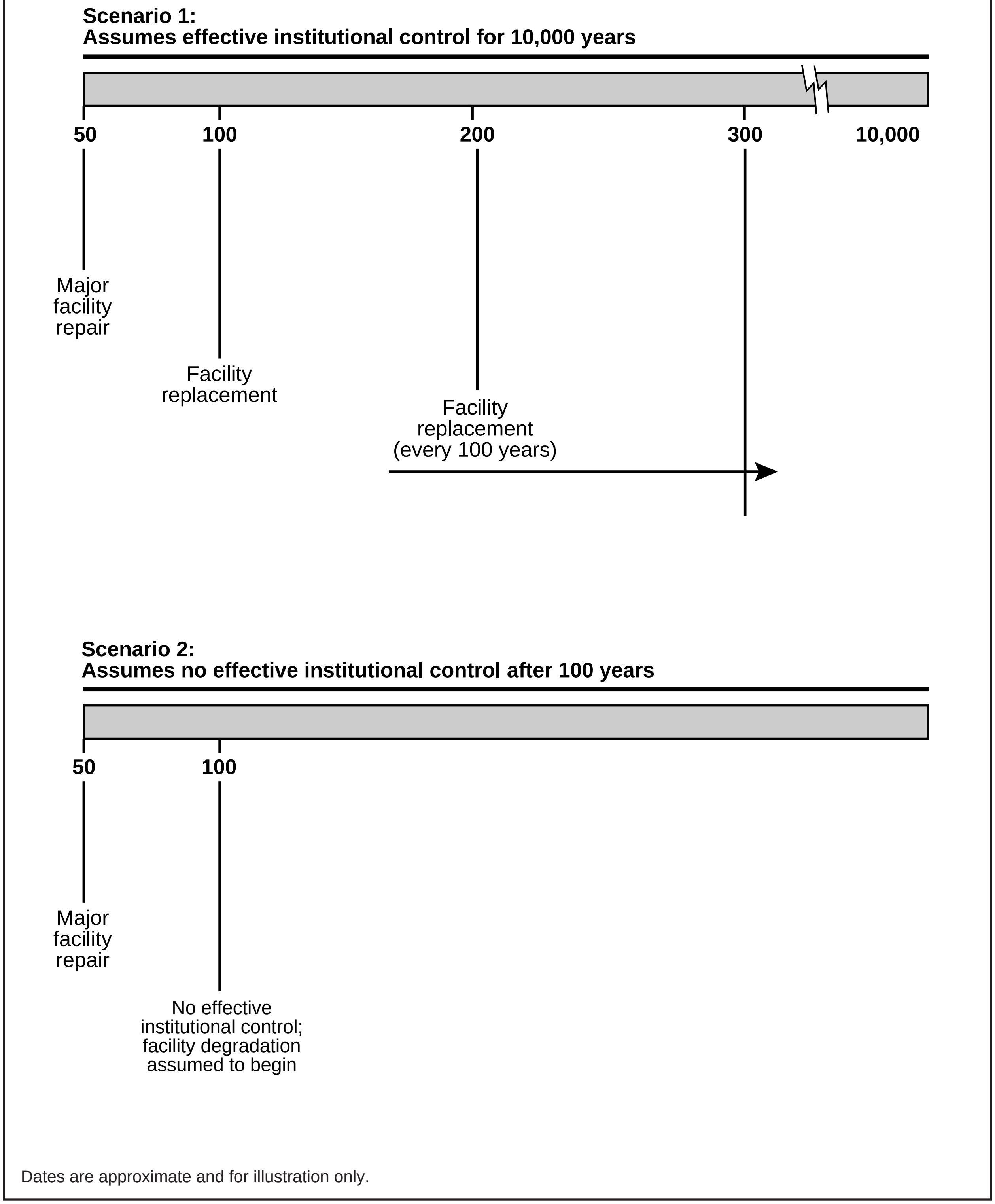


Figure 7-1. Facility timeline assumptions for No-Action Scenarios 1 and 2.

environmental impacts from the proposed repository and the No-Action Alternative. Important consistencies include the following:

- Identical spent nuclear fuel and high-level radioactive waste inventories:
  - Proposed Action: 63,000 metric tons of heavy metal (MTHM) of commercial spent nuclear fuel, 2,333 MTHM of DOE spent nuclear fuel, 8,315 canisters of high-level radioactive waste, and 50 MTHM of surplus weapons-usable plutonium
  - Module 1: Proposed Action materials plus an additional 42,414 MTHM of commercial spent nuclear fuel, 167 MTHM of DOE spent nuclear fuel, and 13,965 canisters of high-level radioactive waste resulting in a total of 105,000 MTHM of commercial spent nuclear fuel, 2,500 MTHM of DOE spent nuclear fuel, 22,280 canisters of high-level radioactive waste, and 50 MTHM of surplus plutonium (see Appendix A, Figure A-2)
- Identical evaluation periods of 100 years (short-term impacts) and of 100 to 10,000 years (long-term impacts)
- Consistent spent nuclear fuel and high-level radioactive waste corrosion and dissolution models
- Identical radiation dose and risk conversion factors
- Similar assumptions regarding the habits and behaviors of future population groups (that is, they would not be greatly different from those of populations today)

DEFINITION OF
METRIC TONS OF HEAVY METAL

Quantities of spent nuclear fuel are traditionally expressed in terms of *metric tons of heavy metal* (typically uranium), without the inclusion of other materials such as cladding (the tubes containing the fuel) and structural materials. A metric ton is 1,000 kilograms (1.1 tons or 2,200 pounds). Uranium and other metals in spent nuclear fuel (such as thorium and plutonium) are called *heavy metals* because they are extremely dense; that is, they have high weights per unit volume. One metric ton of heavy metal disposed of as spent nuclear fuel would fill a space approximately the size of a typical household refrigerator.

7.1 Short-Term Impacts in the Yucca Mountain Vicinity

Chapter 3, Section 3.3, discusses the conditions at the sites that formed the basis for identifying potential impacts associated with the No-Action Alternative. The conditions include the relatively small incremental impacts resulting from continued characterization activities in the Yucca Mountain vicinity until 2002. Under the No-Action Alternative, DOE would terminate characterization activities at the site and would begin site decommissioning and reclamation. Decommissioning and reclamation would include dismantling and removing structures, shutting down some surface facilities, and rehabilitating land disturbed during characterization activities. DOE would salvage usable equipment and materials. Drill holes would be sealed, subsurface drifts and rooms would be left in place, and the portals would be gated. The piles of excavated rock from the tunnel would be landscaped. Areas disturbed by surface studies or used as laydown yards, borrow areas, or the like would be restored. Holding ponds would be backfilled or capped. DOE would not remove foundations or infrastructure such as access roads, parking lots, and sewage systems. The analysis assumed that reclamation activities would take about 1 year. Chapter 2, Section 2.2, describes the No-Action Alternative at Yucca Mountain.

The short-term impacts from reclamation of the Yucca Mountain site would occur regardless of the No-Action Alternative scenario and would be the same for both scenarios.

7.1.1 LAND USE AND OWNERSHIP

Land ownership and control could revert to the original controlling authority.

Under the No-Action Alternative, decommissioning and reclamation would begin as soon as practicable at the Yucca Mountain site, which DOE anticipates would happen in 2002. No new land would be required to support the decommissioning and reclamation activities. Because DOE stored topsoil and material from the mountain during site characterization, it would need no additional land to provide soil for reclaiming the material taken from the mountain or for backfilling holding ponds or the reclamation of other previously disturbed areas. Therefore, the No-Action Alternative would not require the disturbance of additional land at the site. The disturbed land would be restored to its approximate preconstruction condition about 100 years earlier than would occur under the Proposed Action.

7.1.2 AIR QUALITY

Transient effects on air quality would result from the exhausts of the heavy equipment that DOE would use during the decommissioning and reclamation activities that the Department expects to complete over a 1-year period. Recontouring and revegetation activities would generate dust containing particulate matter less than 10 micrometers in diameter (PM_{10}). Impacts on air quality would be no greater than those associated with the construction phase during the Proposed Action for each of the thermal load scenarios, as discussed in Chapter 4, Section 4.1.2, because less land would be disturbed by fewer vehicles during decommissioning and reclamation activities. Because the air quality impacts described in Section 4.1.2 represent a small fraction of the regulatory limit (that is, less than 10 percent of regulatory limits), the No-Action Alternative would not adversely affect air quality.

7.1.3 HYDROLOGY

7.1.3.1 Surface Water

The No-Action Alternative would not adversely affect surface water. During decommissioning and reclamation, adherence to such best management practices as stormwater pollution prevention plans would ensure that cleared areas and exposed earth would be seeded, graveled, or paved to control runoff and minimize soil erosion. To prevent contamination from heavy equipment, workers would monitor the equipment for leaks and would contain and clean up inadvertent spills of industrial fluids following established spill prevention and cleanup plans. DOE would dismantle and remove all surface structures, equipment, and building materials (DOE 1995g, page 2-8), including such items as fuel storage tanks and facilities where petroleum products or potentially hazardous materials like paints and solvents were stored before removal. Hazardous materials removed or generated during decommissioning would be taken from the site and reused, recycled, or disposed of in accordance with applicable regulations (DOE 1995g, page 2-8). After closure, contaminant sources would be gone so there could be no movement of contaminants to surface water (see Chapter 4, Section 4.1.12.2, for details). The analysis assumed that reclamation activities would be complete about 1 year after the decision to implement the No-Action Alternative, which DOE anticipates would occur in 2002.

As part of the reclamation activities, DOE would recontour the landscape to match its precharacterization conditions, ensuring natural drainage patterns. Because the North and South Portal ramps of the Exploratory Studies Facility slope upward to prevent ingress of surface water, they would not appreciably affect natural drainage patterns. Seeding and other erosion control measures would ensure normal infiltration rates. Under the No-Action Alternative, DOE anticipates that the restoration of natural drainage patterns would be complete about 100 years earlier than under the Proposed Action.

7.1.3.2 Groundwater

The No-Action Alternative would not adversely affect groundwater. DOE would remove all sources of contaminants (such as petroleum products and potentially hazardous materials like paints and solvents) from the site. The entrance ramps of the open portals of the Exploratory Studies Facility are sloped such that surface water would drain away from the openings. During reclamation activities (which would take about 1 year), the Exploratory Studies Facility portals would be closed.

7.1.4 BIOLOGICAL RESOURCES AND SOILS

Approximately 1.4 square kilometers (350 acres) of habitat has been disturbed; most of the disturbance is associated with the Exploratory Studies Facility, the storage area for the material removed from the tunnel, the topsoil storage area, borrow pits, boreholes, trenches, and roads. Site reclamation activities would include removal of structures and equipment, soil stabilization, and revegetation plantings at many of the disturbed sites (DOE 1995g, all). Proper soil stabilization would prevent erosion. Once the area was reclaimed, stabilized, and planted with natural vegetation, and once activities at the site decreased, the precharacterization floral and faunal diversity would begin to reestablish itself. Some animal species could take advantage of abandoned tunnels for shelter; for example, the tunnels could provide attractive roosting and nesting sites for bats. Individuals of the threatened desert tortoise species could be adversely affected during the decommissioning and reclamation of the site. The No-Action Alternative would have no other adverse effects on biological resources or soils. In addition, the reclamation would result in the restoration of 1.4 square kilometers of habitat.

7.1.5 CULTURAL RESOURCES

The potential effects of other uses of the Yucca Mountain site on cultural resources are not known because no other uses have been identified; therefore, no assessment of the effects is possible. If the land were to revert to the previous controlling authorities, the stewardship of cultural resources would be consistent with applicable policies, regulations, and procedures.

Because no additional land would be required for decommissioning and reclamation activities, disturbances to cultural resources on undisturbed land in the area would be unlikely. Leaving access roads in place could have an adverse impact on cultural resources if the site boundaries are not secure. Preserving the integrity of important archaeological sites and resources important to Native Americans could be difficult if the public had increased access to the site.

7.1.6 SOCIOECONOMICS

Many of the repository workers would shift to decommissioning and reclamation tasks. An average annual workforce of about 1,800 would complete decommissioning and reclamation tasks at the repository site. After decommissioning and reclamation, the Nevada Test Site would assume the responsibility of preventing inadvertent entry to the North and South Portal areas. A small workforce would protect these areas after reclamation.

After the 1-year decommissioning and reclamation period, the decommissioning and reclamation workforce, along with about 1,400 project-related workers employed away from the repository site, would lose their jobs. The total direct employment reduction, therefore, would be about 3,200 at the completion of decommissioning and reclamation. For every direct job lost, about 0.46 indirect job would also be lost (TRW 1999a, all). *Indirect jobs* are those created as a result of direct employment; examples would include jobs that provide essential services, such as medical and police protection, to the individuals directly employed by the project. Therefore, the overall impact of the No-Action Alternative would be the loss of approximately 4,700 jobs in the region of influence.

As stated in Chapter 3, Section 3.1.7.1, approximately 80 percent of workers at the Yucca Mountain site reside in Clark County, 19 percent reside in Nye County, and less than 1 percent reside in Lincoln County or elsewhere (TRW 1999n, all). Thus, ending characterization activities would have the greatest potential impact in Clark County. If the region (Clark, Lincoln, and Nye Counties) continued to add about 2,800 new jobs every month, impacts would be offset by continued economic growth (Chapter 3, Section 3.1.7.5). Therefore, terminating site characterization activities would have a very minor impact on socioeconomic factors.

The cessation of repository activities would result in the loss of payments by the Federal Government in lieu of taxes. Nye County collects most of the monies associated with the repository project. The 1997 Nye County budget totaled approximately $83.8 million (county government and school district). During the same period, Nye County received approximately $5.4 million as payment in lieu of taxes dollars (TRW 1999n, all).

7.1.7 OCCUPATIONAL AND PUBLIC HEALTH AND SAFETY FOR ROUTINE OPERATIONS

Chapter 2, Section 2.2.1, describes the actions DOE would take at Yucca Mountain under the No-Action Alternative. During the decommissioning and reclamation phase, these actions would expose workers and members of the public to the nonradioactive and radioactive contaminants discussed in Chapter 4, Sections 4.1.2.2, 4.1.3.1, and 4.1.7.2. In addition, these actions would place workers at risk for occupational (industrial safety) incidents such as illnesses, injuries, and fatalities. Appendix F, Section F.2.2.2, describes the statistics used to estimate health and safety impacts from industrial safety incidents. Because the activities that workers would perform under the No-Action Alternative would involve risks similar to those during the construction and closure phases of the Proposed Action, DOE used these statistics to estimate worker health impacts.

Worker exposures to nonradioactive contaminants of concern (diesel engine exhaust and mineral dusts containing respirable erionite and crystalline silica) during decommissioning and reclamation activities would be limited by administrative and engineering means. Exposures would be maintained below occupational levels that could affect worker health adversely, as specified by the Occupational Safety and Health Administration and detailed in the project health and safety plan (TRW 1999t, all). Accordingly, worker exposures to nonradioactive contaminants would not contribute to adverse health impacts.

Tables 7-2 and 7-3 summarize the estimated total impacts from workplace industrial hazards and from radiological exposure, respectively, for reclamation activities. Table 7-4 summarizes impacts to members of the public.

Table 7-2. Estimated industrial safety impacts for surface and subsurface workers during decommissioning and reclamation activities at Yucca Mountain.[a]

Group	Total recordable cases	Lost workday cases	Fatalities
Involved workers[b]	85	41	0
Noninvolved workers[c]	14	7	0
Totals	**99**	**48**	**0**

a. Source: For impact statistics, Appendix F, Table F-2 (for construction and closure, which are the same).

b. Involved worker population of about 1,400 surface and subsurface workers.

c. Noninvolved worker population of about 440 management and administrative personnel.

Table 7-3. Estimated radiation doses and health effects for surface and subsurface workers from decommissioning and reclamation activities at Yucca Mountain.[a,b]

Group	Maximally exposed individual (millirem)	LCF[c] risk to the maximally exposed individual	Collective worker dose[d] (person-rem)	LCF[e]
Involved workers[f]	150	0.00006	77	0.030
Noninvolved workers[g]	120	0.00005	12	0.0050
Totals	**NA**[h]	**NA**	**89**	**0.035**

a. Source: Appendix F, Table F-4 (intermediate thermal load scenario, dual-purpose canister packaging option); data adjusted for 1 year of activity. Values represent most probable (intermediate range) impacts for thermal load and packaging scenarios analyzed.

b. The impacts listed would be the result of 1 year of decommissioning and reclamation activities; adapted from construction phase impacts. Worker doses would result from exposure to radon and other terrestrial radiation sources.

c. LCF = latent cancer fatality.

d. The calculation of doses and health effects assumes no worker rotation for exposure control purposes.

e. Expected number of cancer fatalities for populations. Based on a risk of 0.0004 latent cancer per rem for workers (NCRP 1993b, page 112).

f. Involved worker population of about 1,400 surface and subsurface workers.

g. Noninvolved worker population of about 440 management and administrative personnel.

h. NA = not applicable.

Table 7-4. Estimated public radiation doses and health effects from decommissioning and reclamation activities at Yucca Mountain.[a]

Group	Maximally exposed individual (millirem per year)	Annual increase in risk for contracting an LCF[b]	Collective public dose[c] (person-rem)	LCF
Public	0.12	0.00000006	0.64	0.00032

a. The impacts listed would be the result of 1 year of decommissioning and reclamation activities.

b. LCF = latent cancer fatality; expected number of cancer fatalities for populations. Based on a risk of 0.0005 latent cancer per rem for members of the public (NCRP 1993b, page 112), and a life expectancy of 70 years for a member of the public.

c. The collective dose to 28,000 individuals living within 80 kilometers (50 miles) would be from radon emissions from the subsurface facilities.

Involved and noninvolved worker group losses under the No-Action Alternative would be about 100 total recordable cases of injury and illness, resulting in about 48 lost workday cases and no fatalities (Table 7-2).

Worker population radiation exposures during the year of decommissioning and reclamation activities would result from exposure to radioactive radon decay products that would emanate from the tunnel's rock matrix and from ambient radiation. Exposures to the subsurface workers could result in a collective dose of about 77 person-rem (Table 7-3). Doses to the maximally exposed involved subsurface worker and noninvolved worker could be as high as about 150 millirem and 120 millirem, respectively.

Public radiation exposures during decommissioning and reclamation would result from radon emissions from the subsurface facilities. These exposures could result in an annual dose to the hypothetical maximally exposed individual, about 20 kilometers (12 miles) south of the repository, of 0.12 millirem. The maximum collective dose to the projected population of 28,000 within 80 kilometers (50 miles) would be about 0.64 person-rem (Table 7-4).

The increased likelihood of the maximally exposed individual worker experiencing a latent cancer fatality would be very small (0.0005 to 0.0006). The latent cancer fatality incidence value would be small in comparison to the overall impacts for the Proposed Action (about 1 percent).

7.1.8 ACCIDENTS

Under the No-Action Alternative, DOE would not ship spent nuclear fuel and high-level radioactive waste to Yucca Mountain, and there would be only limited quantities of nonradioactive hazardous or toxic substances. Therefore, accident impacts would be limited to those from traffic and industrial hazards.

Table 7-2 lists impacts from industrial accident scenarios and Section 7.1.14 discusses impacts from traffic accident scenarios.

7.1.9 NOISE

Noise levels during decommissioning and reclamation activities would be no greater than those of site characterization activities. After the decommissioning and reclamation activities were complete, ambient noise would return to levels consistent with a desert environment where natural phenomena account for most background noise (see Chapter 3, Section 3.1.9.1). The No-Action Alternative would not adversely affect the noise levels of the Yucca Mountain region.

7.1.10 AESTHETICS

Site decommissioning and reclamation activities would improve the scenic value of the site. Borrow pits and holding ponds would be filled or graded, stabilized, and revegetated. Most structures would be removed down to their foundations. The North and South Portals would be gated. The surface area of these disturbed areas would represent a small fraction of the total surface area of the repository site and, therefore, would be unlikely to cause adverse impacts to the overall scenic value of the area. Under the No-Action Alternative, the site would be returned to a state as close as possible to the predisturbed state; therefore, DOE would not expect adverse impacts to the scenic value of the area. Site restoration would occur about 100 years earlier than under the Proposed Action.

7.1.11 UTILITIES, ENERGY, AND MATERIALS

Decommissioning and reclamation activities would consume electricity, diesel fuel, and gasoline. Much equipment and many materials would be salvaged and recycled. DOE would recycle buildings as practicable. After the site closed, minimal surveillance activities would require some electricity and gasoline. If the site were abandoned after 100 years, no utilities or energy resources would be consumed. The No-Action Alternative would not adversely affect the utility, energy, or material resources of the region.

7.1.12 WASTE MANAGEMENT

The decommissioning and reclamation of the Yucca Mountain site would generate some waste requiring disposal, including sanitary sewage, sanitary and industrial solid waste, small amounts of demolition debris, and very small amounts of hazardous waste. DOE would dispose of the wastes as it has during the site characterization activities.

DOE would minimize waste generation by salvaging most of the equipment and many materials and redistributing them to other DOE sites or selling them at public auction. Remaining chemical supplies would be redistributed through the DOE excess program, which collects equipment and materials no longer in use for reassignment to other DOE sites or Federal facilities, donation to state governments, or sale to the public. DOE would preserve, rather than demolish, certain facilities that could be useful in the future, such as the electrical distribution and water supply systems. Sanitary sewage would be disposed of in the onsite septic system. At the end of reclamation activities, DOE would cap the inlets to the septic system and leave the system in place. DOE would dispose of sanitary and industrial solid waste and demolition debris in existing Nevada Test Site landfills, where disposal capacity would be available for about 70 years (DOE 1995f, page 8).

7.1.13 ENVIRONMENTAL JUSTICE

An examination of analyses from other technical disciplines associated with terminating characterization and construction activities at Yucca Mountain and decommissioning and reclaiming the site shows no potential for large impacts in areas other than cultural resources and socioeconomics. The cultural resources analysis identified the possibility that increased public access (if roads were left open and site boundaries were not secure) could threaten the integrity of archaeological sites and resources important to Native Americans. The socioeconomic analysis identified a potential loss of as many as 4,700 jobs.

Disproportionate impacts to minority or low-income populations from potential job losses would be unlikely because the workforce would not include a disproportionate number of minority and low-income workers.

7.1.14 TRAFFIC AND TRANSPORTATION

Fatalities from project-related traffic would be unlikely during decommissioning and reclamation. As a gauge of the probability of 1 fatality, decommissioning and reclamation activities would require about 1 year to complete, or about one-sixth to one-fifteenth of the time to close the repository. The analysis in Chapter 6 estimated 1.2 fatalities from traffic accidents during repository closure, so an estimated 0.2 traffic fatality would be likely during decommissioning and reclamation.

7.1.15 SABOTAGE

There would be no nuclear materials at the Yucca Mountain site, so sabotage concerns would not be pertinent.

7.2 Commercial and DOE Sites

This section analyzes short- and long-term impacts of continued storage of spent nuclear fuel and high-level radioactive waste at 72 commercial and 5 DOE sites for 10,000 years (the period considered for the Proposed Action). The analysis includes No-Action Scenarios 1 and 2.

The following paragraphs discuss short-term impacts under No-Action Scenario 1. Because the analysis assumed that all sites would maintain institutional control for the first approximately 100 years, the short-term impacts for Scenarios 1 and 2 would be the same. For consistency with the Proposed Action, this analysis assumed the No-Action scenarios would begin in 2002. This analysis considered the Idaho National Engineering and Environmental Laboratory to be a site for naval spent nuclear fuel because the Laboratory stores such fuel.

Under the No-Action Alternative, commercial utilities would manage their spent nuclear fuel at 72 facilities. DOE would manage its spent nuclear fuel and high-level radioactive waste at five facilities (the Hanford Site, the Idaho National Engineering and Environmental Laboratory, Fort St. Vrain (spent nuclear fuel only) the West Valley Demonstration Project (high-level radioactive waste only), and the Savannah River Site). The No-Action analysis evaluated the DOE spent nuclear fuel and high-level radioactive waste at existing sites or at sites where existing Records of Decisions have placed or will place these materials. For example, the Record of Decision (60 *FR* 18589, April 12, 1995) for the *Final Supplemental Environmental Impact Statement, Defense Waste Processing Facility* (DOE 1994a, all) decided to complete construction and operate the Defense Waste Processing Facility and associated facilities at the Savannah River Site to pretreat, immobilize, and store high-level radioactive waste. Similarly, the *Hanford Site Final Environmental Impact Statement for the Tank Waste Remediation System* (DOE 1996d, all) identified as the preferred alternative *ex situ* vitrification of high-level radioactive waste with onsite storage until final disposition in a geologic repository. For DOE spent nuclear fuel, the Record of Decision (60 *FR* 28680, June 1, 1995) for the *Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement* (DOE 1995a, all) decided that Hanford production reactor fuel would remain at the Hanford Site; aluminum-clad fuel would be consolidated at the Savannah River Site; and non-aluminum-clad fuels (including spent nuclear fuel from the Fort St. Vrain reactor and naval spent nuclear fuel) would be transferred to the Idaho National Engineering and Environmental Laboratory. Therefore, the analysis evaluated DOE aluminum-clad spent nuclear fuel at the Savannah River Site and DOE non-aluminum-clad fuel at the Idaho National Engineering and Environmental Laboratory; most of the Fort St. Vrain spent nuclear fuel at the Colorado generating site; and high-level radioactive waste at the generating sites (the West Valley Demonstration Project, the Idaho National Engineering and Environmental Laboratory, the Hanford Site, and the Savannah River Site).

The No-Action Alternative assumes that the spent nuclear fuel and high-level radioactive waste would be treated, packaged, and stored in a condition ready for shipment to a repository. The amount (inventory) of spent nuclear fuel and high-level radioactive waste considered in this analysis would be the same as that for the Proposed Action—70,000 metric tons consisting of 63,000 MTHM of commercial spent nuclear fuel, 2,333 MTHM of DOE spent nuclear fuel, 8,315 canisters of solidified high-level radioactive waste, and 50 metric tons of surplus plutonium. In addition, DOE recognizes that more than 107,000 MTHM of commercial and DOE spent nuclear fuel and more than 22,000 canisters of high-level radioactive waste could require storage if a disposal site is not available. Section 7.3 describes the assumptions and analytical methods used to estimate impacts for the total projected inventory of spent nuclear fuel and high-level radioactive waste, referred to as Inventory Module 1, and evaluates the potential impacts of the continued storage of the total projected inventory of commercial and DOE spent nuclear fuel and high-level radioactive waste.

Storage Packages and Facilities at Commercial and DOE Sites

A number of designs for storage packages and facilities at the commercial and DOE sites would provide adequate protection from the environment for packages containing spent nuclear fuel and high-level radioactive waste. Because it has not selected specific designs for most locations, DOE selected a representative range of commercial and DOE designs for analysis, as described in the following paragraphs. In addition, for purposes of analysis, the No-Action Alternative assumed that the commercial and DOE sites have sufficient land to construct the initial and replacement storage facilities and that the initial construction of all dry storage facilities would be complete and the facilities filled by 2002.

Spent Nuclear Fuel Storage Facilities

Most commercial sites currently store their spent nuclear fuel in water-filled basins (fuel pools) at the reactor sites. Because they have inadequate storage space, some commercial sites have built what are called *independent spent fuel storage installations,* in which they store dry spent nuclear fuel above ground in metal casks or in welded canisters inside reinforced concrete storage modules. Other commercial sites plan to build independent spent fuel storage installations so they can proceed with the decommissioning of their nuclear plants and termination of their operating licenses (for example, the Rancho Seco and Trojan plants). Because commercial sites could elect to continue operations until their fuel pools became full and then cease operations, the EIS analysis initially considered ongoing wet storage in existing fuel pools to be a potentially viable option for spent nuclear fuel storage. However, dry storage is almost certainly the preferred option for long-term spent fuel storage at commercial sites for the following reasons (NRC 1996, pages 6-76 and 6-85):

- Dry storage is a safe economical method of storage.
- Fuel rods in dry storage are likely to be environmentally secure for long periods.
- Dry storage generates minimal, if any, low-level radioactive waste.
- Dry storage units are simpler and easier to maintain.

Accordingly, this EIS assumes that all commercial spent nuclear fuel would be stored in dry configurations in independent spent fuel storage installations at existing locations (Figure 7-2 is a photograph of the independent spent fuel storage installation at the Calvert Cliffs nuclear electricity-generating site). This assumption includes spent nuclear fuel at sites that no longer have operating nuclear reactors. Although most utilities and DOE have not constructed independent spent fuel storage installations or designed dry storage containers, this analysis evaluates the impacts of storing all commercial and most DOE spent nuclear fuel in horizontal concrete storage modules (Figure 7-3) on a concrete pad at the ground surface. Concrete storage modules have openings that allow outside air to circulate and remove the heat of radioactive decay. The analysis assumed that spent nuclear fuel from both pressurized-water and boiling-water reactors would be stored in a dry storage canister inside the concrete storage module. Figure 7-4 shows a typical dry storage canister, which would consist of a stainless-steel outer shell, welded end plugs, pressurized helium internal environment, and criticality-safe geometry for 24 pressurized-water or 52 boiling-water reactor fuel assemblies.

The combination of the dry storage canister and the concrete storage module would provide safe storage of spent nuclear fuel as long as the fuel and storage facilities were maintained properly. The reinforced concrete storage module would provide shielding against the radiation emitted by the spent nuclear fuel. In addition, the concrete storage module would provide protection from damage resulting from accidents such as aircraft crashes and from natural hazard phenomena such as earthquakes or tornadoes.

This analysis assumed that DOE would store dry spent nuclear fuel at the Savannah River Site, the Idaho National Engineering and Environmental Laboratory, and Fort St. Vrain in stainless-steel canisters inside above-grade reinforced concrete storage modules. In addition, it assumed that the design of DOE above-ground spent nuclear fuel storage facilities would be similar to the independent spent fuel storage installations at commercial sites.

The analysis assumed that DOE would store spent nuclear fuel at Hanford in a dry cask in below-grade storage facilities. DOE would store Hanford N-Reactor fuel in the Canister Storage Building, which would consist of three below-grade concrete vaults with air plenums for natural convective cooling. The vaults would contain vertical storage tubes made of carbon steel. Each storage tube, which would hold two spent nuclear fuel canisters, would be sealed with a shield plug. DOE would cover the vaults with a structural steel shelter.

High-Level Radioactive Waste Storage Facilities

With one exception, this analysis assumed that DOE would store solidified high-level radioactive waste in dry below-grade, high-level radioactive waste storage facilities (Figure 7-5). At the West Valley Demonstration Project, the analysis assumed that DOE would use a dry storage system similar to a commercial independent spent nuclear fuel storage installation for high-level radioactive waste.

A high-level radioactive waste storage facility consists of four areas: below-grade storage vaults, an operating area above the vaults, air inlet shafts, and air exhaust shafts. The canister cavities are galvanized-steel large-diameter pipe sections arranged in a grid. Canister casings are supported by a

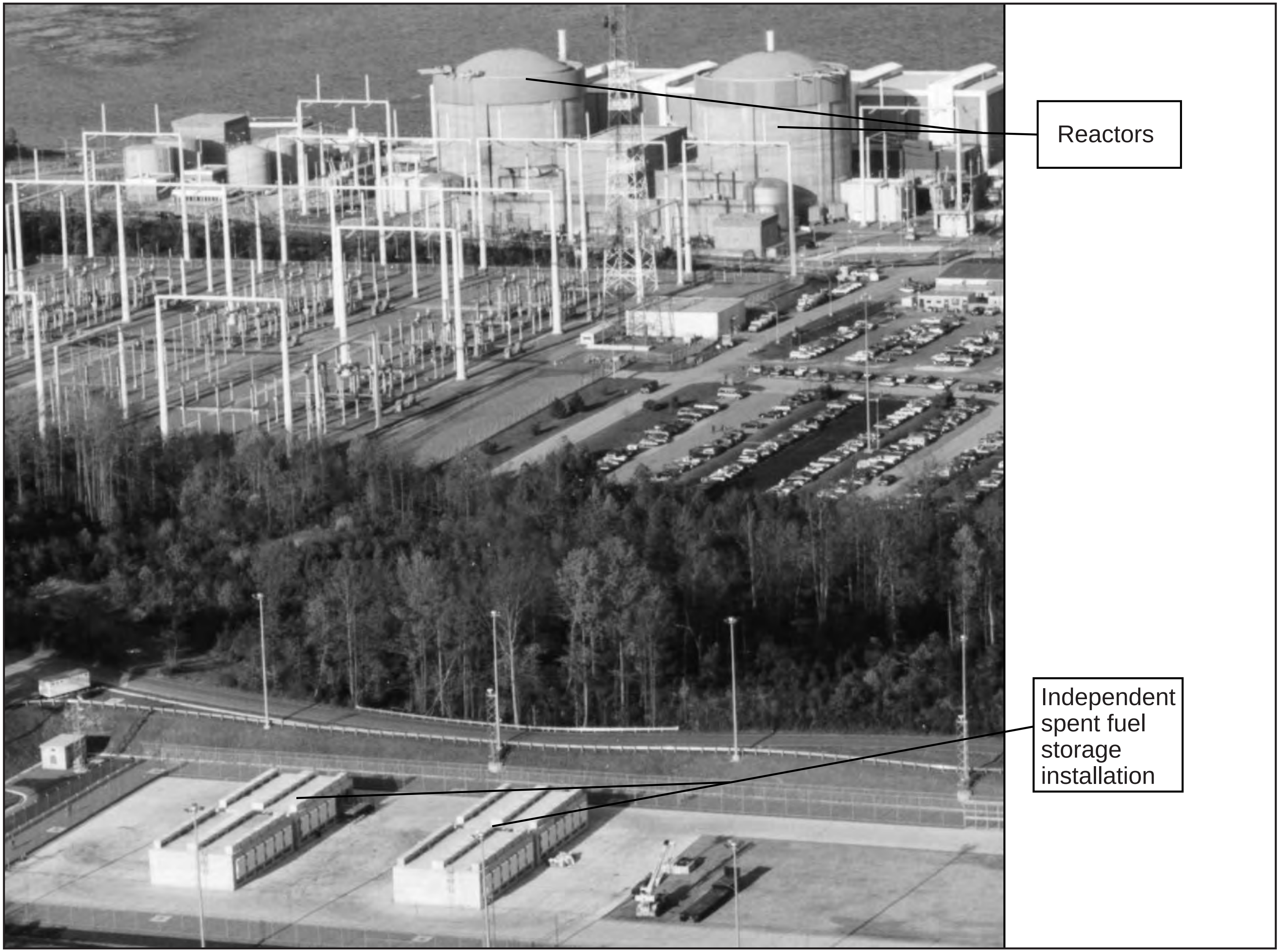
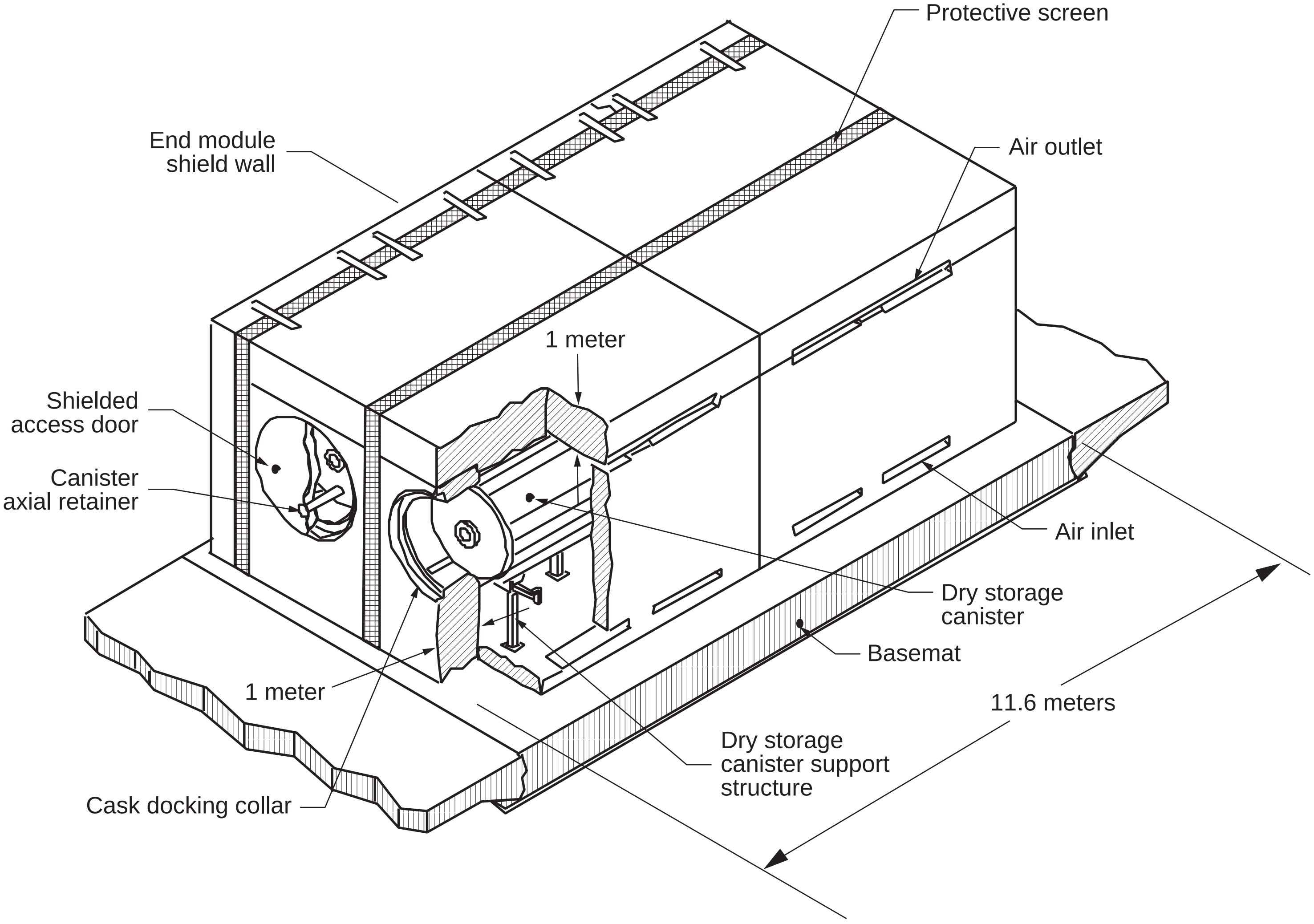


Figure 7-2. Calvert Cliffs independent spent fuel storage installation and reactors.

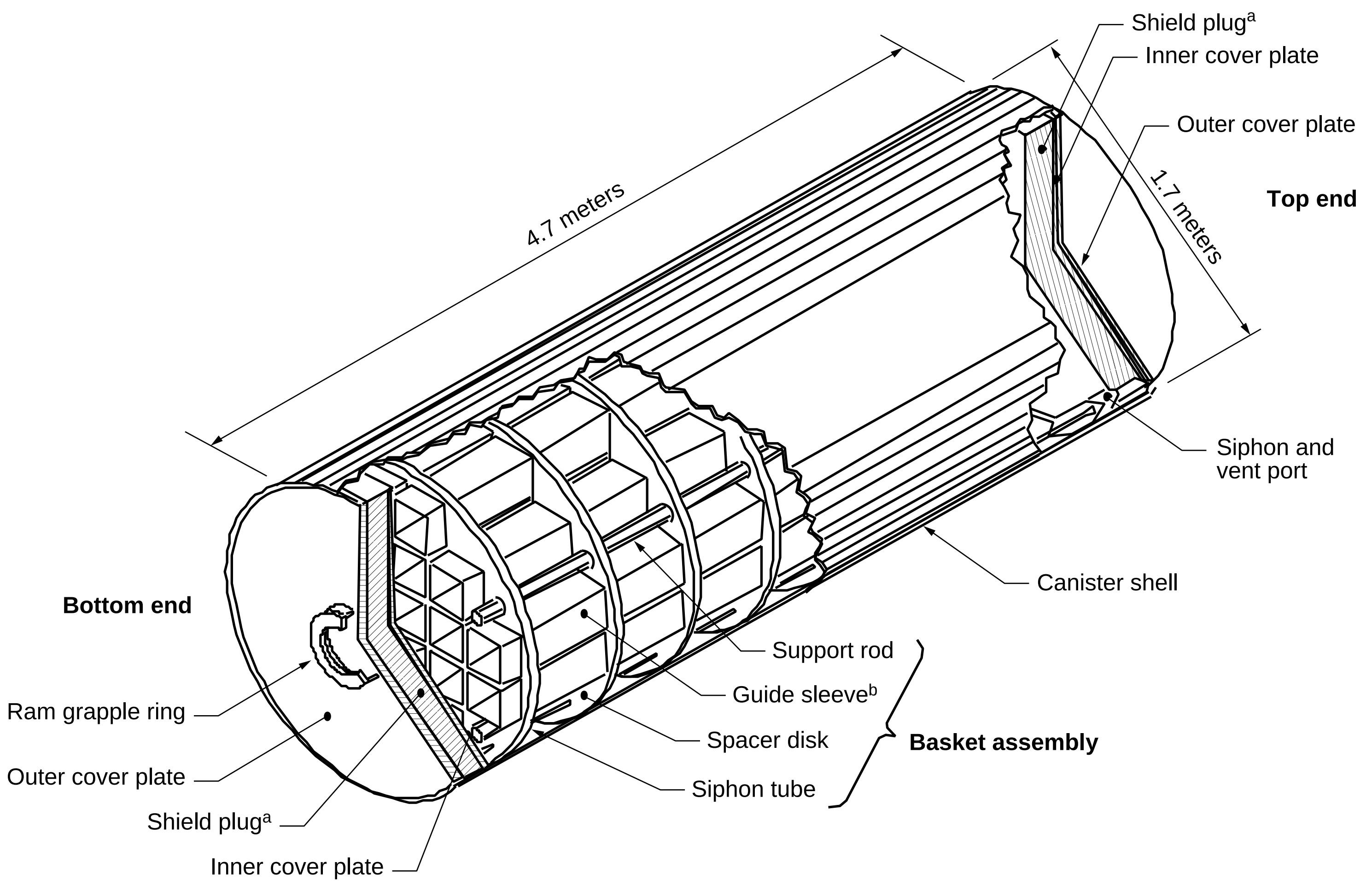


To convert meters to feet, multiply by 3.2808.

Note: Arrangement shown is a row of two storage modules with two canisters in each module.

Source: Modified from Poe (1998a, page 1-2).

Figure 7-3. Spent nuclear fuel concrete storage module.



All materials 304 stainless steel except as noted.

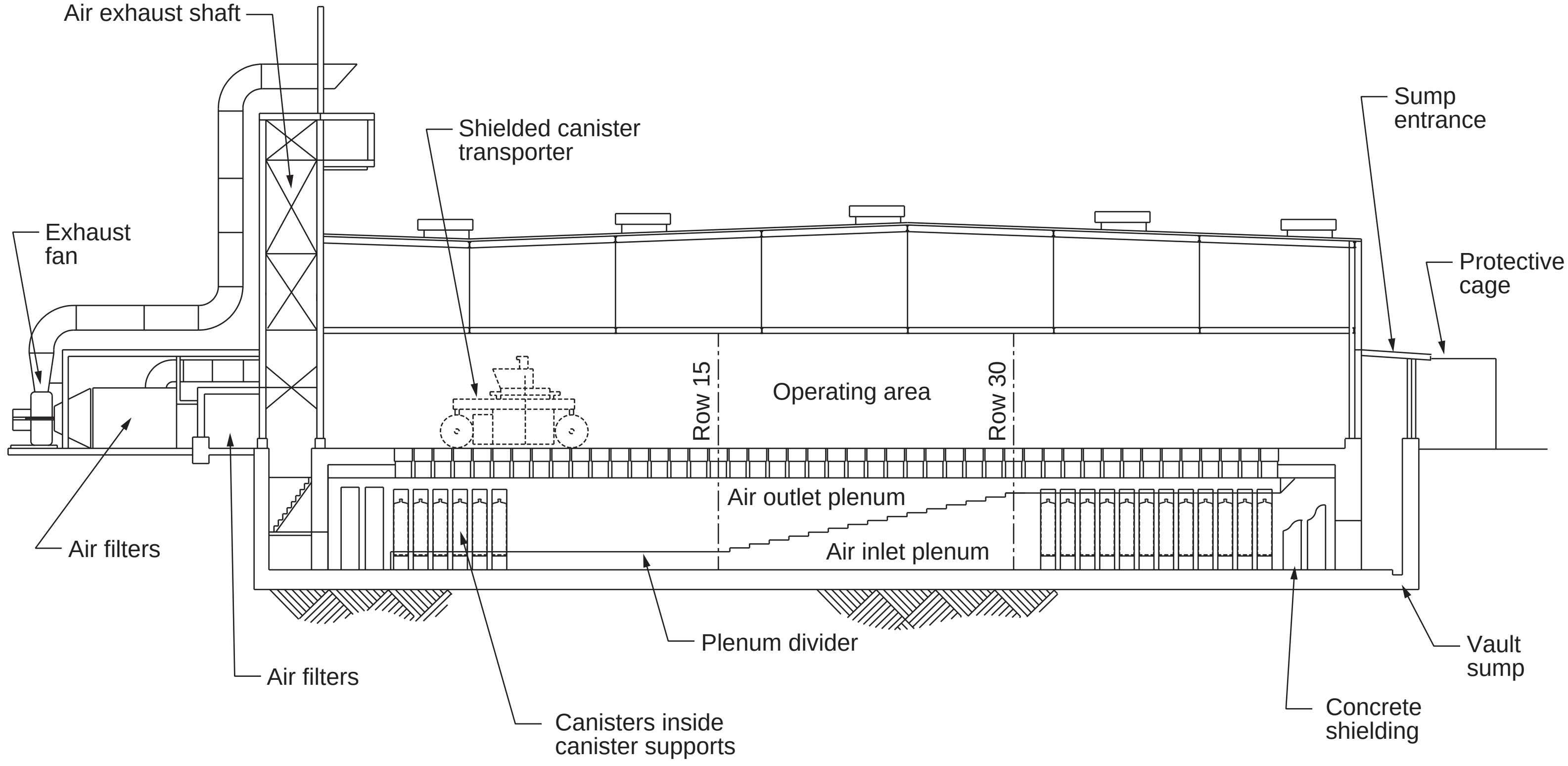
a. Shield plug would be lead.

b. Borated neutron absorber plate for boiling-water reactor spent nuclear fuel assemblies.

To convert meters to feet, multiply by 3.2808.

Source: Modified from Poe (1998a, page 1-5).

Figure 7-4. Spent nuclear fuel dry storage canister.



Source: Derived from Poe (1998a, pages 4-7, 4-8, and 4-11).

Figure 7-5. Conceptual design for solidified high-level radioactive waste storage facility.

concrete base mat. Space between the pipes is filled with overlapping horizontally-stepped steel plates that direct most of the ventilation air through the storage cavities.

The below-grade storage vault would be below the operating floor, which would be slightly above grade. The storage vault would be designed to withstand earthquakes and tornadoes. In addition, the operating area would be enclosed by a metal building, which would provide weather protection and prevent the infiltration of precipitation. The storage vault would be designed to store the canisters and protect the operating personnel, the public, and the environment for as long as the facilities were maintained. The surrounding earth, concrete walls, and a concrete deck that would form the floor of the operating area would provide radiation shielding. Canister cavities would have individual precast concrete plugs.

Each vault would have an air inlet, air exhaust, and air passage cells. The storage facility's ventilation system would remove the heat of radioactive decay from around the canisters. The exhaust air could pass through high-efficiency particulate air filters before it discharged to the atmosphere through a stack. As an alternative, natural convection cooling without filters could be used. The oversized diameter of the pipe storage cavities would allow air to pass around each cavity.

7.2.1 NO-ACTION SCENARIO 1

Under Scenario 1, 72 commercial sites and 5 DOE sites would store spent nuclear fuel and high-level radioactive waste for 10,000 years. Institutional control, which would be maintained for the entire 10,000-year period, would ensure regular maintenance and continuous monitoring at these facilities that would safeguard the health and safety of facility employees, surrounding communities, and the environment. The spent nuclear fuel and immobilized high-level radioactive waste would be inert material encased in durable, robust packaging and stored in above- or below-grade concrete facilities. Release of contaminants to the ground, air, or water would not be expected during routine operations.

DOE and commercial utility workers would perform all maintenance including routine industrial maintenance and maintenance unique to a nuclear materials storage facility under standard operating procedures and best management practices to ensure minimal releases of contaminants (industrial and nuclear) to the environment and minimal exposures to workers and the public. This analysis assumed that DOE would manage these facilities in accordance with Departmental rules (10 CFR Part 835) and Orders (see Chapter 11) and that commercial facilities would meet applicable environmental safety and health requirements. It also assumed that storage facilities would require replacement every 100 years and that they would undergo major repairs halfway through the first 100-year cycle. Chapter 2, Section 2.2, provides additional information pertaining to Scenario 1. The following sections treat short- and long-term impacts separately where appropriate.

7.2.1.1 Land Use and Ownership

The storage facilities for spent nuclear fuel and high-level radioactive waste would be at commercial and DOE sites. Facilities would require replacement every 100 years (beginning about 2110), which would occur on land immediately adjacent to the existing facilities. The land required for a storage facility typically would be a few acres, a small percentage of the land available at current sites. An environmental assessment of an independent spent fuel storage installation determined that operation of the facility would require no more land than it occupied (NRC 1991, page 20).

At the end of each 100-year cycle, a new facility constructed next to the old one would contain the spent nuclear fuel or high-level radioactive waste. The old facility would be demolished and the land reclaimed and maintained for the next 100 years. By alternating the facility between two adjacent locations, minimal land would be required.

Storage facilities would be on land owned by either DOE or a utility. Storage at these sites would be unlikely to affect land use and ownership.

7.2.1.2 Air Quality

As a part of routine operations, best management practices and effective monitoring procedures would ensure that any contaminant releases to the air would be minimal and would not exceed current regulatory limits (40 CFR Part 61 for hazardous air pollutant emissions and Part 50 for air quality standards). Therefore, the No-Action Alternative would not produce adverse impacts to air quality during routine operations.

The analysis assumed that the storage facilities would require complete replacement every 100 years. During the construction of the replacement facility, exhaust from construction vehicles would temporarily increase local levels of hydrocarbons, carbon monoxide, and oxides of nitrogen, but these and other atmospheric pollutants would be likely to remain within National Ambient Air Quality Standards (see Chapter 3, Table 3-5). Temporary increases in particulate matter would result from these construction activities. Mitigation measures such as watering unpaved roads would limit the generation of fugitive dust. In addition, after replacement the old site would be seeded, graveled, or paved to reduce air emissions. Detrimental air quality impacts would be short-term, minimal, and transient.

Very small air quality impacts would be likely from repackaging materials removed from dry storage containers that could degrade to the point that they no longer met licensing requirements; these impacts were not included in the overall impact estimates. Long-term dry storage canister degradation would be highly variable and difficult to estimate from site to site, and DOE did not want to overestimate the accompanying air quality impacts from repackaging.

7.2.1.3 Hydrology

7.2.1.3.1 *Surface Water*

As part of routine operations, best management practices such as stormwater pollution prevention plans and stormwater holding ponds would ensure that, in the unlikely event of an inadvertent contaminant release, contaminants did not reach surface-water systems. Effective monitoring procedures would ensure that operation of the facility did not adversely affect surface waters and that no discharges would contaminate surface waters in excess of drinking water regulatory limits (40 CFR Part 141). Detention basins would capture all runoff, which would be monitored for contamination and treated, as necessary, before it was released to the environment. If the storage facility required active cooling systems, those systems would be designed to contain any inadvertent spill of operating fluids so they could not reach the environment. Therefore, No-Action Scenario 1 would be unlikely to produce adverse impacts to surface-water quality during routine operations.

During construction of the replacement storage facilities, adherence to stormwater pollution prevention plans would ensure that cleared areas and exposed earth would be seeded, graveled, or paved to control runoff and minimize soil erosion that could adversely affect surface-water quality. Surface-water runoff detention ponds would prevent eroded material from entering surface water systems. These erosion control practices would ensure minimal impacts to surface-water quality during construction. To prevent contamination from construction equipment, workers would monitor the equipment for leaks. Inadvertent spills of industrial fluids would be contained and cleaned up in accordance with established spill prevention and cleanup plans. Therefore, the No-Action Alternative would be unlikely to produce adverse impacts to surface-water quality during construction operations.

7.2.1.3.2 *Groundwater*

During routine operations, best management practices such as spill prevention and cleanup plans and procedures and effective monitoring procedures would ensure that inadvertent contaminant releases would not reach groundwater. Therefore, the No-Action Alternative would be unlikely to produce adverse impacts to groundwater quality during routine operations.

The spent nuclear fuel storage facilities at the commercial sites would be surface structures with shallow foundations such that their construction would not disturb groundwater systems. Some DOE storage facilities would be subsurface structures for which construction might require minimal dewatering of the groundwater aquifer. However, the area occupied by the structure would be small in relation to the size of the aquifer, so no adverse impacts would be likely to result from dewatering activities.

Excavations would remove the soil buffer between surface activities and groundwater, increasing the likelihood of groundwater contamination from an inadvertent spill or leak of construction-related fluids (for example, diesel fuel, oil, hydraulic fluids). Construction activities would be as described above for surface water; thus, the penetration of spilled construction fluids to groundwater would be unlikely. Therefore, the No-Action Alternative would be unlikely to produce adverse impacts to groundwater quality during construction operations.

7.2.1.4 Biological Resources and Soils

Impacts to biological resources or soils from the construction and operation of spent nuclear fuel and high-level radioactive waste storage facilities would be minimal. Heat from the storage modules would not affect nearby vegetation. The storage facilities would be fenced to keep wildlife out. However, some smaller animal species could take advantage of the warm air from storage facility vents in winter, and individual animals could receive adverse impacts, including death, from direct exposure to radiation. As the heat of radioactive decay decreased, these sites would become less attractive to animals seeking warm environments.

The storage facilities would have a minimal effect on the soil. Because the operating and decommissioned facilities would alternate between two locations, the amount of soil disturbed by construction would be very small. By adhering to best management practices and standard operating procedures, DOE expects that spills would be minimal. A spill would be contained and cleaned up immediately, thus minimizing the area of soil affected.

7.2.1.5 Cultural Resources

Replacement spent nuclear fuel and high-level radioactive waste storage facilities would generally be on undeveloped land in rural areas owned by DOE or the commercial utilities. The size of each facility and supporting infrastructure would be small enough to avoid known cultural resources. If construction activities uncovered previously unknown archaeological sites, human remains, or funerary objects, DOE or the commercial utility would comply with Executive Orders and Federal and state regulations for the protection of cultural resources (see Chapter 11, Section 11.2.5, for details). Therefore, the No-Action Alternative would be unlikely to produce adverse impacts to cultural resources during construction and operations.

7.2.1.6 Socioeconomics

Storage facilities for spent nuclear fuel and high-level radioactive waste would be at existing DOE and commercial sites. A staff of about eight workers (two individuals on duty per shift, 24 hours per day) would monitor and maintain each facility (Orthen 1999, Table 2, page 4). The analysis assumed that facilities would require replacement every 100 years, and that there would be a major facility repair halfway through the first 100-year cycle. Facility replacement every 100 years would require approximately 40 workers for 2 years (Orthen 1999, Table 2 and Table 6). Major repairs halfway through the first 100-year cycle would require about 40 workers for 1 year (Orthen 1999, Table 2 and Table 6).

Each of the 77 sites that stores spent nuclear fuel or high-level radioactive waste employs monitoring and maintenance personnel. Additional staffing for facility replacement [and the one-time major repair (see Appendix E, Section E.2.1.1)] would be temporary and comprise about 40 employees at a site during construction. (Construction of DOE facilities could require more workers, but the Department would have only five of these facilities reconstructed every 100 years). This temporary increase in employment would be small in proportion to the existing workforces in affected communities. Therefore, the No-Action Alternative would be unlikely to have adverse effects on socioeconomic factors such as infrastructure and regional economy.

7.2.1.7 Occupational and Public Health and Safety

7.2.1.7.1 *Nonradiation Exposures*

Maintenance, repairs, repackaging, and construction at the storage facilities would be conducted in accordance with requirements of the Occupational Health and Safety Administration and National Institute of Occupational Safety and Health. Administrative controls and design features would minimize worker exposures to industrial nonradioactive hazardous materials during the construction and operation of the storage facilities so exposures would remain below hazardous levels.

7.2.1.7.2 *Industrial Hazards*

The industrial hazards evaluated were (1) total recordable injury and illness cases, (2) lost workday cases associated with workplace injuries and illnesses, and (3) workplace fatalities. The estimates of these traumas were based primarily on the staffing level of involved workers assigned to spent nuclear fuel and high-level radioactive waste management tasks, coupled with representative workplace loss indicators maintained by the Bureau of Labor Statistics (BLS 1998, all) or the DOE Computerized Accident/ Incident Reporting System database (DOE 1999c, all). Involved worker risk exposure estimates were based on crew sizes to determine the number of full-time equivalent work years assigned to construction and to operations, surveillance, and maintenance tasks. DOE used representative historic total recordable case, lost workday case, and fatality incident data to project the associated trauma incidence based on the number of workers and their job functions.

This analysis assumed that replacement facilities would be constructed every 100 years and that a major repair and upgrade of the initial facilities would be required once after the first 50 years. Impacts from decommissioning retired facilities were included as part of construction.

The analysis separated the short-term impacts for the first approximately 100-year period (from 2002 to 2116) from the long-term impacts for the remaining 9,900-year analysis period to enable a comparison with the short-and long-term environmental impacts associated with the Proposed Action at the Yucca Mountain Repository. This 114-year period includes the estimated time of receipt, emplacement, and monitoring of spent nuclear fuel and high-level radioactive waste at the repository between 2010 and 2110 (the assumed time when DOE would begin repository closure). It includes the period from 2002 through 2010 to enable a comparison between when a potential decision on repository development could be made through initial receipt and emplacement of spent nuclear fuel and high-level radioactive waste. The analysis included the period from 2110 through 2116 to capture the decommissioning and closure period of the repository, again to enable comparison of continued storage and repository development. Conducting the analysis on the basis of these periods was the only way DOE could make consistent comparisons of impacts between continued storage and repository construction, operation and monitoring, and closure.

For the approximately 100-year construction and operation cycle (2002 to 2116), about 72,000 full-time equivalent work years of effort would be required to maintain and repair about 6,600 concrete storage modules and 4 below-grade storage vaults at the 72 commercial and 5 DOE sites (Orthen 1999, Table 1). Based on this level of effort, as listed in Table 7-5, about 2,300 industrial safety incidents would be likely, resulting in about 1,000 lost workday cases and 2 fatalities (an average of 1 fatality every 50 years).

In addition, for the remaining 9,900 years, Table 7-5 indicates about 290,000 estimated industrial safety incidents, of which about 130,000 would be lost workday cases and 320 would involve fatalities (an average of 1 fatality every 30 years or about one every 2,500 years at each of the 77 sites). Surveillance tasks would consume 94 percent of the total worker level of effort, construction tasks would consume nearly all of the remaining 6 percent, and operations tasks would consume less than 0.001 percent (Orthen 1999, Table 2).

Table 7-5. Estimated industrial safety impacts at commercial and DOE sites during the first 100 years and the remaining 9,900 years of the 10,000-year analysis period under Scenario 1.[a]

Industrial safety impacts	Short-term[b] (100 years) construction and operation (2002-2116)	Long-term (9,900 years)[c] construction and operation (2116-12010)
Total recordable cases	2,300	290,000
Lost workday cases	1,000	130,000
Fatalities	2.4	320

a. Source: Orthen (1999, Tables 6 and 7).
b. The estimated impacts would result from a single 100-year period of storage module construction (renovation), operation, surveillance, and repair.
c. Period from 100 to 10,000 years.

7.2.1.7.3 *Radiation Exposures*

For Scenario 1, the analysis assumed that the facilities would undergo major repairs once during the first 100 years and would be replaced every 100 years thereafter. Very low exposures to future construction workers would occur as they built replacement facilities adjacent to the existing facilities. Transferring the dry storage canisters from old to new concrete storage modules would result in some additional exposures to workers.

During normal operations, facility workers would be exposed to low levels of external radiation while performing routine surveillance and monitoring activities, changing high-efficiency particulate air filters on ventilation systems (for high-level radioactive waste storage facilities), transferring dry storage canisters between concrete storage modules, and maintaining and repairing the facilities. In addition, individuals employed at the nearby nuclear powerplant but not directly involved with activities at the spent nuclear fuel storage facility (noninvolved workers) would be exposed to low levels of external radiation emanating from the filled concrete storage modules. Activities within the facility boundaries would be in accordance with DOE or Nuclear Regulatory Commission guidelines for nuclear facility worker protection (10 CFR Part 835 and 10 CFR Part 20). Table 7-6 lists estimated maximum annual individual doses and the total average collective dose for worker populations during the 10,000-year analysis period for commercial and DOE sites.

The Scenario 1 analysis treated the dose rates from DOE spent nuclear fuel as equivalent to commercial spent nuclear fuel on a volume basis. This simplifying assumption had minimal effect on estimated

Table 7-6. Estimated radiological impacts (dose) and consequences from construction and routine operation of commercial and DOE spent nuclear fuel and high-level radioactive waste storage facilities – Scenario 1.[a]

Receptor	Short-term (100 years) construction and operation (2002-2116)	Long-term (9,900 years) construction[b] and operation (2116-12010)
Population[c]		
MEI[d] (millirem per year)	0.20	0.06
Dose[e] (person-rem)	810	5,200
LCFs[f]	0.41	2.6
Involved worker[g]		
MEI[h] (millirem per year)	170	50
Dose[e] (person-rem)	2,600	31,000
LCFs[f]	1.0	12
Noninvolved workers[i]		
MEI[j] (millirem per year)	13	0[k]
Dose[e] (person-rem)	36,000	0[k]
LCFs[f]	15	0[k]

a. Source: Adapted from NRC (1991, all); Orthen (1999, all).

b. Assumes construction of 6,600 concrete storage modules and three below-grade vaults at 77 sites every 100 years (Orthen 1999, Table 1).

c. Members of the general public living within 3 kilometers (2 miles) of the facilities; estimated to be 140,000 over the first approximately 100 years and approximately 14 million over the duration of the analysis period [estimated using Humphreys, Rollstin, and Ridgely (1997, all)].

d. MEI = maximally exposed individual; assumed to be approximately 1.4 kilometers (0.8 mile) from the center of the storage facility (NRC 1991, page 22).

e. Estimated doses account for radioactive decay.

f. LCF = latent cancer fatality; expected number of cancer fatalities for populations. Based on a risk of 0.0004 and 0.0005 latent cancer fatality per rem for workers and members of the public, respectively (NCRP 1993b, page 112), and a life expectancy of 70 years for a member of the public and a 50-year career for workers.

g. Involved workers would be those directly associated with construction and operation activities (NRC 1991, pages 23 to 25). For this analysis, the involved worker population would be approximately 1,400 individuals (700 individuals at any one time) at 77 sites over 100 years (Orthen 1999, Table 6). This population would grow to about 160,000 over 10,000 years.

h. Based on maximum construction dose rate of 0.11 millirem per hour and 1,500 hours per year (NRC 1991, page 23).

i. Noninvolved workers would be employed at the powerplant but would not be associated with facility construction or operation. For this analysis, the noninvolved worker population would be 80,000 individuals who would receive exposures until the powerplants were decommissioned (50 years).

j. Based on a projected area workforce of 1,200 and an average estimated annual dose of 16 person-rem (NRC 1991, page 24).

k. During this period the powerplants would have ended operation, so there would be no noninvolved workers.

individual and population doses because of the relatively small quantities of DOE spent nuclear fuel (less than 10 percent of the total) and essentially equal radiation exposure rates in comparison to commercial spent nuclear fuel on a volume basis. The analysis separated the calculation of dose rates from high-level radioactive waste because of the difference in source materials.

For Scenario 1, dose rates from high-level radioactive waste were estimated based on the isotopic distributions provided in Appendix A, Tables A-25, A-26, and A-27. As with commercial and DOE spent nuclear fuel, estimated dose rates to facility workers considered shielding provided by the concrete facility structures and decay over the 10,000-year analysis period. However, because of the relatively large distance from the storage facilities to the site boundary [typically more than 3 kilometers (2 miles) at the Hanford Site, the Idaho National Engineering and Environmental Laboratory, and the Savannah River Site], doses to the public were not included. Although the distance to the site boundary at the West Valley Demonstration Project is less than 3 kilometers, not including public exposures from above-grade storage facilities would result in a very small underestimation of impacts because DOE stores only about 4 percent of the high-level radioactive waste at that facility.

Very small air quality impacts would be likely from repackaging materials removed from dry storage containers that could degrade to the point that they no longer met licensing requirements. However, overall impact estimates did not include these impacts because long-term dry storage canister degradation would be highly variable and difficult to estimate from site to site, and DOE did not want to overestimate the accompanying air quality impacts from repackaging.

As listed in Table 7-6, the estimated dose to the hypothetical maximally exposed offsite individual during the short-term operational period between 2002 and 2116 would be about 0.20 millirem per year (NRC 1991, page 22). For the remaining 9,900 years of the analysis period (long-term impacts), the dose to the hypothetical maximally exposed individual would decrease to about 0.060 millirem per year because of radioactive decay of the source material. During about the first 100 years, the dose (accounting for radioactive decay) could result over a 70-year lifetime of exposure in an increase of 0.0000043 in the lifetime risk of contracting a fatal cancer, an increase over the lifetime natural fatal cancer incidence rate of 0.0018 percent. During the remaining 9,900 years of the analysis period, the dose could result in an increase of 0.0000013 in the lifetime risk of contracting a fatal cancer, an increase of 0.00055 percent over the lifetime natural fatal cancer incidence rate.

Based on the Nuclear Regulatory Commission computer program SECPOP (Humphreys, Rollstin, and Ridgely 1997, all), in 1990 approximately 100,000 people lived within 3 kilometers (2 miles) of some type of commercial nuclear facility (Rollins 1998, page 9). Over the 100-year analysis period, the total number of people that would be exposed would be approximately 140,000 because more than one 70-year lifetime would be spanned during the 100-year period. As listed in Table 7-6, between 2002 and 2116 these people would be likely to receive a total collective dose of 810 person-rem.

Long-term doses and latent cancer fatalities for the approximately 9,900-year period between 2116 and 12010 were based on the assumptions described above, with a few notable exceptions. Impacts to noninvolved workers were not calculated because all of the nuclear powerplants would be closed by the beginning of this period. In addition, the total exposed populations of workers and the public would increase by a factor of 100 above the 100-year exposed population because this period would span 140 lifetimes of 70 years. As noted above, for the first 100 years of operation approximately 140,000 people living within 3 kilometers (2 miles) of the storage facilities (100,000 people multiplied by 1.4 consecutive 70-year average human lifetimes [the average number of 70-year lifetimes in 100 years]) would be exposed to external radiation. Over 10,000 years the exposed population would total approximately 14 million people. Therefore, for the period between 2116 and 12010, the offsite population would receive an estimated total collective dose of 5,200 person-rem (adjusted for radioactive decay).

Population statistics indicate that in 1990 cancer caused about 24 percent of the deaths in the United States (NCHS 1993, page 5). If this percentage of deaths from cancer continued, about 24 people out of every 100 in the U.S. population would contract a fatal cancer from some cause. For approximately the first 100 years, the radiation exposure dose from the storage facilities could cause an additional 0.41 latent cancer fatality in the surrounding populations. This would be in addition to about 33,000 cancer fatalities that would be likely in the exposed population of 140,000 from all other causes, or an increase in the natural incidence rate of 0.0012 percent. For the remaining 9,900 years of the analysis, the radiation exposure dose from the storage facilities could result in an additional 2.6 latent cancer fatalities in the surrounding populations. This would be in addition to about 3.3 million cancer fatalities that would be likely to occur in the exposed population of 14 million, or an increase of 0.000079 percent over the natural incidence rate.

The analysis assumed the maximally exposed individual in the involved worker population would be involved in constructing and loading replacement facilities. Assuming a maximum dose rate of 0.11 millirem per hour and an average exposure time of 1,500 hours per year, this construction worker would receive about 170 millirem per year. During about the first 100 years, the dose could result (over 3 years of construction) in an increase in the lifetime risk of contracting a fatal cancer of 0.00020, an increase of 0.090 percent over the national fatal cancer incidence rate of about 24 percent. During the remaining 9,900 years of the analysis period, the dose could result (over 3 years of construction) in an increase in the risk of contracting a fatal cancer of 0.000060 percent, an increase of 0.030 percent over the natural fatal cancer incidence rate.

For the involved worker population of 1,400 individuals, approximately 330 would be likely to contract a fatal cancer from some cause other than occupational exposure. In this population (during the first 100 years), the collective dose of 2,600 person-rem (correcting for decay) between 2002 and 2116 could result in about 1 additional latent cancer fatality (Orthen 1999, Table 6), an increase of 0.33 percent over the natural incidence rate of fatal cancers from all causes. During the remaining 9,900 years of the analysis period, the approximately 160,000 involved workers would receive a collective dose of 24,000 person-rem (corrected for decay). This dose could result in an additional 10 latent cancer fatalities (about 1 every 1,000 years during the 9,900-year analysis period), an increase of 0.027 percent over the natural incidence rate of fatal cancers.

Noninvolved workers would be those employed at an operating nuclear powerplant but not directly involved with the day-to-day operation of the spent nuclear fuel storage facility. The analysis assumed that noninvolved workers (about 800 for each of the approximately 100 reactor units at 72 commercial sites) would be generally several hundred to several thousand feet from the storage facilities. In addition, it assumed that noninvolved workers would be at the sites until 2052 (that is, for 50 years).

The Nuclear Regulatory Commission estimated that the dose to noninvolved workers at a nuclear powerplant from a fully loaded independent spent fuel storage installation would be about 16 person-rem per year (NRC 1991, page 24) for the protected-area workforce of 1,200 individuals (NRC 1991, page 26) at the two-unit station of Calvert Cliffs. This collective dose would result in an average maximum dose to the noninvolved worker of 13 millirem per year. Over a 50-year career, this exposure (accounting for radioactive decay) could result in an increase in lifetime risk of contracting a fatal cancer of 0.00018, an increase of 0.077 percent over the natural incidence rate of fatal cancers.

The analysis made the conservative assumption that there are about 80,000 powerplant workers in the United States (800 per reactor unit and about 100 units currently operating), and that these workers would receive radiation exposure from the adjacent storage facilities until powerplant decommissioning, which the analysis assumed will occur in 2052. In the total noninvolved worker population of 80,000 powerplant workers (all sites), the collective dose of 36,000 person-rem (accounting for radioactive decay) between 2002 and 2116 could result in 15 additional latent cancer fatalities. This would be about 0.079 percent more than the 19,000 cancer fatalities that would be likely to occur from all other causes in the same worker population.

Figure 7-6 shows the calculated dose to these populations as a function of time, expressed as 70-year doses. For the noninvolved worker population, the population dose would occur during only the first 70-year interval. The public dose would decrease over time due to the inherent radioactive decay that will occur in the spent nuclear fuel and high-level radioactive waste as time elapses. Many of the radioactive constituents have half-lives substantially less than 10,000 years; therefore, it is likely that the dose to the public would decrease noticeably over time. The involved worker population dose also would decrease over time because of radioactive decay. The involved worker dose would fluctuate as new concrete storage modules were constructed and radioactive material was transferred from the old to the new modules every 100 years. During those 70-year intervals in which construction and transfer would occur,

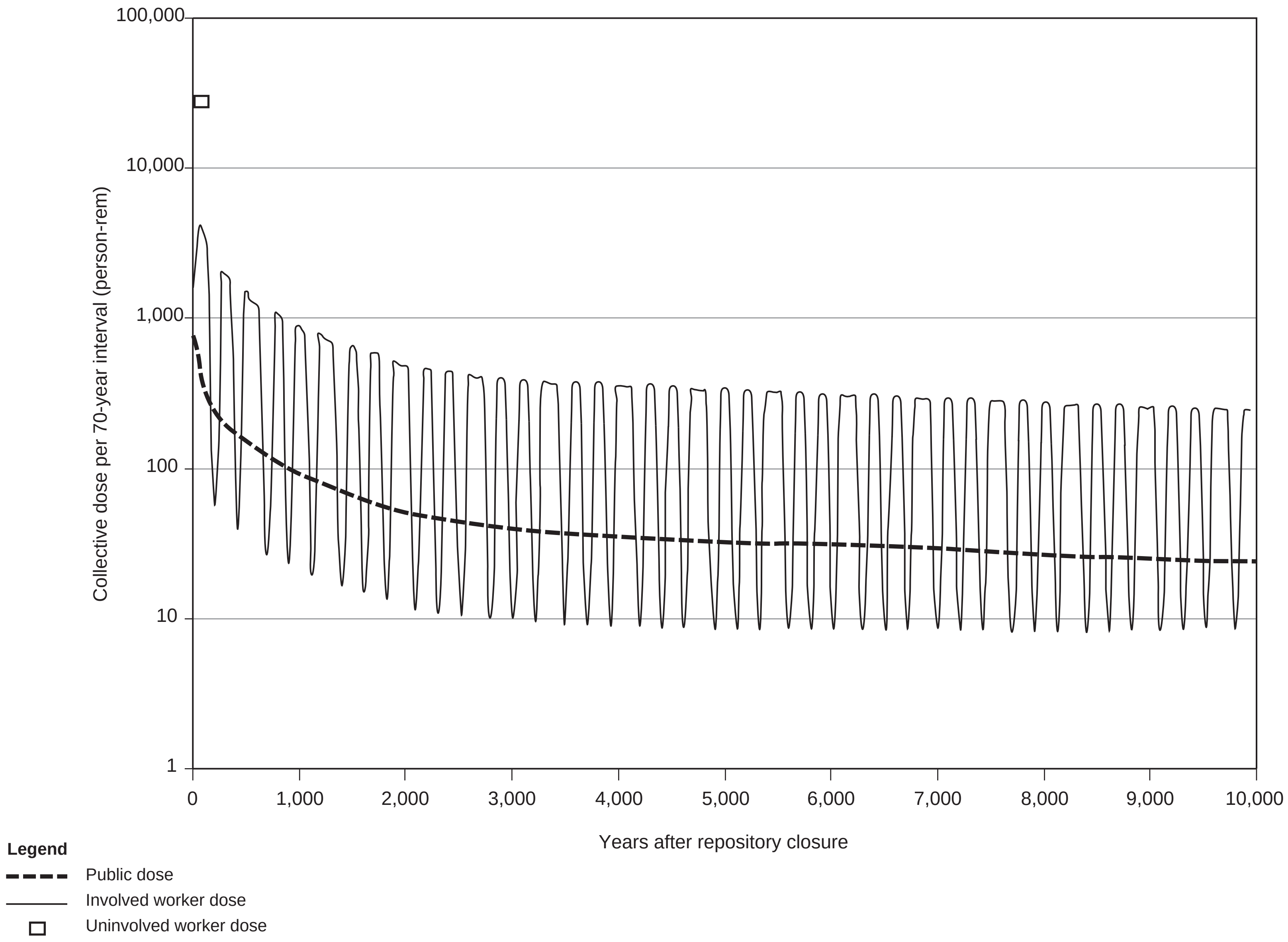


Figure 7-6. Collective dose for 70-year intervals for No-Action Scenario 1.

the dose would be higher; the dose would be lower during those 70-year intervals when these activities did not occur.

Because no liquid or airborne effluents would emanate from the storage facilities, direct and air-scattered radiation would comprise the total source of radiation exposure to the public. For populations more than 3 kilometers (2 miles) from the facilities (as is the case for most DOE facilities), direct and air-scattered external radiation exposure would be small (NRC 1991, page 22).

7.2.1.8 Accidents

For Scenario 1, activities at each facility would include surveillance, inspection, maintenance, and equipment replacement, when required. The facilities and the associated systems, which the Nuclear Regulatory Commission would license, would have certain required features. License requirements would include isolation of the stored material from the environment and its protection from severe accident conditions. The Nuclear Regulatory Commission requires an extensive safety analysis that considers the impacts of plausible accident-initiating events such as earthquake, fire, high wind, and tornado. In addition, the license would specify that facility design requirements include features to provide protection from the impacts of severe natural events. This analysis assumed indefinite maintenance of these features for the storage facilities.

DOE performed an analysis to identify the kinds of events that could lead to releases of radioactive material to the environment prior to degradation of concrete storage modules and found none. The two events determined to be the most challenging to the integrity of the concrete storage modules would be the crash of an aircraft into the storage facility and a severe seismic event.

- Davis, Strenge, and Mishima (1998, all) concluded that the postulated aircraft crash would be potentially more severe than a postulated seismic event because storage facility damage from an aircraft crash probably would be accompanied by a fire. The analysis showed that hurtling aircraft components produced by such an event would not penetrate the storage facility and that a subsequent fire would not result in a facility failure. This conclusion is consistent with representative analyses performed in support of Nuclear Regulatory Commission license applications for above-grade dry storage (PGE 1996, all; CP&L 1989, all).

- For the seismic event, major damage would be unlikely because storage facilities would be designed to withstand severe earthquakes. Even if such an event caused damage, immediate release of radioactive particulates would be unlikely because analyses have identified no mechanism that would cause fuel pellet damage sufficient to create respirable airborne particles (PGE 1996, all; CP&L 1989, all). Therefore, the source term would be limited to gaseous fission products, carbon-14, and a very small amount of preexisting fuel-pellet dust. Subsequent repairs to damaged facilities or concrete storage modules would preclude the long-term release of radionuclides.

Criticality events are not plausible for Scenario 1 because water, which is required for criticality, could not enter the dry storage canister. The water would have to penetrate several independent barriers, all of which would be maintained and replaced as necessary under Scenario 1. Therefore, DOE determined that potential accident consequences would be bounded by a severe seismic event (see Appendix K, Section K.2.5). DOE analyzed this event and concluded that such an accident scenario would not result in radiological impacts to members of the public in the immediate vicinity of the storage facility. In addition, there would be limited quantities of nonradioactive hazardous or toxic substances stored at the facilities. Therefore, nonradiological accident impacts would be limited to those from industrial hazards and traffic, as discussed in Sections 7.2.1.7.2 and 7.2.1.14, respectively.

7.2.1.9 Noise

During routine operations, noise levels would not affect workers, the public near the facility, or the environment. Most of the storage facilities would have passive cooling, although a few could have active cooling with fans and blowers. Because the storage facilities would be away from population centers or homes, the noise of blowers, if used, would not affect the nearby public. The noise would not be loud enough to produce adverse impacts on the facility workers' hearing.

The analysis assumed for Scenario 1 that the storage facilities would require complete replacement every 100 years. During construction, noise levels due to construction traffic and activities would exceed ambient noise levels. To protect personnel, Occupational Safety and Health Administration standards would be followed (29 CFR 1910.95). The noise could cause wildlife to leave the immediate vicinity of the construction activities, but would not be loud enough to affect individual animals permanently. Adverse impacts to wildlife would be temporary.

7.2.1.10 Aesthetics

Impacts from the storage facilities to aesthetic or scenic resources would be low. There would be two adjacent locations at each site on land that would already be disturbed. Every 100 years, a new facility would be constructed on the idle site, and the storage containers transferred. The old facility would be demolished and the site would remain idle for the next 100 years. Adverse impacts could occur during construction and demolition activities, but these impacts would be short-term and temporary.

7.2.1.11 Utilities, Energy, and Materials

As mentioned above, spent nuclear fuel and high-level radioactive waste storage facilities would have passive cooling, although a few could have active cooling with fans and blowers. Electricity would be required for these cooling systems and to light the storage facilities, but DOE anticipates that the amount of electricity would be small in comparison to the amount available. Fuel and materials would be needed to maintain and repair the facilities and to construct and demolish facilities every 100 years, but DOE expects impacts to these resources to represent a small fraction of the resources available to each of the 77 sites. Therefore, the No-Action Alternative would not produce adverse impacts on these resources during operation and construction activities.

7.2.1.12 Waste Management

Construction of new facilities and demolition of old facilities every 100 years (and the one-time refurbishment of existing facilities after the first 50 years) would generate construction debris and sanitary and industrial solid waste. In addition, routine repairs and maintenance to the facilities and storage containers, routine radiological surveys, and overpacking of failed containers would generate sanitary and industrial solid and low-level radioactive wastes. Because there would not be a dedicated workforce at the storage facilities, only small amounts of sanitary wastes would be generated except during construction periods. The greatest amount of waste would be generated by the demolition of facilities at the 72 commercial and 5 DOE storage sites every 100 years. The demolition of facilities once every 100 years at all the sites would generate, on average, an estimated 770,000 cubic meters (1 million cubic yards) of nonhazardous demolition debris, recyclable steel, and potentially a small amount of low-level waste if a dry storage canister were to fail while in storage (Orthen 1999, Table 7). The debris and wastes would be disposed of at commercial or DOE disposal facilities across the Nation. The impacts to available capacity would be spread nationwide, thus minimizing impacts to any one disposal facility. The capacities of the disposal facilities would accommodate the wastes generated at the storage facilities.

7.2.1.13 Environmental Justice

Potential impacts of continued storage with institutional control would be minimal for all populations living near the storage facilities. Because adverse impacts would be unlikely for any population, effects on minority or low-income populations would be unlikely to be disproportionately high and adverse.

Storage facilities would require small areas and would be on lands already owned by commercial utilities or DOE. Therefore, continued storage at these sites would be unlikely to introduce environmental justice issues. If the United States determines that it will use continued storage at existing sites for the long-term disposition of spent nuclear fuel and high-level radioactive waste, site-specific analyses of storage facilities would be required to determine if environmental justice issues could result. The Nuclear Regulatory Commission has established this approach (NRC 1996, page 9-16).

7.2.1.14 Traffic and Transportation

DOE analyzed short-term impacts (traffic fatalities) that could result from commuting to and from storage facilities for a single 100-year cycle. The amount of travel was determined from estimates of personnel needed to construct the storage facilities, load and reload the canisters into the storage modules, and conduct routine surveillance and repairs (Orthen 1999, all). Because the workforce at each storage facility would be small, opportunities for carpooling would be limited. Therefore, the analysis assumed each worker would commute individually.

An estimated 700 workers (see Section 7.2.1.7.3) would commute to and from work approximately 18 million times during the first 100 years. The analysis assumed an average one-way commute of 19 kilometers (12 miles) based on personal travel reported in the Nationwide Personal Transportation Survey by the Oak Ridge National Laboratory (ORNL 1999, page 9). The analysis also used national data to estimate fatalities [in 1994, 1 fatality per 100 million kilometers (about 62 million miles) traveled by automobile (BTS 1999b, page 4)] over a single 100-year period. Based on the expected workforce, estimated number of trips, estimated average distance, and fatality data, approximately 7 traffic fatalities would occur in the workforce at the 77 sites in 100 years (or an average of less than 1 fatality every 10 years) (Orthen 1999, Table 6).

In addition, the analysis estimated the long-term traffic fatalities for the remaining 9,900-year analysis period. Using the estimated number of full-time equivalent work years of 7.4 million, about 730 traffic fatalities would be likely during the 9,900-year analysis period at the 77 sites (or, on average, less than 1 fatality every 10 years).

The analysis also estimated traffic fatalities and latent cancer fatalities from trucks transporting construction materials to and demolition debris from the 77 sites assuming an 80-kilometer (50-mile) roundtrip distance. For the 9,900-year period, during the construction of replacement facilities, construction vehicles would travel about 1.2 billion kilometers (750 million miles), resulting in approximately 26 prompt traffic fatalities, or less than 1 fatality every 300 years (BTS 1999b, page 4) and 0.1 latent cancer fatality from vehicle exhaust emissions (Orthen 1999, Table 7).

7.2.1.15 Sabotage

Storage of spent nuclear fuel and high-level radioactive waste over 10,000 years would entail a continued risk of intruder access at each of the 77 sites. Sabotage could result in a release of radionuclides to the environment around the facility. In addition, intruders could attempt to remove fissile material, which could result in releases of radioactive material to the environment. Under Scenario 1, the analysis assumed that safeguards and security measures currently in place would remain in effect during the

10,000-year analysis period at the 77 sites. Therefore, the risk of sabotage would continue to be low. However, as discussed in the Record of Decision (*62 FR* 3014, January 21, 1997) for the *Storage and Disposition of Weapons-Usable Fissile Materials Final Environmental Impact Statement* (DOE 1997n, all), disposition and storage does not make it impossible to recover plutonium for use in weapons. Therefore, the difficulty of maintaining absolute control over 77 sites for 10,000 years would suggest that the cumulative risk of intruder attempts could increase.

7.2.2 NO-ACTION SCENARIO 2

DOE and commercial utilities intend to maintain control of the nuclear storage facilities as long as necessary to ensure public health and safety. However, Scenario 2 assumes no effective institutional control of the storage facilities after approximately the first 100 years to provide a basis for evaluating an upper limit of potential adverse human health impacts to the public from the continued storage of spent nuclear fuel and high-level radioactive waste. After about 100 years, Scenario 2 assumes that there would be no effective institutional control and that the storage facilities would be abandoned. Therefore, there would be no health risks for workers during that period. For the long-term impacts after about 100 years and for as long as 10,000 years, the analysis assumed that the spent nuclear fuel and high-level radioactive waste storage facilities at 72 commercial and 5 DOE sites would begin to deteriorate and that radioactive materials would be released to the environment, contaminating the local atmosphere, soil, surface water, and groundwater. Appendix K provides details of facility degradation, radioactive material environmental transport, and human radiological exposure and dose models.

Because Scenario 2 assumes effective institutional control during the first 100 years of the 10,000-year analysis period, the short-term impacts of that first 100 years would be the same as the impacts described for Scenario 1 (see Section 7.2.1). Therefore, this discussion focuses on long-term impacts (after the first approximately 100 years). However, after about 100 years under Scenario 2, when there would no longer be effective institutional control, construction and operation activities would not occur at the storage sites; therefore, socioeconomic and cultural resources would be unlikely to receive adverse impacts. In addition, noise would not emanate from the facilities; utilities, energy, or materials would not be expended; waste would not be generated; and workers would not commute to the sites. Thus, after approximately the first 100 years, No-Action Alternative Scenario 2 would not adversely affect cultural resources; scenic resources; noise; utilities, energy and materials; waste management; or traffic and transportation. Aesthetic resources would not change until the facilities began to degrade, at which time the aesthetic value of the sites would change.

7.2.2.1 Land Use and Ownership

Without maintenance and periodic replacement, facilities, storage containers, and the spent nuclear fuel and high-level radioactive waste would begin to deteriorate. Eventually radioactive materials would contaminate the land surrounding the storage facilities, possibly rendering it unfit for human habitation or agricultural uses for hundreds or thousands of years. The amount of land contaminated would depend on several factors including the climate of the region, the amount of spent nuclear fuel and high-level radioactive waste at the site, and the rate of deterioration. Although the size of the affected area would be impossible to predict accurately for each site, DOE believes it would involve tens to hundreds of acres at each of the 77 sites.

By assuming that there would be no effective institutional control, this scenario also assumes that there would not be an orderly conversion of land use and ownership to other uses or ownership and that all knowledge of the purpose and content of the facilities would be lost. This would increase the likelihood that members of the public would move onto storage facility lands because they would not be aware of the potential radioactive material contamination.

7.2.2.2 Air Quality

As discussed in Appendix K, Section K.2.3, the degraded facilities would provide sufficient protection of the spent nuclear fuel and high-level radioactive waste materials to preclude the release of particulate radioactive materials in sufficient quantities to affect air quality adversely. Small releases of gaseous carbon-14 would be likely in the form of carbon dioxide gas but would not adversely affect ambient air quality.

7.2.2.3 Hydrology

7.2.2.3.1 *Surface Water*

As the concrete storage facilities, storage canisters, and spent nuclear fuel and high-level radioactive waste materials deteriorated, contaminants would enter surface waters from stormwater runoff from the failed facilities and storage containers and exposed radioactive materials. The introduction of contaminants would continue over a long period until the depletion of the source materials. During this release period, contaminant releases to surface waters could be sufficient to produce adverse impacts to human health. Section 7.2.2.5.3 discusses impacts to the public using this water for drinking.

7.2.2.3.2 *Groundwater*

As the concrete storage facilities, storage canisters, and spent nuclear fuel and high-level radioactive waste materials deteriorated, contaminants would enter the groundwater. Once contaminated, aquifers beneath the degraded storage facilities would remain contaminated for the period required for the depletion of the spent nuclear fuel and high-level radioactive waste materials and the migration of the contaminants from the groundwater system. Contaminant concentrations in the groundwater could be sufficient to produce adverse impacts to human health. Section 7.2.2.5.3 discusses impacts to the public using groundwater for drinking, bathing, and irrigation.

7.2.2.4 Biological Resources and Soils

As the concrete storage facilities, storage canisters, and spent nuclear fuel and high-level radioactive waste materials deteriorated, the potential for individual animals to be exposed to radiation at the storage sites would increase. In addition, animals could drink contaminated surface water. Direct radiation from the exposed spent nuclear fuel and high-level radioactive waste storage canisters and concentrations of contaminants in surface waters could produce adverse impacts to animals. While the contaminant exposure could have negative effects, including death, on individual animals, adverse effects to entire populations would be unlikely because the lethal area surrounding the degraded facilities would be limited to a few hundred acres.

Soils at the storage facilities could be contaminated by radioactive materials leaching from the spent nuclear fuel and high-level radioactive waste material. Soils downslope of the facilities could be contaminated by surface-water runoff. Crops grown on these soils would take up some of the contamination, thus making the contaminated soils a pathway for human exposure. Section 7.2.2.5.3 discusses impacts to members of the public from ingesting food grown in or livestock fed from contaminated soils.

7.2.2.5 Occupational and Public Health and Safety

7.2.2.5.1 *Nonradiation Exposures*

Analyses performed for the repository (see Chapter 5, Section 5.6) indicate that uranium concentrations from degraded spent nuclear fuel and high-level radioactive waste in the groundwater would be extremely low. Therefore, because of the relatively greater abundance of water and the greater precipitation at the storage locations than at the repository, uranium concentrations in the groundwater and surface water at the storage sites would be much lower than those estimated for the repository. The only other toxic material, chromium, would be present in the packaging at the storage sites in extremely low concentrations [most of the chromium analyzed at the repository comes from corrosion-resistant alloys (Alloy-22) that would not be present in continued storage location packaging materials]. Therefore, concentrations of chemically toxic materials would be extremely low and probably would not result in adverse impacts.

7.2.2.5.2 *Industrial Hazards*

For about the first 100 years, industrial hazards would be the same as for the first 100 years under Scenario 1 (see Section 7.2.1.7.2). After about 100 years, Scenario 2 assumes there would be no effective institutional control and that the storage facilities would be abandoned and, therefore, there would be no industrial safety impacts.

7.2.2.5.3 *Radiation Exposures*

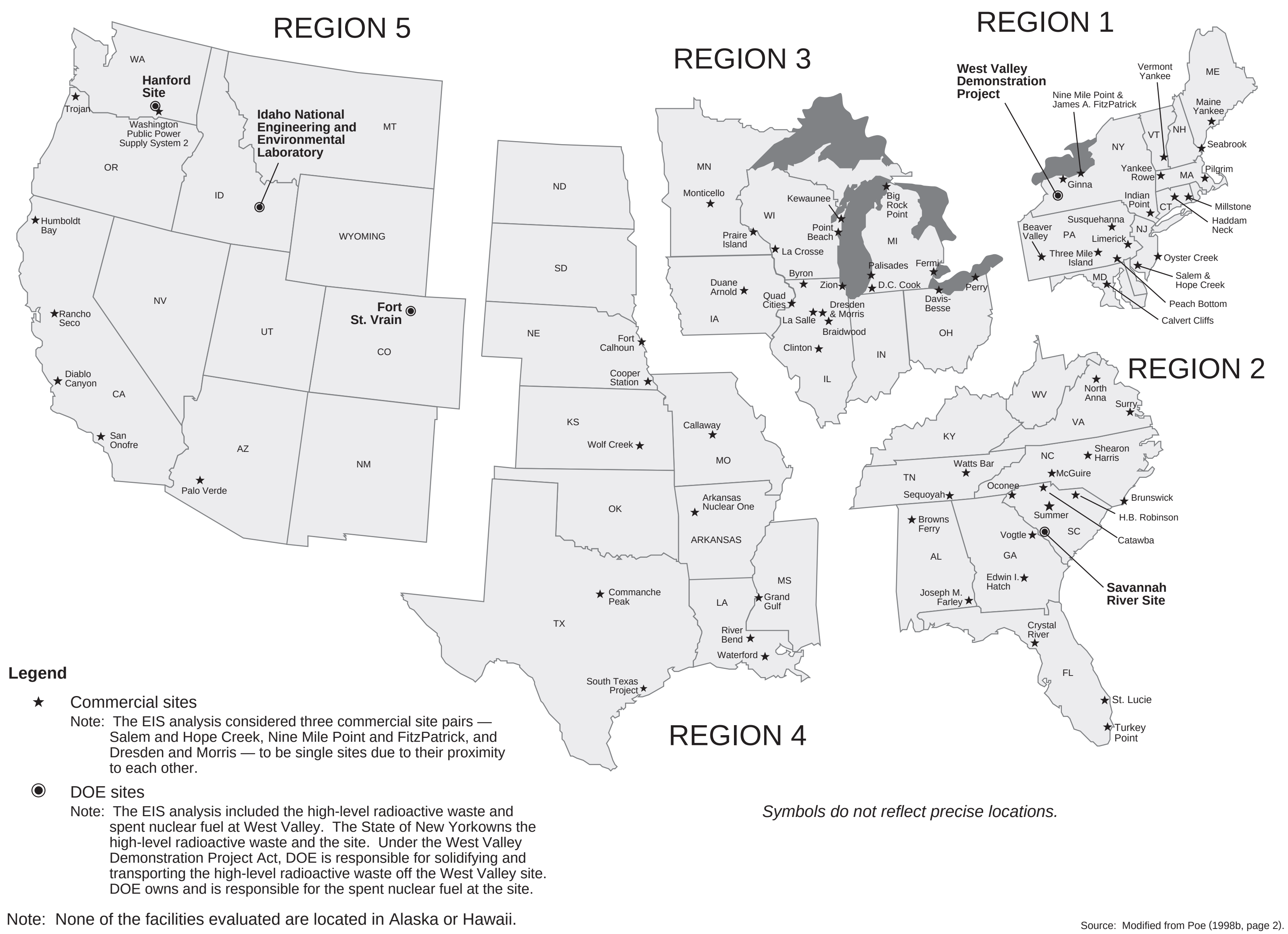
To simplify the analysis, DOE divided the United States into five regions (Figure 7-7). Regional radiological impacts were estimated by assuming all spent nuclear fuel and high-level radioactive waste in a particular region was stored at a single hypothetical site in that region. Appendix K, Section K.2.1.6, provides details of the methods and assumptions used in the regional analysis.

Radiological impacts to occupational workers and the offsite public from initial construction, routine maintenance and operations, and refurbishment after the first 50 years would be the same as those for the same period under Scenario 1 (see Section 7.2.1.7.3 and Table 7-6).

For Scenario 2 DOE assumed that after approximately the first 100 years there would be no institutional control and that deterioration of the facilities would occur over time. Based on regional climate and degradation models (see Appendix K), the spent nuclear fuel and high-level radioactive waste storage facilities and dry storage containers would corrode and fail over time, exposing radioactive material to the environment (wind and rain). Once exposed to the environment, the spent nuclear fuel and high-level radioactive waste storage packages and facilities would begin releasing small quantities of radioactive material to the atmosphere (gaseous carbon-14), soil, surface water, and groundwater, resulting in exposures to the public. These released materials could produce chronic exposures to the public, which could result in adverse health impacts. Figure 7-8 shows the conceptual timeline for activities and degradation processes at the storage facilities for Scenario 2.

Appendix K describes the methods used to estimate impacts to human health from long-term environmental releases and human intrusion. The radiological impacts on human health include internal exposure from intake of radioactive materials in surface water and groundwater.

Table 7-7 lists the estimated radiological drinking water impacts during the 9,900 years under Scenario 2 with the assumption of no effective institutional control. The impacts listed in Table 7-7 are from drinking water only and would result from consuming water from the major waterways contaminated with



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

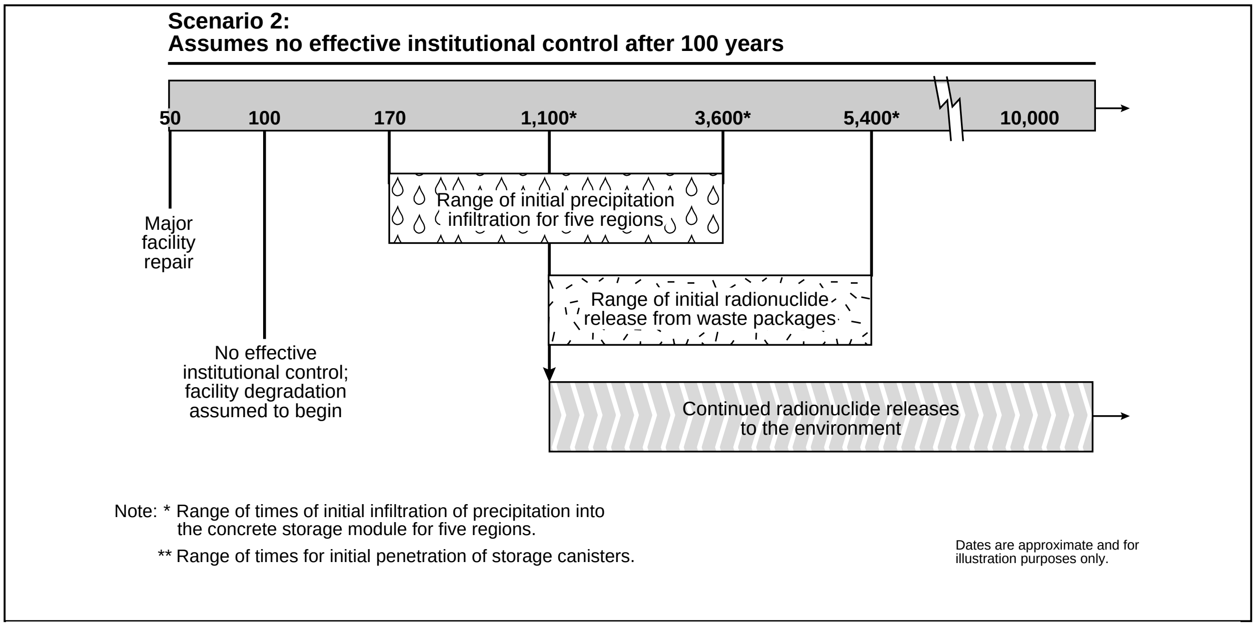
Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

Note: None of the facilities evaluated are located in Alaska or Hawaii.

Symbols do not reflect precise locations.

Source: Modified from Poe (1998b, page 2).

Figure 7-7. Commercial and DOE sites in each No-Action Alternative analysis region.



Note: * Range of times of initial infiltration of precipitation into the concrete storage module for five regions.

** Range of times for initial penetration of storage canisters.

Dates are approximate and for illustration purposes only.

Figure 7-8. Conceptual timeline for activities and degradation processes for No-Action Scenario 2.

Table 7-7. Estimated long-term collective drinking water radiological impacts to the public from long-term storage of spent nuclear fuel and high-level radioactive waste at commercial and DOE sites – Scenario 2.

9,900-year population dose[a] (person-rem)	9,900-year LCFs[b]	Years to peak impact[c]
6,600,000	3,300	3,400

a. Estimated total population (collective) dose from drinking water pathway (Toblin 1998, page 4).

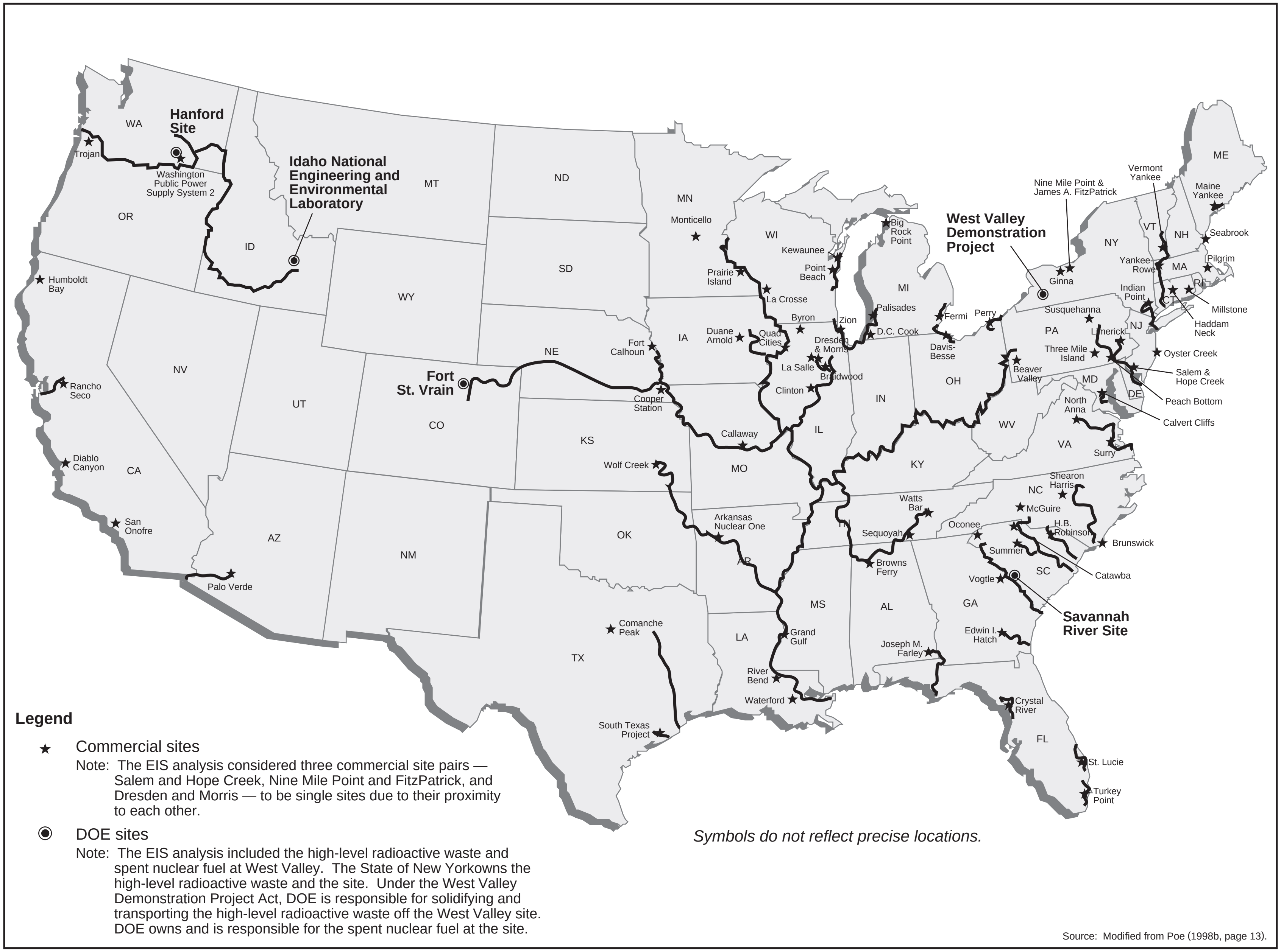
b. LCFs = latent cancer fatalities; estimated for the exposed population group based on an assumed risk of 0.0005 latent cancer fatality per person-rem of collective dose (NCRP 1993b, page 112).

c. Years after period of institutional control when the maximum doses would occur.

radioactive materials by groundwater discharge and surface-water runoff from degraded spent nuclear fuel and high-level radioactive waste storage facilities. DOE evaluated other potential impacts to populations (for example, exposure to people living on the contaminated floodplains) and to individuals (for example, consumption of contaminated food) and determined that certain individuals could receive doses as much as three times higher than for drinking water alone but that doses to populations from contaminated floodplains would represent less than 10 percent of the impacts listed in Table 7-7. DOE did not include these impacts in Table 7-7 because the dose to an individual would depend largely on highly variable subsistence habits and because DOE did not want to overestimate the impacts from Scenario 2.

Figure 7-9 shows the locations of the commercial and DOE sites in the United States and the more than 20 major waterways potentially affected. At present, municipal water systems that serve 31 million people have intakes along the potentially affected portions of these waterways. The analysis assumed these populations would remain constant over the entire analysis period (9,900 years). Over the 9,900-year analysis period, about 140 70-year lifetime periods would be affected. Because the analysis estimated that releases would not occur during the first 1,000 years for most regions, the estimated potentially exposed population would be about 3.9 billion.

Table 7-7 indicates that over 9,900 years, a collective drinking water dose of 6.6 million person-rem could result in an additional 3,300 latent cancer fatalities in the total potentially exposed population of 3.9 billion. This latent cancer fatality rate would affect an average of about 24 people per 70-year



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

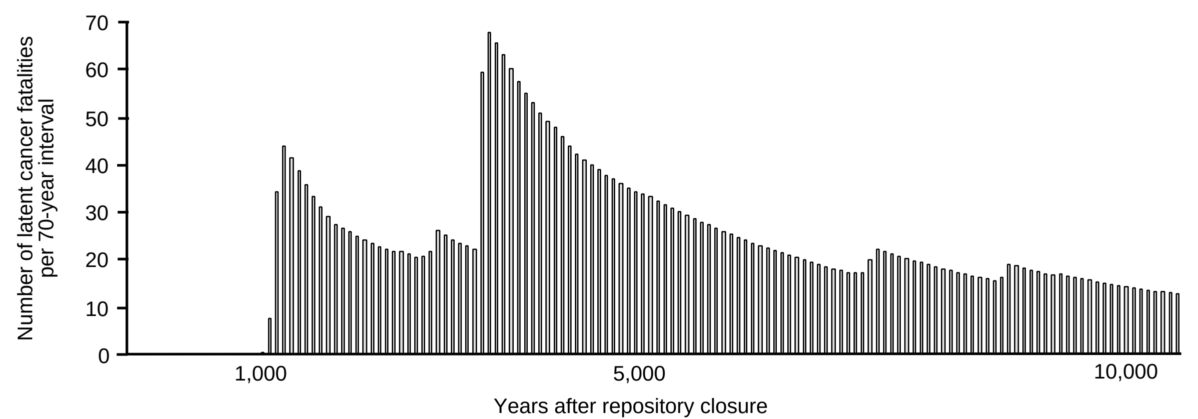
Symbols do not reflect precise locations.

Source: Modified from Poe (1998b, page 13).

Figure 7-9. Major waterways near commercial and DOE sites.

lifetime, or about 1 latent cancer fatality at each of the 77 sites every 200 years. These radiation-induced latent cancer fatalities would be in addition to about 900 million fatal cancers (using the lifetime fatal cancer risk of 24 percent [NCHS 1993, page 5]) that would be likely from all other causes in the exposed population, an incremental increase over the natural incidence of fatal cancer of about 0.0004 percent.

Figure 7-10 shows the estimated latent cancer fatalities for approximately 140 70-year periods during the 9,900-year period of analysis. The five peaks shown in Figure 7-10 generally result from contributions of each of the five regions (see Appendix K, Figure K-8). The major peak, which would occur about 3,400 years after effective institutional control ended (in 2100), would be due to radionuclide releases at the sites that drain to the Mississippi River and the relatively large populations along the Mississippi and its tributaries.



Source: Adapted from Toblin (1998, page 8).

Figure 7-10. Potential latent cancer fatalities throughout the United States from No-Action Scenario 2.

In addition to the 3,300 potential cancer fatalities under Scenario 2, more than 20 major waterways of the United States that currently supply domestic water to about 31 million people (for example, the Great Lakes; the Mississippi, Ohio, and Columbia Rivers; and many smaller rivers along the Eastern Seaboard) could be contaminated with radioactive material. Under this scenario, the shorelines could be contaminated with long-lived radioactive materials (for example, plutonium, uranium, and americium), resulting in exposures to individuals who came in contact with the sediments and, potentially, an increase in latent cancer fatalities. Because individuals would not be in constant contact with the sediments, these impacts represent a small fraction of the impacts estimated for the drinking water pathways listed in Table 7-7.

For purposes of comparison with impacts associated with the Proposed Action, DOE evaluated potential radiological impacts for a maximally exposed individual by constructing hypothetical exposure scenarios for individuals living near the degraded facilities. The exposure scenarios maximized external and internal exposure over each 70-year lifetime period in the 9,900-year period of analysis. The following paragraphs describe the results of these evaluations.

For Scenario 2, localized impacts to individuals from degraded facilities at the 77 sites could be severe. DOE estimated that within a few hundred years at the several sites where early concrete failure was predicted, hypothetical individuals living close to the storage facilities would receive lethal doses of external radiation [800 millirem per hour at a distance of 10 meters (33 feet)] from the exposed dry storage containers (see Appendix K, Section K.2.4.3.2).

To evaluate impacts from ingestion of radioactive materials, the analysis assumed that individuals would live near the degraded storage facilities and would consume contaminated groundwater and food from gardens irrigated with groundwater withdrawn from the contaminated aquifer directly below their locations. DOE estimated that within 6,000 years from now a hypothetical individual living within several hundred meters of a degraded facility could receive an internal committed effective dose equivalent to several thousand rem per year from ingestion of plutonium-239 and -240 (see Appendix F for further information on committed dose equivalent). Using the National Council on Radiation Protection and Measurements risk factors (NCRP 1993b, page 112), ingestion of plutonium at this rate could increase the individual's lifetime risk of contracting a fatal cancer after only a few years of exposure.

In addition, DOE estimated impacts for a hypothetical individual living 5 kilometers (3 miles) from the degraded facility on the downgradient of the contaminated aquifer. Although this individual would be too distant from the facility to receive any appreciable external radiation dose, the internal dose from the consumption of contaminated groundwater and contaminated crops could still be as high as 30 rem per year from ingestion of plutonium-239 and -240. Ingestion of plutonium at this rate could increase the individual's risk of contracting a fatal cancer after several decades of exposure. Appendix K provides details on the methods DOE used to evaluate localized impacts.

7.2.2.6 Atmospheric Radiological Consequences

As discussed in Appendix K, Section K.2.3.3, the analysis assumed that the configuration of the degraded storage facilities would cause debris to cover the radioactive material, which would remain inside the dry storage canisters. While the dry storage canisters could fail sufficiently to permit water to enter, they would probably retain their structural characteristics, thereby minimizing the dispersion of particulate radioactive material to the atmosphere (Mishima 1998, all). However, the radionuclides carbon-14 and iodine-129 would have a relatively large inventory and a potential for gas transport. Although iodine-129 can exist in a gas phase, DOE expects it would dissolve in the precipitation and migrate in surface water and groundwater.

7.2.2.7 Accidents

For Scenario 2, the analysis examined the impacts of accident scenarios that could occur during the above-ground storage of spent nuclear fuel and high-level radioactive waste and concluded that the most severe accident scenarios would be an airplane crash into a concrete storage module and a severe seismic event.

In Scenario 2, the concrete storage modules would deteriorate with time. DOE concluded that an airplane crash into a degraded concrete storage module would dominate the consequences from external initiating events (see Appendix K, Section K.3.2.1). The analysis evaluated the potential for criticality accidents and concluded that an event severe enough to produce large consequences would be extremely unlikely, and that the consequences would be bounded by the airplane crash consequences. Table 7-8 lists the consequences of an airplane crash on a degraded concrete storage module.

Table 7-8. Estimated consequences of an aircraft crash on a degraded spent nuclear fuel concrete storage module.[a]

Impact	High population site[b]	Low population site[c]
Collective population dose (person-rem)	26,000	6,100
Latent cancer fatalities	13	3

a. Source: Davis, Strenge, and Mishima (1998, page 11).
b. Within 80 kilometers (50 miles) of site, an average of 330 persons per square mile.
c. Within 80 kilometers of site, an average of 77 persons per square mile.

7.2.2.8 Environmental Justice

Deteriorating facilities, storage containers and packaging, and spent nuclear fuel and high-level radioactive waste could produce adverse effects to the nearby public. Any nearby minority or low-income communities could experience disproportionately high and adverse human health impacts. In addition, financial considerations could make it more difficult for members of any affected minority or low-income populations to obtain uncontaminated resources or to move away from contaminated soils and water. Because subsistence patterns for low-income and minority populations could vary from those of persons not in these groups, any affected low-income and minority populations could be exposed to greater than average doses. The result of differing potentials for exposure could be disproportionately high and adverse impacts to minority or low-income populations.

If the United States determines that it will use continued storage at existing sites for the long-term disposition of spent nuclear fuel and high-level radioactive waste, site-specific analyses of storage facilities would be required to identify if environmental justice issues could result. The Nuclear Regulatory Commission established this approach (NRC 1996, page 9-16). With the assumption of no effective institutional control after about 100 years, potential environmental justice issues identified under Scenario 2 probably would be more severe than those identified under Scenario 1 (see Section 7.2.1.13).

7.2.2.9 Sabotage

For Scenario 2, the storage of spent nuclear fuel and high-level radioactive waste over 10,000 years without institutional controls would entail a greater risk of intruder access at the 77 sites than current conditions. Potential sabotage could result in a release of radionuclides to the environment around the facility. In addition, intruders could attempt to remove fissile material, which could result in releases of radioactive material at remote sites. The analysis assumed that safeguards and security measures would not be maintained at the 77 sites after approximately the first 100 years. For the remaining 9,900 years of the analysis period, the cumulative risk of intruder attempts would increase. The stored spent nuclear fuel and high-level radioactive waste would not be in a weapons-usable form. The condition of the spent nuclear fuel and high-level radioactive waste would require the application of specialized equipment and technologies to reprocess it into a weapons-usable form. However, as discussed in the Record of Decision (*62 FR* 3014, January 21, 1997) for the *Storage and Disposition of Weapons-Usable Fissile Materials Final Environmental Impact Statement* (DOE 1997n, all), disposition and storage does not make it impossible to recover plutonium for use in weapons. In addition, the material would contaminate areas with radioactivity if released from its storage containers. Therefore, the risks of sabotage would increase substantially under this scenario in comparison to Scenario 1.

7.3 Cumulative Impacts for the No-Action Alternative

DOE evaluated the disposal of 70,000 MTHM of spent nuclear fuel and high-level radioactive waste in the Proposed Action analysis. To provide a direct comparison of impacts with the Proposed Action, the No-Action analysis in Sections 7.1 and 7.2 evaluated the impacts of the continued storage of 70,000 MTHM of spent nuclear fuel and high-level radioactive waste at 72 commercial and 5 DOE sites across the United States. DOE chose the volume of 70,000 MTHM for analysis because the NWPA prohibits the Nuclear Regulatory Commission from approving the emplacement of more than 70,000 MTHM in a first repository until a second repository is in operation. This section describes the results of the analysis of the cumulative impacts of the continued storage at the 77 existing sites of all spent nuclear fuel and high-level radioactive waste (called Inventory Module 1) (Table 7-9). Chapter 8 discusses the cumulative impacts of disposing of radioactive waste at the Yucca Mountain repository in excess of the Proposed Action repository.

Table 7-9. Inventories for Proposed Action and Module 1.[a]

Material	Proposed Action	Module 1
DOE spent nuclear fuel	2,333 MTHM	2,500 MTHM
Commercial spent nuclear fuel	63,000 MTHM	105,000 MTHM
High-level radioactive waste	8,315 canisters	22,280 canisters
Surplus plutonium[b]	50 MTHM	50 MTHM

a. Source: Appendix A, Section A.1.1.4.1.

b. The surplus plutonium (fissile material) would be in the form of mixed-oxide fuel (assumed to be 32 MTHM) or encapsulated into high-level radioactive waste canisters (assumed to be 18 MTHM) and, for purposes of storage analysis, is included in the commercial spent nuclear fuel and high-level radioactive waste canister inventories, respectively.

The Council on Environmental Quality regulations that implement the procedural provisions of the National Environmental Policy Act of 1969, as amended (42 USC 4321 *et seq.*), define a cumulative impact as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions" (40 CFR 1508.7). Cumulative impact assessment is based on both the geographic (spatial) and time (temporal) considerations of past, present, and reasonably foreseeable actions. Geographic boundaries can vary by discipline depending on the time an effect remains in the environment, the extent to which the effect can migrate, and the magnitude of the potential impact. The proximity of other actions to the spent nuclear fuel storage sites is not the only decisive factor for determining the inclusion of an action in the assessment of cumulative impacts. Another, and for this analysis more important, factor is if the other actions would have some influence on the resources in the same time and space affected by continued storage (CEQ 1997, page 17).

The cumulative impacts of past actions have either passed through the environment or are part of existing baseline conditions. For example, the construction impacts of spent nuclear fuel storage facilities will have passed through the environment before the potential impacts associated with continued storage and refurbishment would first be seen in 2002.

DOE based its estimates of the potential impacts from continued storage of commercial spent nuclear fuel on a representative site. The results of the analysis described in the previous section are consistent with the Nuclear Regulatory Commission's findings in its *Generic Environmental Impact Statement for License Renewal of Nuclear Plants* (NRC 1996, pages 6-85 and 6-86). The NRC stated:

> *The Commission's regulatory requirements and the experience with on-site storage of spent fuel in fuel pools and dry storage has been reviewed. Within the context of a license renewal review and determination, the Commission finds that there is ample basis to conclude that continued storage of existing spent fuel and storage of spent fuel generated during the license renewal period can be accomplished safely and without significant environmental impacts. Radiological impacts will be well within regulatory limits; thus radiological impacts of on-site storage meet the standard for a conclusion of small impact. The nonradiological environmental impacts have been shown to be not significant; thus they are classified as small. The overall conclusion for on-site storage of spent fuel during the term of a renewed license is that the environmental impacts will be small for each plant. The need for the consideration of mitigation alternatives within the context of renewal of a power reactor license has been considered, and the Commission concludes that its regulatory requirements already in place provide adequate mitigation incentives for on-site storage of spent fuel.*

Although this finding is applicable only to the continued storage of existing spent nuclear fuel and spent nuclear fuel generated during the 20-year license renewal period for the nuclear powerplant, DOE has concluded that potential environmental and radiological impacts for the storage facility would remain small for much longer periods. Environmental impacts would remain small because no additional fuel would be generated beyond the operation of the nuclear powerplant (plants are assumed to be closed after the first 20-year license renewal period), and radiological impacts would remain within regulatory limits specified in the storage facility license (10 CFR Part 172).

In general, the analysis of cumulative effects can exclude future actions if:

- The action is outside the geographic boundaries or timeframe established for the cumulative effects analysis.
- The action will not affect resources that are the subject of the cumulative effects analysis.
- Including the action would be arbitrary (CEQ 1997, page 19).

Because the estimated impacts would be small, DOE has not attempted to speculate on other arbitrary generic actions that could influence the cumulative impacts generated at a given site. However, the total incremental impact nationally of selected parameters is presented in the preceding section. In addition, the potential impacts at each site do not overlap because the storage sites are located throughout the United States. Therefore, cumulative impacts among the sites on resources would be unlikely.

For the 5 DOE sites, there is a long legacy of EISs and annual monitoring reports. The incremental impacts associated with continued storage of spent nuclear fuel can be added to the results reported in these documents to obtain an estimate of total impacts. For the 72 diverse commercial sites, information on other present and reasonably foreseeable actions varies in terms of data availability and quality. As a consequence, a comparison of cumulative assessments would be problematic, even if the impacts were not as small as the analyses indicate.

The cumulative analysis in this section includes the total projected inventory of commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste (referred to as Module 1) that would come to the repository. Table 7-9 lists the inventories for the Proposed Action analysis and the Module 1 cumulative analysis.

For consistency with the cumulative impact analysis in Chapter 8, the No-Action analysis considered the same spectrum of environmental impacts as the Proposed Action. Quantitative estimates of the cumulative impacts in this section are limited to the disciplines for which DOE made quantitative assessments for the Proposed Action, as discussed in Section 7.2. These disciplines include occupational and public health and safety, waste management, and traffic and transportation. However, because of the DOE commitment to manage spent nuclear fuel and high-level radioactive waste safely, the Department decided to focus the No-Action cumulative analysis on the short- and long-term health and safety of workers and members of the public. The qualitative discussions of other disciplines are included for completeness.

DOE recognizes that approximately 2,054 cubic meters (10,900 cubic feet) of commercial low-level radioactive waste will exceed Nuclear Regulatory Commission Class C limits (listed in 10 CFR 61.55, Tables 1 and 2 for long and short half-life radionuclides, respectively). This type of waste, called *Greater-Than-Class-C low-level waste*, is generally not suitable for near-surface disposal (see Appendix A, Section A.2.5, for a detailed description). Similarly, DOE low-level radioactive waste that exceeds the Nuclear Regulatory Commission Class C limits (referred to as *Special-Performance-Assessment-Required waste*) will amount to about 4,017 cubic meters (142,000 cubic feet) (see Appendix A, Section A.2.6, for a detailed description). Together these waste types, added to the Module 1 inventory, comprise the Module 2 inventory.

The NWPA does not specifically consider Greater-Than-Class-C or Special-Performance-Assessment-Required wastes. Therefore, DOE has not included either waste type in the Proposed Action inventory for the consideration of potential impacts that could occur from the disposal of spent nuclear fuel and high-level radioactive wastes in a geologic repository at Yucca Mountain. The disposal of these wastes at Yucca Mountain, however, is part of the cumulative impact analysis (see Chapter 8) because the impacts of that disposal are reasonably foreseeable as the results of future actions.

Further, DOE has not included Module 2 in its consideration of potential impacts under the No-Action Alternative. DOE does not have enough information about Module 2 wastes at present to be able to perform a meaningful analysis with respect to the No-Action Alternative. As discussed in Appendix A, Section A.2.5, Greater-Than-Class-C waste could include, for example, certain commercial nuclear powerplant operating and decommissioning wastes and sealed radioisotope sources. DOE Special-Performance-Assessment-Required waste could include certain production reactor operating wastes, production and research reactor decommissioning wastes, sealed radioisotope sources, and isotope production-related wastes (see Appendix A, Section A.2.6). As just one example of the confounding potential sources of these types of wastes, in 1993 DOE estimated that 2,552 Greater-Than-Class-C low-level waste fixed-gauge and X-ray fluorescence sealed sources (general licensees) and 7,582 sealed sources (for example, calibration, medical, well logging sources) were used and stored by private industry at hundreds of locations in the United States (DOE 1994d, all).

As this example illustrates, a meaningful analysis would need to consider the sites, or combination of sites, at which these waste types are currently in use and storage. The analytic approach used to construct the regional representative sites for which the continued storage of spent nuclear fuel and high-level radioactive waste was evaluated would not apply to the hundreds of additional locations associated with Greater-Than-Class-C and Special-Performance-Assessment-Required wastes.

For the spent nuclear fuel and high-level radioactive waste analysis in this EIS (see Appendix K, Section K.2.1), DOE collected information from published sources for each of the 77 sites where spent nuclear fuel and high-level radioactive waste is located and, to simplify the analysis, divided the country into five regions. The Department then configured a single hypothetical site in each region (see Appendix K, Section K.2.1.6), which enabled it to estimate the potential release rate of the radionuclide inventory from the spent nuclear fuel and high-level radioactive waste, based on forecast interactions of the environment (rainfall, freeze-thaw cycle) with the engineered barrier (concrete storage modules).

Environmental information at the hundreds of sites in which Greater-Than-Class-C and Special-Performance-Assessment-Required wastes are in use and storage is not readily available and DOE could not obtain it without an exorbitant commitment of resources. Relevant environmental evaluations such as those prepared by the Nuclear Regulatory Commission for operating commercial nuclear powerplants or spent nuclear fuel storage installations are not available for most of the locations at which these waste types are in use or storage. Further, the manner in which Greater-Than-Class-C and Special-Performance-Assessment-Required low-level wastes are stored varies by waste types, and the great variety of storage methods could not be simplified for analytical purposes without distorting the resulting potential environmental impacts.

Even if such information were gathered and the means of storage could be reduced by the use of simplifying assumptions, the results of the analysis (the impacts) would tend to reinforce the results of the impact analysis performed for the Module 1 inventory. That is, short-term impacts such as those to socioeconomics and land use would not increase appreciably, but health effects probably would increase over the long term because workers and the public would be exposed to these waste types in addition to spent nuclear fuel and high-level radioactive waste at the many locations across the United States.

7.3.1 SHORT-TERM IMPACTS IN THE YUCCA MOUNTAIN VICINITY

Candidate materials would not be transported to the repository. Therefore, impacts from Module 1 would be the same at the Yucca Mountain site as those presented in Section 7.1.

7.3.2 SHORT- AND LONG-TERM IMPACTS AT COMMERCIAL AND DOE SITES

7.3.2.1 Land Use and Ownership

Under Scenario 1 (long-term institutional control), as discussed in Section 7.2.1.1, the land required for storage facilities typically would be a few acres. For the Module 1 inventory, the analysis assumed that the land required would increase, on average, by about 60 percent (the ratio of Proposed Action and Module 1 inventories). This additional land requirement [less than 0.04 square kilometer (10 acres) per site] would represent a small percentage of the land currently available at the sites; therefore, the incremental impacts on land use would be minimal but larger than those for the Proposed Action facilities. These storage facilities would be on land currently owned by DOE or a utility and, therefore, would be unlikely to affect land ownership.

Under Scenario 2 (assumption of no effective institutional control after about 100 years), as discussed in Section 7.2.2.1, without maintenance and periodic replacement, facilities, storage containers, and the spent nuclear fuel and high-level radioactive waste would begin to deteriorate, eventually contaminating the land surrounding the storage facilities and rendering it unfit for human habitation or agricultural uses for hundreds or thousands of years. The additional inventories of Module 1 probably would increase the concentrations of radioactive materials in the soils and the size of the affected areas over those expected for the Proposed Action inventory. As with the Proposed Action, these concentrations and areas would be impossible to estimate but even with the additional inventories of Module 1, DOE believes it would involve less than several hundred acres at each of the 77 sites.

In addition, as with the Proposed Action, because Scenario 2 assumes no effective institutional control after approximately 100 years, there would not be an orderly conversion of land use and ownership to other uses or ownership. Therefore, the potential for members of the public to move onto storage facility lands with Module 1 inventories would be unchanged from that expected for the Proposed Action.

7.3.2.2 Air Quality

As discussed in Section 7.2.1.2, under Scenario 1 best management practices and effective monitoring procedures would ensure that contaminant releases to the air would be minimal and would not exceed current regulatory limits (40 CFR Part 61 for hazardous air pollutants emissions and Part 50 for air quality standards). In addition, DOE expects that these controls would be effective with the additional inventories of Module 1. Therefore, air quality under Scenario 1, Module 1 would not be adversely affected during routine operations.

As discussed in Section 7.2.1.2, during the construction of replacement facilities, exhaust from construction vehicles would temporarily increase local concentrations of hydrocarbons, carbon monoxide, and oxides of nitrogen for a few years during each 100 years. DOE expects that these temporary increases in particulate matter resulting from construction activities would persist for slightly longer periods because of the additional facilities required to store the additional inventories of Module 1. However, mitigation measures such as watering unpaved roads would limit the generation of fugitive dust. As with the Proposed Action, after replacement the old site would be seeded, graveled, or paved to reduce air emissions. Therefore, although adverse air quality impacts during construction would be slightly higher for the Module 1 inventory, DOE expects them to be minimal and transient.

The Module 1 air quality impacts under Scenario 2, as discussed in Section 7.2.2.2, would be minimal because even degraded facilities would limit the release of radioactive particulate material to the atmosphere.

7.3.2.3 Hydrology

7.3.2.3.1 *Surface Water*

For Scenario 1, as discussed in Section 7.2.1.3.1, under long-term institutional control, best management practices such as stormwater pollution prevention plans and stormwater holding ponds would ensure that, in the unlikely event of an inadvertent release, contaminants would not reach surface-water systems. These controls and monitoring procedures would be effective for the additional inventories of Module 1. Therefore, as with the Proposed Action inventory, surface-water quality would not be adversely affected by routine operations.

For long-term impacts from Scenario 2, after about 100 years when there is an assumption of no effective institutional control, the Module 1 contaminants could enter surface water via stormwater runoff from degraded facilities in quantities greater than those expected for the Proposed Action. Section 7.3.2.7.3 discusses the incremental impacts to the public expected from these additional surface water contaminants resulting from the Module 1 inventory.

7.3.2.3.2 *Groundwater*

Under Scenario 1, Module 1 groundwater impacts from the storage of 105,000 MTHM of commercial spent nuclear fuel, 2,500 MTHM of DOE spent nuclear fuel, and 22,280 canisters of high-level radioactive waste would be minimal because best management practices such as spill prevention and cleanup plans and procedures and effective effluent monitoring procedures would ensure that inadvertent contaminant releases did not reach groundwater.

In addition, although the analysis assumed that the average square footage of storage facilities would increase by about 60 percent for the additional Module 1 inventory, the shallow foundations of these surface structures would not disturb groundwater systems. Some additional DOE storage facilities would be subsurface structures for which construction could require minimal dewatering of the groundwater aquifer. However, the larger square footage of the Module 1 structures would be relatively small (a few acres) in relation to the size of the aquifer, so no adverse impacts would result from dewatering activities.

For long-term impacts from Scenario 2, Module 1 contaminants would be likely to enter the underlying groundwater from degraded facilities in quantities greater than those expected for the Proposed Action. Section 7.3.2.7.3 discusses the incremental impacts to the public from these additional groundwater contaminants resulting from the Module 1 inventory.

7.3.2.4 Biological Resources and Soils

For Scenario 1, as discussed in Section 7.2.1.4, under long-term institutional control, impacts to biological resources or soils from the construction every 100 years and operation of the storage facilities would be minimal for the expanded Module 1 inventory. The facilities necessary to store the expanded Module 1 inventory would be fenced to keep wildlife out and replacement facilities would be constructed on previously disturbed soil. In addition, as with the Proposed Action, spills would be contained and cleaned up immediately, thus minimizing the area of soil affected.

For long-term impacts from Scenario 2, the analysis assumed that the potential for individual animals to be exposed to radiation at the storage sites would increase in proportion to the increased Module 1 inventory in comparison to the Proposed Action inventory (approximately 60 percent). While the increased contaminant exposure could have negative effects, including death, on individual animals, adverse impacts to entire populations would be unlikely because the lethal area surrounding the degraded facilities would be limited to a few hundred acres.

Contamination of soils at the storage facilities by radioactive materials leaching from the spent nuclear fuel and high-level radioactive waste material would be likely to increase in proportion to the increase in Module 1 inventory. Appendix K, Section K.2.4, discusses impacts to members of the public from eating food grown in contaminated soils or livestock fed on such soils.

7.3.2.5 Cultural Resources

For Scenario 1, the analysis assumed that the Module 1 replacement of spent nuclear fuel and high-level radioactive waste storage facilities would increase by about 60 percent over the Proposed Action. However, these additional facilities would generally be on undeveloped land owned by DOE or the commercial utilities in rural areas. As with the Proposed Action, the size of the additional facilities and supporting infrastructure would be small enough that the facility probably would avoid known cultural resources. In addition, if previously unknown archaeological sites, human remains, or funerary objects were uncovered during construction, DOE or the commercial utility would comply with Executive Orders and Federal and state regulations for the protection of cultural resources. Therefore, construction and operations would not affect cultural resources.

For long-term impacts from Scenario 2, construction and operation for about the first 100 years would be as described for Scenario 1. After this time, no construction or operation activities would occur at the generating sites; therefore, cultural resources would not be adversely affected.

7.3.2.6 Socioeconomics

For Scenario 1, the total staff required at 77 sites to monitor, maintain, and replace the Module 1 facilities would increase from about 700 for the Proposed Action inventory of 70,000 MTHM to more than 800 for the Module 1 inventory of 105,000 MTHM (Orthen 1999, Table 6). This increase is approximately equivalent to adding no more than two individuals at each of the 77 sites. Therefore, the additional storage requirements of the Module 1 inventory would be unlikely to affect socioeconomic factors such as infrastructure and regional economy.

For long-term impacts from Scenario 2, because there is an assumption of no effective institutional control after about 100 years, there would be no workers for either the Proposed Action or Module 1 inventories. Therefore the Module 1 socioeconomic impacts would be essentially the same as those for the Proposed Action for the first 100 years, but after that approximately 800 jobs would be lost. Because these jobs would be spread over 72 commercial and 5 DOE sites (about 10 jobs per site), socioeconomic impacts would be very small for a given region.

7.3.2.7 Occupational and Public Health and Safety

7.3.2.7.1 *Nonradiation Exposures*

For Scenario 1, Module 1, as with the Proposed Action, maintenance, repairs, repackaging, and construction at the storage facilities would be conducted in accordance with Occupational Health and Safety Administration and National Institute of Occupational Safety and Health requirements (29 CFR).

Worker exposures to industrial nonradioactive hazardous materials during construction and operation of the storage facilities would be minimized through administrative controls and design features such that exposures would remain below hazardous levels.

For long-term impacts from Scenario 2, the increased inventory of Module 1 would be likely to result in a proportional increase in concentrations of uranium and other toxic materials (such as chromium) in the groundwater and surface waters at the storage sites. However, these concentrations would remain extremely low and would not result in adverse human health impacts.

7.3.2.7.2 *Industrial Hazards*

For Scenario 1, as discussed in Section 7.2.1.7.2, the majority of the industrial accidents would occur as a result of surveillance (about 94 percent) and construction tasks. Operations tasks would contribute less than 0.001 percent of the total number of accidents. Therefore, to estimate the number of industrial accidents that would be likely to occur at the storage sites for the Module 1 inventory, the number of additional concrete storage modules required to store the additional inventory was calculated.

For Module 1 during the approximately 100-year construction and operation cycle (2002 to 2116), about 80,000 full-time equivalent work years would be required to maintain about 11,000 concrete storage modules and 8 below-grade storage vaults at the 77 sites (Orthen 1999, Table 1). Based on this level of effort, as listed in Table 7-10, about 2,800 industrial safety incidents would be likely, resulting in about 1,200 lost workday cases and 3 fatalities (an average of about 1 fatality every 30 years).

In addition, for Module 1, Table 7-10 indicates about 410,000 projected industrial safety incidents, of which about 180,000 would be lost workday cases and 490 would involve fatalities (an average of about 1 fatality every 20 years or about 1 every 1,600 years at each of the 77 sites). Surveillance tasks would provide about 94 percent of the total worker level of effort, construction tasks would provide nearly all of the remaining 6 percent, and operations tasks would provide less than 0.001 percent.

Table 7-10. Estimated Module 1 industrial safety impacts at commercial and DOE sites during the first 100 years and the remaining 9,900-year period of analysis under Scenario 1.[a]

Industrial safety impacts	Short-term (100 years)[b] construction and operation (2002-2116)	Long-term (9,900 years)[c] construction and operation (2116-12010)
Total recordable cases	2,800	410,000
Lost workday cases	1,200	180,000
Fatalities	3	490

a. Source: Orthen (1999, Tables 6 and 7).

b. The estimated impacts would result from a single 100-year period of storage module construction (renovation), operation, surveillance, and maintenance.

c. Period from 100 to 10,000 years.

7.3.2.7.3 *Radiation Exposures*

For Scenario 1, radiation exposures to offsite populations, involved workers, and noninvolved workers would increase because of the additional Module 1 inventory and the construction of additional facilities required to store the materials. The analysis assumed that radiation exposures to offsite and noninvolved worker individuals would increase by the ratio of the Module 1 inventory to the Proposed Action inventory, a factor of about 1.7. Radiation dose rates for the involved maximally exposed worker (construction) would not increase because of the self-shielding effect of the concrete storage modules. Table 7-11 lists radiological human health impacts resulting from the Module 1 inventory.

Table 7-11. Estimated Module 1 radiological human health impacts for Scenario 1.[a]

Receptor	Short-term (100 years) construction and operation (2002-2116)	Long-term (9,900 years) construction[b] and operation (2116-12010)
Population[c]		
MEI[d] (millirem per year)	0.34	0.10
Dose[e] (person-rem)	1,400	8,800
LCFs[f]	0.70	4.4
Involved workers[g]		
MEI[h] (millirem per year)	170	50
Dose (person-rem)	4,700	41,000
LCFs	1.9	16
Noninvolved workers[i]		
MEI[j] (millirem per year)	23	0[k]
Dose (person-rem)	61,000	0[k]
LCFs	25	0[k]

a. Source: Adapted from NRC (1991, all); Orthen (1999, all).

b. Assumes construction of 11,000 concrete storage modules, 1 above-grade vault, and 8 below-grade vaults at 77 sites (Orthen 1999, Table 1) every 100 years.

c. Members of the general public living within 3 kilometers (2 miles) of the facilities; estimated to be 140,000 over the first approximately 100 years and approximately 14 million over the 9,900-year long-term analysis period [estimated using Humphreys, Rollstin, and Ridgely (1997, all)].

d. MEI = maximally exposed individual; assumed to be approximately 1.4 kilometers (0.8 mile) from the center of the storage facility (NRC 1991, page 22).

e. Estimated doses account for radioactive decay.

f. LCF = latent cancer fatality; expected number of cancer fatalities for populations. Based on a risk of 0.0004 and 0.0005 latent cancer per rem for workers and members of the public, respectively (NCRP 1993b, page 112), and a life expectancy of 70 years for a member of the public and a 50-year career for workers.

g. Involved workers would be those directly associated with construction and operation activities (NRC 1991, pages 23 to 25). For this analysis, the involved worker population would be about 1,600 individuals (800 individuals at any one time) at 77 sites over 100 years (Orthen 1999, Table 6). This population would grow to more than 190,000 over 10,000 years.

h. Based on maximum construction dose rate of 0.11 millirem per hour and 1,500 hours per year (NRC 1991, page 23).

i. Noninvolved workers would be employed at the powerplant but would not be associated with facility construction or operation. For this analysis, the noninvolved worker population would be 80,000 individuals who would receive exposure until the powerplants were decommissioned (50 years).

j. Based on a projected area workforce of 1,200 and an average estimated annual dose of 16 person-rem (NRC 1991, page 24).

k. During this period the powerplants would have ended operation, so there would be no noninvolved workers.

As listed in Table 7-11, the estimated dose to the hypothetical maximally exposed offsite individual for the Module 1 inventory during the operational period between 2002 and 2116 would be about 0.34 millirem per year [adapted from NRC (1991, page 22)]. For the remaining 9,900 years of the analysis period, the dose to the hypothetical maximally exposed individual would decrease to about 0.10 millirem per year because of radioactive decay of the source material. During about the first 100 years, the dose (accounting for radioactive decay) could result (over a 70-year lifetime of exposure) in an increase in the lifetime risk of contracting a fatal cancer of 0.0000073, an increase over the lifetime natural fatal cancer incidence rate of 0.0031 percent. During the remaining 9,900 years of the analysis period, the dose (accounting for radioactive decay) could result (over a 70-year lifetime of exposure) in an increase in the lifetime risk of contracting a fatal cancer of 0.0000022, an increase over the lifetime natural fatal cancer incidence rate of 0.00092 percent.

For the short-term impacts, over about the first 100 years the offsite exposed population of approximately 140,000 would be likely to receive a total collective dose of 1,400 person-rem (adjusted for radioactive decay). This dose could result in 0.70 latent cancer fatality in addition to the 33,000 fatal cancers likely in the exposed population from all other causes. This represents an increase of about 0.0021 percent over the estimated number of cancer fatalities that would occur in the exposed population from all other causes.

For the long-term impacts from Scenario 1, the radiation dose of 8,800 person-rem from the storage facilities could result in an additional 4.4 latent cancer fatalities in the surrounding population of about 14 million. This would be in addition to about 3.3 million cancer fatalities that would be likely to occur in the exposed population of 14 million, an increase of 0.00013 percent over the natural incidence rate.

The analysis assumed the maximally exposed individual in the involved worker population would be a construction worker involved with construction and loading of replacement facilities. Assuming a maximum dose rate of 0.11 millirem per hour (unchanged from the Proposed Action) and an average exposure time of 1,500 hours per year, this construction worker would receive about 170 millirem per year. During about the first 100 years, this dose could result (over three years of construction) in an increase in the lifetime risk of contracting a fatal cancer of 0.00020, an increase of 0.083 percent over the natural fatal cancer incidence rate. During the remaining 9,900 years of the analysis period, the dose could result (over three years of construction) in an increase in the risk of contracting a fatal cancer of 0.000060, an increase over the natural fatal cancer incidence rate of 0.025 percent.

For the involved worker population of 1,600 individuals, approximately 380 would be likely to contract a fatal cancer from some cause other than occupational exposure. In the involved population of 1,600 storage facility workers (during the first 100 years), the collective dose of 4,700 person-rem (corrected for radioactive decay) between 2002 and 2116 could result in 1.9 additional latent cancer fatalities (Orthen 1999, Table 6), which would result in an increase of 0.51 percent over the natural incidence rate of fatal cancers from all causes. During the remaining 9,900 years of the analysis period, the involved estimated worker population of more than 190,000 would receive a collective dose of about 41,000 person-rem (corrected for radioactive decay). This dose could result in 16 latent cancer fatalities in addition to the 45,000 cancer fatalities that would be likely in the exposed population from all other causes. These additional cancers would represent an increase of 0.036 percent over the natural incidence rate of fatal cancers.

The estimated Module 1 collective dose to noninvolved workers at a nuclear powerplant from the Module 1 inventory would be about 27 person-rem per year [adapted from NRC (1991, page 24)] for the protected area workforce of 1,200 individuals (NRC 1991, page 26) at the two-unit station at Calvert Cliffs. This collective dose would result in an average maximum dose to the noninvolved worker of 23 millirem per year. Over a 50-year career, this exposure (corrected for radioactive decay) could result in an increase in the lifetime risk of contracting a fatal cancer of 0.00032. This incremental increase in risk would represent an increase of 0.13 percent over the incidence of fatal cancers from all other causes.

In the total noninvolved worker population of 80,000 powerplant workers (all sites), the estimated Module 1 collective dose of 61,000 person-rem (corrected for decay) between 2002 and 2116 could result in 25 additional latent cancer fatalities. This increase represents about an 0.13-percent increase over the 19,000 cancer fatalities that would be likely to occur from all other causes in the same worker population.

After about 100 years, Scenario 2 assumes no effective institutional control of the 77 sites and assumes that the storage facilities would be abandoned. Therefore, there would be no health risk for workers during that period. For the long-term impacts from Scenario 2, the analysis estimated human health impacts to the public on a regional basis (Poe 1999, page 15). The estimated total population dose would increase from 6.6 million person-rem to about 7.3 million person-rem, resulting in an increase in the number of latent cancer fatalities from about 3,300 to almost 3,700 over the 9,900-year analysis period. Appendix K (Sections K.2.4.1 and K.3.1) contains details of the Proposed Action analysis.

7.3.2.8 Accidents

For Scenario 1, both short- and long-term accident consequences for the additional inventory of Module 1 would be bounded by the severe seismic event and could result in slightly higher impacts than those predicted for the Proposed Action inventory. However, this accident scenario would probably produce only minor radiological impacts to persons in the immediate vicinity of the storage facility.

For Scenario 2, the long-term impacts for Module 1 would be the same as those for the Proposed Action (see Section 7.2.2.7) because only a single concrete storage module would be affected, regardless of inventory.

7.3.2.9 Noise

For Scenario 1, noise levels for the Module 1 inventory should not be noticeably greater than those for the Proposed Action. Therefore, the noise would not adversely affect the hearing of facility workers or frighten wildlife from the area.

For the long-term impacts from Scenario 2, as with the Proposed Action, no noise would emanate from the facilities; therefore, no adverse impacts would occur. For about the first 100 years, noise levels would be the same as those for Scenario 1.

7.3.2.10 Aesthetics

As for the Proposed Action, Scenario 1 impacts to aesthetic or scenic resources from storage facilities resulting from the Module 1 inventory would be unlikely. Though the inventory would be larger than that for the Proposed Action, Module 1 would still require only two adjacent locations at each site. Every 100 years, a new facility would be constructed on the idle site, and the storage containers would be transferred. The old facility would be demolished and the site would remain idle for the next 100 years.

For the long-term impacts from Scenario 2, aesthetics would not change until facilities began to degrade, at which time the aesthetic value of the sites would change.

7.3.2.11 Utilities, Energy, and Materials

For Scenario 1, decommissioning and reclamation activities every 100 years associated with the increased number of concrete storage modules required for the Module 1 inventory would consume slightly more diesel fuel, gasoline, and materials than those for the Proposed Action. However, as with the Proposed Action, much equipment and many materials would be salvaged and recycled. DOE would recycle building materials as practicable. Minimal surveillance activities would require some gasoline. Therefore, the increased Module 1 inventory would not adversely affect the utility, energy, or material resources of the region or the country.

For the long-term impacts from Scenario 2, as with the Proposed Action, DOE would not use utilities, energy, or materials after about 100 years and, therefore, impacts to these resources would be unlikely.

7.3.2.12 Waste Management

Under Scenario 1, the construction of new facilities and the demolition of old facilities every 100 years (and the one-time refurbishment of existing facilities after the first 50 years) would generate construction debris and sanitary and industrial solid waste. In addition, routine repairs and maintenance to the facilities and storage containers, routine radiological surveys, and overpacking of failed containers would generate sanitary and industrial solid and low-level radioactive wastes. Because there would not be a dedicated workforce at the storage facilities, only small amounts of sanitary wastes would be generated except during periods of construction. The greatest amount of waste would be generated during the demolition of facilities at the 72 commercial and 5 DOE storage sites every 100 years. The demolition of facilities once every 100 years at all the sites would generate, on average, an estimated 1.4 million cubic meters (1.8 million cubic yards) of nonhazardous demolition debris, recyclable steel, and potentially a small amount of low-level waste if a dry storage canister failed while in storage. The debris and wastes would be disposed of at commercial or DOE disposal facilities across the Nation. The impacts to available capacity would be spread nationwide, thus minimizing impacts to a single disposal facility. The capacities of the disposal facilities would accommodate the wastes generated at the storage facilities.

For Scenario 2, demolition activities would terminate after about 100 years and, therefore, no additional long-term waste management impacts would be likely after this period.

7.3.2.13 Environmental Justice

For Scenario 1, the potential impacts of continued storage of the Module 1 inventory with institutional control would be minimal. Therefore, minority or low-income populations would not be disproportionately or adversely affected.

For the long-term impacts from Scenario 2, the increased number of facilities required to store the Module 1 inventory could adversely affect the nearby public to a degree greater than that for the Proposed Action inventory. As with the Proposed Action inventory, nearby minority or economically disadvantaged communities could experience disproportionately high and adverse human health impacts. In addition, financial considerations could make it more difficult for members of minority or low-income populations to obtain uncontaminated resources or to move away from contaminated soils and water. Because subsistence patterns vary for minority or low-income populations, members of these populations could be exposed to greater than average doses. The result of differing potentials for exposure could result in disproportionately high and adverse impacts to minority or low-income populations.

7.3.2.14 Traffic and Transportation

For Scenario 1, the estimated number of workers commuting to and from work would increase from about 700 to about 800 (Orthen 1999, Table 7). The analysis assumed that the number of personnel required for round-the-clock surveillance would not increase but would remain at two individuals per shift per site.

The estimated number of traffic fatalities, which DOE calculated using the assumptions of Section 7.2.1.14, would be approximately 7 for the first 100 years and would increase from about 730 to about 900 for the remaining 9,900 years (Orthen 1999, Table 7).

For about the first 100 years, there would be no fatalities or latent cancer fatalities from exhaust emissions because there would be no construction or demolition of facilities. For the remaining 9,900 years, trucks would travel over 2.2 billion kilometers (1.4 billion miles), resulting in approximately 49 prompt traffic fatalities and 0.16 latent cancer fatality from vehicle exhaust emissions (Orthen 1999, Table 7).

The long-term impacts from Scenario 2 would be the same as those estimated for the first 100 years under Scenario 1 for Module 1. After the first 100 years, there would be no traffic or transportation-related impacts because all activity would cease.

7.3.2.15 Sabotage

For Scenarios 1 and 2, the risk of intruder access at each of the 77 sites would be essentially the same for Module 1 as for the Proposed Action inventory because the number of sites would remain the same. Therefore, the difficulty of maintaining 77 sites over 100 or 10,000 years also would remain essentially unchanged.

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8

Cumulative Impacts

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8. CUMULATIVE IMPACTS

The Council on Environmental Quality regulations that implement the procedural provisions of the National Environmental Policy Act of 1969, as amended (42 USC 4321 *et seq.*), define a cumulative impact as “the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions” (40 CFR 1508.7). Cumulative impacts can result from individually minor but collectively important actions taking place over a period of time. An evaluation of cumulative impacts is necessary to an understanding of the environmental implications of implementing the Proposed Action and is essential to the development of appropriate mitigation measures and the monitoring of their effectiveness.

This chapter evaluates the environmental impacts of repository activities coupled with the impacts of other Federal, non-Federal, and private actions. As part of this process, the chapter includes a detailed analysis of nuclear materials in need of permanent disposal in excess of those evaluated in the Proposed Action. It describes and evaluates these waste quantities, referred to as Inventory Modules 1 and 2, evaluated in terms of their environmental impacts in comparison with those of the Proposed Action impacts. The evaluation of these inventories provides sufficient information for future actions and decisionmaking on inventory selection. This chapter evaluates cumulative short-term impacts from the construction, operation and monitoring, and closure of a geologic repository at Yucca Mountain, and cumulative long-term impacts following repository closure. It also evaluates cumulative transportation impacts from the shipment of spent nuclear fuel and high-level radioactive waste to the repository and of other material to or from the repository. The analysis of cumulative transportation impacts includes the possible construction and operation in Nevada of a branch rail line, or of an intermodal transfer station along with highway improvements for heavy-haul trucks. In addition, the analysis considers cumulative impacts from the manufacturing of disposal containers and shipping casks.

The cumulative impact analysis in this chapter includes as a reasonably foreseeable future action the disposal in the proposed Yucca Mountain Repository of the total projected inventory of commercial spent nuclear fuel, U.S. Department of Energy (DOE) spent nuclear fuel, and high-level radioactive waste, as well as the disposal of commercial Greater-Than-Class-C waste and DOE Special-Performance-Assessment-Required waste. The total projected inventory of spent nuclear fuel and high-level radioactive waste is more than the 70,000 metric tons of heavy metal (MTHM) considered for the Proposed Action. Its emplacement at Yucca Mountain would require legislative action by Congress unless a second licensed repository was in operation.

There were several reasons to evaluate the potential for disposing of Greater-Than-Class-C waste and Special-Performance-Assessment-Required waste at Yucca Mountain as reasonably foreseeable actions. First, because both materials exceed Class C limits for specific radionuclide concentrations as defined in 10 CFR Part 61, they are generally unsuitable for near-surface disposal. Second, the U.S. Nuclear Regulatory Commission specifies in 10 CFR 61.55(a)(2)(iv) the disposal of Greater-Than-Class-C waste in a repository unless the Commission approved of disposal elsewhere. Finally, during the scoping process for this environmental impact statement (EIS), several commenters requested that DOE evaluate the disposal of other radioactive waste types that might require isolation in a repository. The disposal of Greater-Than-Class-C and Special-Performance-Assessment-Required wastes at the proposed Yucca Mountain Repository could require a determination by the Nuclear Regulatory Commission that these wastes require permanent isolation. In addition to spent nuclear fuel, high-level radioactive waste, surplus plutonium, Greater-Than-Class-C waste, and Special-Performance-Assessment-Required waste (materials such as depleted uranium), other radioactive wastes could be considered in the future for disposal in the Yucca Mountain Repository.

In general, the analysis of cumulative impacts in this chapter follows the process recommended in the Council on Environmental Quality's handbook *Considering Cumulative Effects Under the National Environmental Policy Act* (CEQ 1997, all). This process includes the identification, through research and consultations, of Federal, non-Federal, and private actions with possible effects that would be coincident with those of the Proposed Action on resources, ecosystems, and human communities. Coincident effects would be possible if the geographic and time boundaries for the effects of the Proposed Action and past, present, and reasonably foreseeable future actions overlapped. Using the methods and criteria described in Chapters 4, 5, and 6 of this EIS and their supporting appendixes, DOE assessed the potential cumulative impacts of coincident effects.

This chapter has five sections. Section 8.1 identifies and analyzes past, present, and reasonably foreseeable future actions with impacts that could combine with impacts of the Proposed Action. Sections 8.2 and 8.3 present the analyses of cumulative short-term (the period before the completion of repository closure) and long-term (the first 10,000 and first 1 million years following closure) impacts, respectively, in the proposed Yucca Mountain Repository region. Section 8.4 describes cumulative transportation impacts, nationally and in Nevada. Section 8.5 addresses cumulative impacts associated with the manufacturing of disposal containers and shipping casks.

8.1 Past, Present, and Reasonably Foreseeable Future Actions

This section identifies past, present, and reasonably foreseeable future actions with impacts that could combine with impacts of the Proposed Action. It describes these actions and their relationships to the Proposed Action that could result in cumulative impacts (see Table 8-1 for a summary). Sections 8.2 through 8.5 present the cumulative impacts from the past, present, and reasonably foreseeable future actions identified in this section.

8.1.1 PAST AND PRESENT ACTIONS

The description of existing (baseline) environmental conditions in Chapter 3 includes the impacts of most past and present actions on the environment that the Proposed Action would affect. This includes site characterization activities at Yucca Mountain. The impacts of past and present actions are, therefore, generally encompassed in the Chapter 4, 5, and 6 analyses of potential environmental impacts of the Proposed Action because the baseline for these analyses is the affected environment described in Chapter 3.

Two past actions that are not addressed in the Chapter 3 environmental baseline were identified for inclusion in the cumulative impact analysis in Sections 8.2, 8.3, and 8.4—past DOE activities at the Nevada Test Site (nuclear weapons testing, etc.) and past disposal of low-level radioactive waste at the Beatty Waste Disposal Area. Resources identified where past Nevada Test Site activities could add to impacts from the Proposed Action include air quality, groundwater, public health and safety, and transportation. For the Beatty Waste Disposal Site, the analysis included potential cumulative impacts from past transportation of waste to the Beatty site and from potential groundwater contamination.

8.1.2 REASONABLY FORESEEABLE FUTURE ACTIONS

This section describes the reasonably foreseeable future actions that the cumulative impacts analysis considered. The analysis included cumulative impacts from the disposal in the proposed repository of all projected spent nuclear fuel and high-level radioactive waste as well as Greater-Than-Class-C waste and Special-Performance-Assessment-Required waste as reasonably foreseeable future actions (Inventory Modules 1 and 2; see Section 8.1.2.2). Sections 8.1.2.3 and 8.1.2.4 describe other Federal, non-Federal, and private actions that could result in cumulative impacts. DOE did not analyze the No-Action

Table 8-1. Past, present, and reasonably foreseeable future actions that could result in cumulative impacts (page 1 of 2).

Action	Potential cumulative impacts			
	Impacts in the Yucca Mountain Repository region			
Name and description	Short-term (Section 8.2)	Long-term (Section 8.3)	Transportation (Section 8.4)[a]	Manufacturing (Section 8.5)
Past and present actions[b]				
Nevada Test Site				
Nuclear weapons testing, waste management, etc.	None	Air quality, groundwater, and public health and safety	Occupational and public radiological health and safety	None
Beatty Waste Disposal Area				
Low-level radioactive waste disposal	None	Groundwater	Occupational and public radiological health and safety	None
Reasonably foreseeable future actions				
Inventory Module 1[c]				
Disposal of all spent nuclear fuel and high-level radioactive waste in the proposed Yucca Mountain Repository	Same resources as the Proposed Action	Same resources as the Proposed Action	Same resources as the Proposed Action	Same resources as the Proposed Action
Inventory Module 2[c]				
Disposal of all spent nuclear fuel and high-level radioactive waste, as well as Greater-Than-Class C waste and Special-Performance-Assessment-Required waste, in the proposed Yucca Mountain Repository	Same resources as the Proposed Action	Same resources as the Proposed Action	Same resources as the Proposed Action	Same resources as the Proposed Action
Nellis Air Force Range				
National testing and training for military equipment and personnel	The Air Force is proposing no substantial new activities in the future at the Nellis Air Force Range.	The Air Force is proposing no substantial new activities in the future at the Nellis Air Force Range.	The Air Force is proposing no substantial new activities in the future at the Nellis Air Force Range.	The Air Force is proposing no substantial new activities in the future at the Nellis Air Force Range.
Nevada Test Site				
Defense (stockpile stewardship and management, material disposition, nuclear emergency response), waste management, environmental restoration, nondefense research and development, work for others	Air quality, groundwater, socioeconomics, public health and safety. (Note: The accident analysis of potential external events in Appendix H addresses the effects of possible future resumption of nuclear weapons tests).	Groundwater and public health and safety	Occupational and public radiological health and safety	None

Table 8-1. Past, present, and reasonably foreseeable future actions that could result in cumulative impacts (page 2 of 2).

Action	Potential cumulative impacts			
	Impacts in the Yucca Mountain Repository region			
Name and Description	Short-term (Section 8.2)	Long-term (Section 8.3)	Transportation (Section 8.4)[a]	Manufacturing (Section 8.5)
Reasonably foreseeable future actions (continued)				
DOE Complex-Wide Waste Management Activities Affecting the Nevada Test Site				
Treatment, storage, and disposal of low-level radioactive waste, mixed waste, transuranic waste, high-level radioactive waste, and hazardous waste from past and future nuclear defense and research activities	None[d]	Groundwater and public health and safety	Occupational and public radiological health and safety	None
Low-Level Waste Intermodal Transfer Station				
Construction and operation of an intermodal transfer station for the shipment of low-level radioactive waste to the Nevada Test Site near Caliente	None	None	Same resources as the Proposed Action (Caliente intermodal transfer station and highway route for heavy-haul trucks)	None
Timbisha Shoshone Reservation				
Creation of a discontiguous reservation in eastern California and southwestern Nevada for people of the Timbisha Shoshone Tribe	None	None	Water consumption, public safety, environmental justice	None
Cortez Pipeline Gold Deposit Projects				
Continued operation and potential expansion of a gold mine and processing facility	None	None	Land use and ownership (Carlin rail corridor)	None
Apex Bulk Commodities Intermodal Transfer Station				
Construction and operation of an intermodal transfer station for copper concentrate near Caliente	None	None	Same resources as the Proposed Action (Caliente intermodal transfer station and highway route for heavy-haul trucks)	None
Shared use of a DOE branch rail line				
Increase in rail operations and traffic resulting from rail service options for nearby mine operators and communities	None	None	Same resources as the Proposed Action	None

a. In addition to the specific actions identified in Section 8.1 and summarized in this table, the cumulative impacts for national transportation consider the occupational and public radiological health impacts of other past, present, and reasonably foreseeable future shipments of radioactive material.

b. The impacts of most past and present actions are included in the existing environmental baseline described in Chapter 3 and, therefore, are generally encompassed in the analysis of potential impacts of the Proposed Action in Chapters 4, 5, and 6. This includes site characterization activities at Yucca Mountain.

c. As described in Section 8.1.2.1, there would be essentially no difference in the design and operation of the repository for Inventory Module 1 or 2. Therefore, the cumulative impacts from Inventory Module 1 are generally considered the same as those from Inventory Module 2.

d. DOE waste management activities at the Nevada Test Site are included above for the continuation of waste management activities at current levels, plus additional wastes that could be received as a result of decisions based on the Waste Management Programmatic EIS (DOE 1997b, all). This includes cumulative impacts of transportation and disposal.

Alternative for cumulative impacts. Chapter 7, Section 7.3, describes the cumulative impacts for the No-Action Alternative. Chapters 2 and 7 contain details on this alternative and also on continued storage of the material at its current locations or at one or more centralized location(s). Interim storage is not analyzed for cumulative impacts because, as stated in Chapter 7, the potential for such storage is highly uncertain.

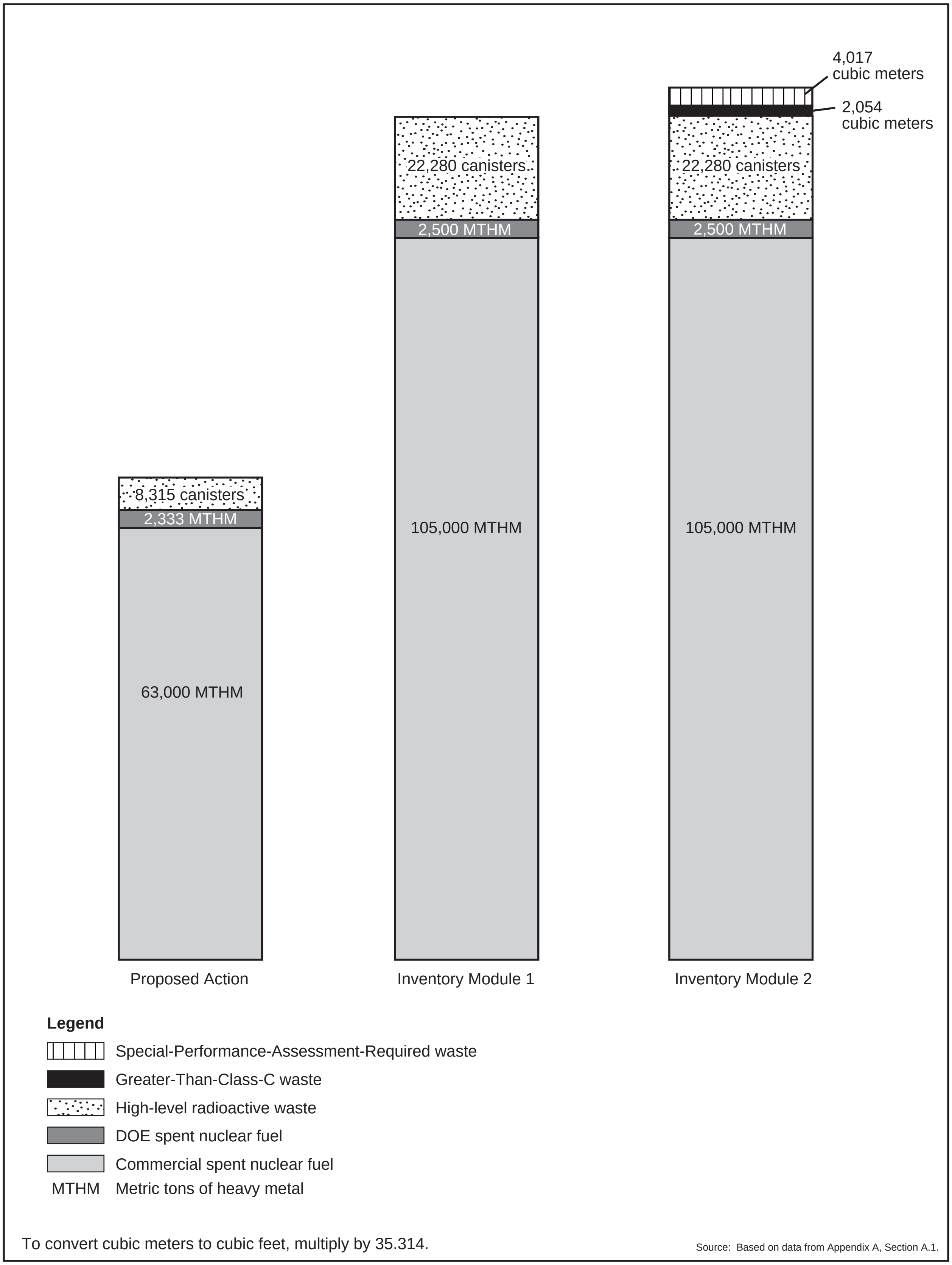
DOE gathered information on Federal, non-Federal, and private actions to identify reasonably foreseeable future actions that could combine with the Proposed Action to produce cumulative impacts. The types of documents reviewed included other EISs, resource management plans, environmental assessments, Notices of Intent, Records of Decision, etc. Consultations with Federal agencies, state and local agencies, and Native American tribes (see Appendix C) also contributed to the information used in the cumulative impact analysis.

8.1.2.1 Inventory Modules 1 and 2

Under the Proposed Action, DOE would emplace in the proposed Yucca Mountain Repository as much as 70,000 MTHM of spent nuclear fuel and high-level radioactive waste. Of the 70,000 MTHM, approximately 63,000 MTHM would be commercial spent nuclear fuel. The remaining 7,000 MTHM would consist of approximately 2,333 MTHM of DOE spent nuclear fuel and approximately 8,315 canisters (4,667 MTHM) containing solidified high-level radioactive waste. To determine the number of canisters of high-level radioactive waste included in the Proposed Action waste inventory, DOE used an equivalence of 0.5 MTHM per canister of defense high-level radioactive waste. DOE has consistently used the 0.5-MTHM-per-canister equivalence since 1985. Using a different approach would change the number of canisters of high-level radioactive waste analyzed. Regardless of the number of canisters, the impacts from the entire inventory of high-level radioactive waste are analyzed in this chapter. In addition, the 70,000 MTHM inventory would include 50 metric tons (55 tons) of surplus plutonium as spent mixed-oxide fuel or immobilized plutonium.

Inventory Modules 1 and 2 represent the reasonably foreseeable future actions of disposing of all projected commercial and DOE spent nuclear fuel and all high-level radioactive waste as well as Greater-Than-Class-C waste and Special-Performance-Assessment-Required waste in the proposed repository (see Figure 8-1). Under Inventory Module 1, DOE would emplace all projected commercial spent nuclear fuel (about 105,000 MTHM), all DOE spent nuclear fuel (about 2,500 MTHM), and all high-level radioactive waste (approximately 22,280 canisters). Inventory Module 2 includes the Module 1 inventory plus other radioactive material that could require disposal in a monitored geologic repository (commercial Greater-Than-Class-C waste and DOE Special-Performance-Assessment-Required waste). The estimated quantities of these other wastes are about 2,100 cubic meters (74,000 cubic feet) and about 4,000 cubic meters (140,000 cubic feet), respectively. Appendix A contains further details on these inventories.

The following paragraphs summarize the differences in repository facilities and operations to receive, package, and emplace the additional materials in Inventory Module 1 or 2. The information on Modules 1 and 2 in this section is from TRW (1999a,b,c, all) unless otherwise noted. Table 8-2 summarizes the increased number of shipments that would be required to transport the Module 1 or 2 inventory to the repository. As for the Proposed Action, the estimated numbers of shipments were based on the characteristics of the materials, shipping capabilities at the commercial nuclear sites and DOE facilities, the assumption that there would be one shipping cask per truck or railcar (a train would normally use multiple rail cars and ship more than one cask), various cask designs, and the transportation mode mix (mostly legal-weight truck or mostly rail). Appendix J contains additional details on Inventory Module 1 and 2 transportation requirements.



To convert cubic meters to cubic feet, multiply by 35.314.

Source: Based on data from Appendix A, Section A.1.

Figure 8-1. Proposed Action, Module 1, and Module 2 inventories evaluated for emplacement in a repository at Yucca Mountain.

Table 8-2. Estimated number of shipments for the Proposed Action and Inventory Modules 1 and 2.[a,b]

	Proposed Action				Module 1				Module 2			
	Mostly legal-weight truck		Mostly rail		Mostly legal-weight truck		Mostly rail		Mostly legal-weight truck		Mostly rail	
Material	Truck	Rail[c]	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail	Truck	Rail
Commercial SNF[d]	38,000	0	2,600	8,400	67,000	0	3,700	14,000	67,000	0	3,700	14,000
DOE SNF	3,500	300	0	770	3,700	300	0	800	3,700	300	0	800
HLW[e]	8,300	0	0	1,700	22,000	0	0	4,500	22,000	0	0	4,500
GTCC[f] waste	0	0	0	0	0	0	0	0	1,100	0	0	280
SPAR[g] waste	0	0	0	0	0	0	0	0	2,000	0	0	400
Totals	**50,000**	**300**	**2,600**	**11,000**	**93,000**	**300**	**3,700**	**19,000**	**96,000**	**300**	**3,700**	**20,000**

a. Source: Appendix J, Section J.1.3.1.
b. Totals might differ from sums due to rounding.
c. For this EIS, each combination of a shipping cask and railcar is assumed to be a single shipment.
d. SNF = spent nuclear fuel.
e. HLW = high-level radioactive waste.
f. GTCC = Greater-Than-Class-C.
g. SPAR = Special-Performance-Assessment-Required.

The following are the major differences between the repository facilities and operations for Inventory Modules 1 and 2 and those for the Proposed Action, which are described in Chapter 2:

- The longer time required to receive, package, and emplace the additional spent nuclear fuel, high-level radioactive waste, Greater-Than-Class-C waste, and Special-Performance-Assessment-Required waste, and to close the repository, for Inventory Module 1 or 2 versus that for the Proposed Action. The periods for the various project phases for Inventory Modules 1 and 2 would be the same.

- The need for more subsurface area to emplace about 17,000 to 19,000 waste packages for Inventory Module 1 and about 18,000 to 20,000 waste packages for Module 2 in comparison to about 10,000 to 11,000 waste packages for the Proposed Action (see Table 8-34)

Table 8-3 lists the differences in the expected time sequence for the repository construction, operation and monitoring, and closure phases for the Proposed Action and Inventory Module 1 or 2.

Table 8-3. Expected time sequence (years) of Yucca Mountain Repository phases for the Proposed Action and Inventory Module 1 or 2.[a]

Inventory	Construction phase (2005-2010)	Operation and monitoring phase (2010-2110)				Closure phase (starts in 2110)
		Development[b]	Emplacement	Monitoring	Total	
Proposed Action	5	22	24	76	100[c]	6-15[d]
Module 1 or 2	5	36	38	62	100	13-27[e]

a. Source: TRW (1999b, all); TRW (1998k,m,n,o,p,q,r,s,t,u,v, all); Jessen (1999b, all).
b. Continuing subsurface construction (development) activities are concurrent with emplacement activities.
c. Closure is assumed to begin 100 years following initial emplacement for the Proposed Action and Module 1 or 2 for the evaluation of cumulative impacts.
d. 6, 6, and 15 years for the high, intermediate, and low thermal load scenarios, respectively.
e. 13, 17, and 27 years for the high, intermediate, and low thermal load scenarios, respectively.

The amount of land required for surface facilities would increase only slightly for Inventory Module 1 or 2 from that for the Proposed Action (see Table 8-4). The design and operation of the repository surface facilities for Inventory Modules 1 and 2, including a Cask Maintenance Facility if it was at the Yucca Mountain site, would not differ much from those of the Proposed Action. The rate of material receipt, packaging, and emplacement would be approximately the same and would require an extra 14 years beyond the 24-year emplacement period for the Proposed Action. There would be no difference in the duration of the emplacement period between Inventory Modules 1 and 2 because the surface and subsurface facilities could accommodate the small number of additional shipments and waste packages for Module 2.

Table 8-4. Amount of land disturbed at the proposed Yucca Mountain Repository for the Proposed Action and Inventory Module 1 or 2 (square kilometers).[a,b,c]

	Proposed Action			Module 1 or 2		
Area	High thermal load	Intermediate thermal load	Low thermal load	High thermal load	Intermediate thermal load	Low thermal load
North Portal Operations Area[d]	0.62	0.62	0.62	0.62	0.62	0.62
South Portal Operations Area	0.15	0.15	0.15	0.15	0.15	0.15
Ventilation Shaft Operations Areas	0.02 (2 shafts)	0.02 (2 shafts)	0.06 (5 shafts)	0.02 (2 shafts)	0.04 (3 shafts)	0.06 (5 shafts)
Excavated rock storage area	1.02	1.17	1.15	1.17	1.40	2.00
Totals	**1.82**	**1.97**	**1.98**	**1.97**	**2.21**	**2.83**

a. Source: Jessen (1998, all).

b. To convert square kilometers to acres, multiply by 247.1.

c. Totals might differ from sums due to rounding.

d. The amount of land disturbance in the vicinity of the North Portal would vary slightly among the three packaging scenarios. The 0.62 square kilometer includes the surface facilities at the North Portal Operations Area and roads.

The repository subsurface facilities for Inventory Module 1 or 2 would require about 60 percent more subsurface excavation than the Proposed Action. About 5.0, 7.1, and 17 square kilometers (1,240, 1,750, and 4,200 acres) would be required for the high, intermediate, and low thermal load scenarios, respectively, for Module 1 or 2. This compares to 3.0, 4.25, and 10 square kilometers (740, 1,050, and 2,500 acres) for the high, intermediate, and low thermal load scenarios, respectively, for the Proposed Action (TRW 1999b, all). Additional subsurface area would be needed beyond the one to three blocks for the Proposed Action. DOE would characterize these blocks, which would be adjacent to the blocks identified for the Proposed Action, more fully before their use. The subsurface facilities would not differ between Inventory Modules 1 and 2 because the additional waste packages for Greater-Than-Class-C and Special-Performance-Assessment-Required wastes would be placed between commercial spent nuclear fuel waste packages. There would be no difference in emplacement operations for Inventory Module 1 or 2 from those described for the Proposed Action in Chapter 2. With the exception of the shorter duration after the completion of emplacement (62 rather than 76 years) (see Table 8-3), there would be no difference in monitoring and maintenance activities for Inventory Module 1 or 2 in comparison to the Proposed Action.

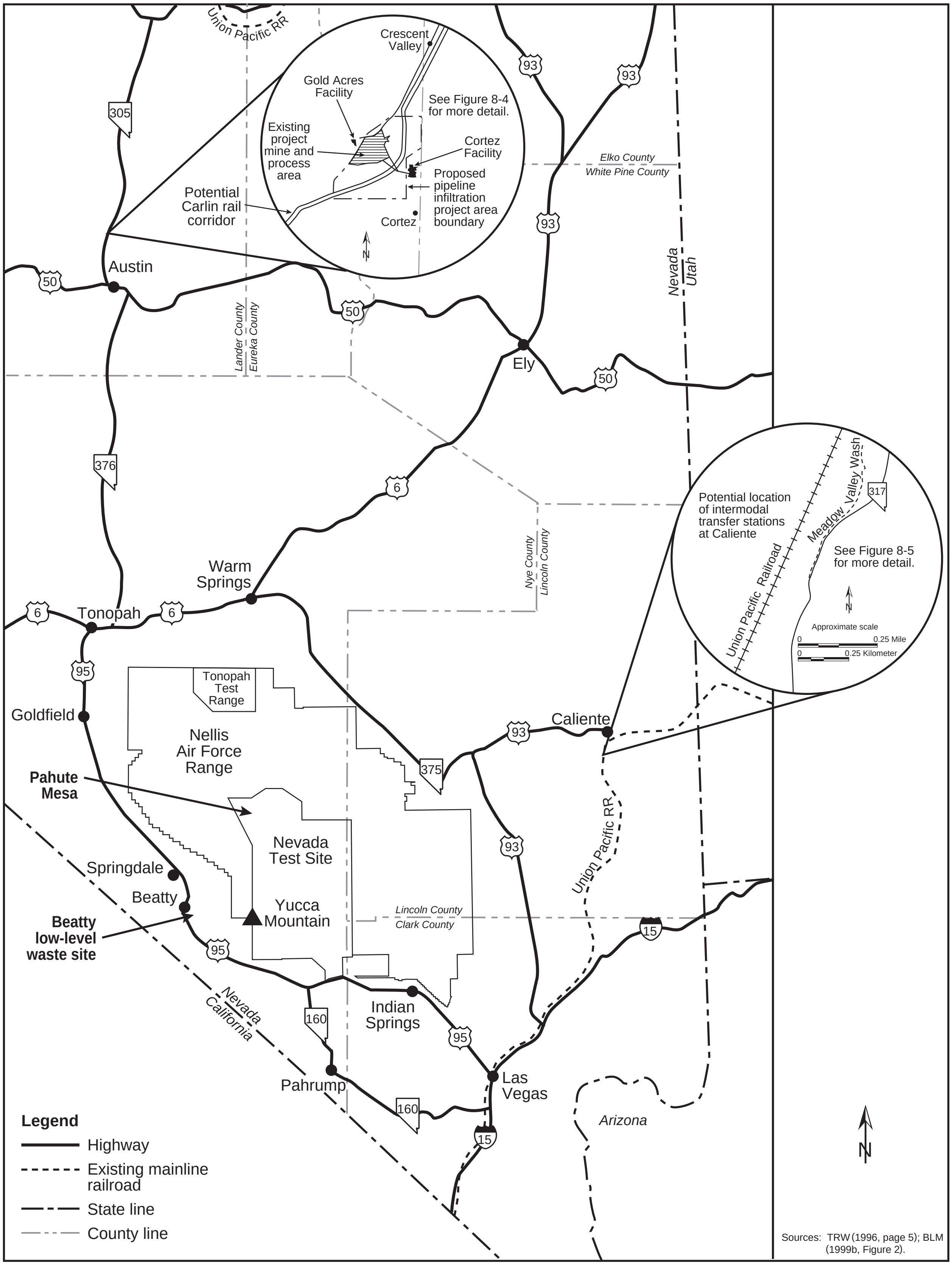
Because of the longer tunnels that would require the use of rock or other material to fill and seal the tunnels for Inventory Module 1 or 2, the duration of the closure phase would be longer, 6 to 15 years for the Proposed Action and 13 to 27 years for Module 1 or 2, depending on the thermal load scenario (see Table 8-3). Inventory Module 1 or 2 closure phase activities would not otherwise differ from those described in Chapter 2 for the Proposed Action.

8.1.2.2 Federal Actions

The following paragraphs describe reasonably foreseeable future actions of Federal agencies that could result in cumulative impacts in addition to those from Inventory Module 1 or 2.

Nellis Air Force Range

The Nellis Air Force Range in south-central Nevada (see Figure 8-2) is a national test and training facility for military equipment and personnel. The *Renewal of the Nellis Air Force Range Land Withdrawal Department of the Air Force Legislative Environmental Impact Statement* (USAF 1999, all) addresses the potential environmental consequences of the Air Force proposal to continue the Nellis Air Force Range



Sources: TRW (1996, page 5); BLM (1999b, Figure 2).

Figure 8-2. Locations of past, present, and reasonably forseeable future actions considered in the cumulative impact analysis.

land withdrawal for military use. The Air Force is proposing no substantial new activities in the future; the descriptions of the affected environment in Chapter 3 and the potential impacts of the Proposed Action in Chapters 4, 5, and 6 include the effects of present activities at the Nellis Air Force Range.

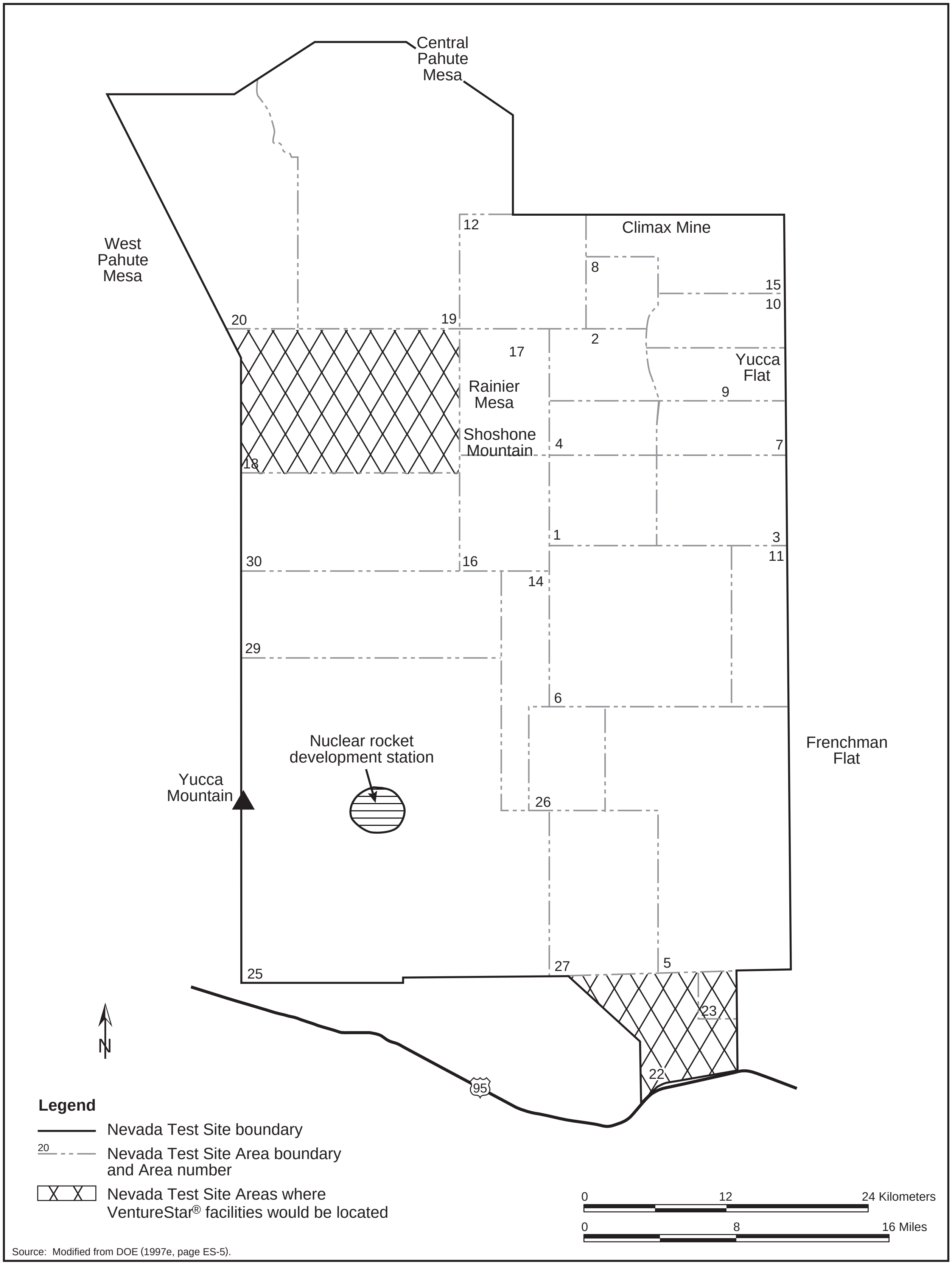
Nevada Test Site

The *Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada* (DOE 1996f, all) examines current and future DOE activities in southern Nevada at the Nevada Test Site, Tonopah Test Range, and sites the Department formerly operated in Nevada. The Record of Decision for that EIS (61 *FR* 65551, December 13, 1996) states that DOE would implement a combination of three alternatives: Expanded Use, No Action (continue operations at current levels) regarding mixed and low-level radioactive waste management, and Alternate Use of Withdrawn Lands regarding public education.

The Expanded Use Alternative incorporates all the activities and operations from ongoing Nevada Test Site programs and increases some of those programs. Activities of the Office of Defense Programs would expand at both the Nevada Test Site and the Tonopah Test Range, primarily in the areas of stockpile stewardship and management, materials disposition, and nuclear emergency response. As part of the Stockpile Stewardship and Management Program, there are continuing subcritical weapons test activities to study aging of weapons components and their reliability after aging. Waste management activities would continue at current levels pending decisions by DOE based on the *Final Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste* (DOE 1997b, all). Based on the preferred alternative in the programmatic EIS, this cumulative impact analysis included the additional low-level and mixed waste that could come to the Nevada Test Site. The Environmental Restoration Program would continue, potentially at an accelerated rate, at the Nevada Test Site and all offsite locations. Under the Work for Others Program, military use of the airspace over the Nevada Test Site and the Tonopah Test Range would increase, as would the use of certain lands on the Nevada Test Site by the military for training, research, and development. Public education activities would include the possible construction of a museum that highlights Nevada Test Site testing activities. The Nevada Test Site Development Corporation is considering the VentureStar® program initiative from the Lockheed Martin Corporation for a launch/recovery system that would link with the Kistler Aerospace Satellite launch and recovery project. The VentureStar® program would require two spaceports, a manufacturing and assembly facility, and a payload processing and administrative complex. These activities could occur in Areas 18, 22, and 23, respectively (Figure 8-3). Construction activities could begin in 2002 with an initial launch by 2004. Activities associated with VentureStar® and Kistler could result in the creation of as many as 2,500 jobs, road improvements, power upgrades, and a natural gas supply to the Nevada Test Site. However, there is not enough information at this time to perform a cumulative impacts analysis for this project.

The Nondefense Research and Development Program would continue to support ongoing program operations and pursue new initiatives, such as constructing and operating a solar power production facility (Solar Enterprise Zone facility) at the Nevada Test Site and a proposal by the Kistler Aerospace Corporation to use the Nevada Test Site for launching communication and other commercial and government satellites and recovering reusable launch vehicles.

An analysis of the environmental impacts presented in the Nevada Test Site EIS (DOE 1996f, all) and summarized in the DOE Record of Decision (61 *FR* 65551, December 13, 1996) (including impacts from weapons testing and the VentureStar®/Kistler project) identified the following resources for which impacts could overlap in relation to geography and timing with impacts from the proposed repository: air quality, groundwater, socioeconomics, public health and safety, and transportation. The effects on the Yucca Mountain Repository if a decision were made in the future to resume nuclear weapons testing or



Source: Modified from DOE (1997e, page ES-5).

Figure 8-3. Potential locations of proposed cumulative activity associated with VentureStar® at the Nevada Test Site.

from a possible vehicle launch or recovery accident at the proposed VentureStar®/Kistler project are considered in the accident analysis of potential external events in Appendix H.

DOE Waste Management Activities

The Waste Management Programmatic EIS (DOE 1997b, all) evaluates the environmental impacts of managing five types of radioactive and hazardous wastes generated by past and future nuclear defense and research activities at a variety of DOE sites in the United States. The five waste types are low-level radioactive waste, mixed low-level waste (referred to in this EIS as simply mixed waste), transuranic waste, high-level radioactive waste, and hazardous waste. The Waste Management Programmatic EIS provides information to assist DOE with decisions on the management of, and facilities for, the treatment, storage, and disposal of these radioactive, hazardous, and mixed wastes.

Based on the Waste Management Programmatic EIS, DOE will make national, programmatic disposal decisions for both low-level waste and mixed waste. The DOE preferred alternative is to send its low-level radioactive waste and mixed waste to regional disposal sites after it is treated. After consultations with stakeholders, DOE plans to select two or three preferred sites from the following six: Hanford, Idaho National Environmental and Engineering Laboratory, Los Alamos National Laboratory, Nevada Test Site, Oak Ridge Reservation, and Savannah River Site. DOE could select the Nevada Test Site as a regional disposal site for low-level radioactive waste, mixed waste, or both with about 99 to 100 percent, respectively, of the waste being generated from non-Nevada Test Site generators. DOE waste management actions described in the Waste Management Programmatic EIS would have cumulative transportation impacts and, depending on the selected low-level radioactive waste and mixed waste disposal sites, potential cumulative short- and long-term impacts in the proposed Yucca Mountain Repository region.

In addition, based on the Waste Management Programmatic EIS, DOE will make national, programmatic decisions on the locations at which DOE will store immobilized high-level radioactive waste prior to its disposal at the proposed Yucca Mountain Repository. The DOE preferred alternative is to store its high-level radioactive waste at Hanford, the Idaho National Engineering and Environmental Laboratory, the Savannah River Site, and the West Valley Demonstration Project until acceptance at a geologic repository or other facility managed by DOE.

The *Waste Isolation Pilot Plant Disposal Phase Final Supplemental Environmental Impact Statement* (DOE 1997o, Chapter 5) identifies potential cumulative transportation impacts from the shipment of transuranic wastes from DOE sites across the United States, including the Nevada Test Site, to the Waste Isolation Pilot Plant in southeastern New Mexico for disposal.

Low-Level Waste Intermodal Transfer Station

DOE prepared a draft environmental assessment (DOE 1998m, all) on a proposed action to encourage low-level radioactive waste generators and their contractors to use transportation alternatives that would minimize radiological risk, enhance safety, and reduce the cost of waste shipments to the Nevada Test Site. However, DOE determined that there was no decision for it to make relative to transportation of low-level radioactive waste that would require a National Environmental Policy Act analysis, and therefore no longer plans to issue a National Environmental Policy Act document. DOE will publish a technical report which provides its low-level radioactive waste generators with a comparative risk analysis of alternative highway routes and intermodal transportation facilities.

Road improvements to accommodate legal-weight trucks and the construction of a rail siding or spur on a 0.02-square-kilometer (5-acre) site 1.2 kilometers (0.75 mile) south of Caliente would be needed for the low-level radioactive waste intermodal transfer station. Lifting equipment (crane or forklift) would transfer containers of low-level radioactive waste from railcars to trucks for transport to the Nevada Test

Site. Based on a 10-year average estimate of low-level waste volumes and shipments for the expanded use alternative from the Nevada Test Site EIS (DOE 1996f, pages 5-110 to 5-112), DOE expects the traffic through the intermodal transfer station to be less than 3 trains per day and about 14 trucks per day (7 outbound from the station and 7 returning from the Nevada Test Site). Intermodal transfer operations would occur only during daytime working hours, with containers dropped off during the night transported to the Nevada Test Site the following morning. A staff of three would be adequate to conduct operations at the station. Trucks would be inspected and decontaminated, as necessary, at the Nevada Test Site before returning to the station (DOE 1998m, pages 2-1 to 2-10 unless otherwise noted).

A high-end estimate for the planned trucking operation to support the low-level radioactive waste intermodal transfer station indicates a terminal on about 0.04 to 0.06 square kilometer (10 to 15 acres), a maintenance building 21 by 23 meters (70 by 75 feet), 9 tractors and 27 trailers, and 11 employees. One proposed location would be south and just outside of Caliente. Trucks would not pass through the Town of Caliente to reach the intermodal transfer station site (DOE 1998m, page 5-4).

The projections of low-level radioactive waste shipments from current DOE-approved generators to the Nevada Test Site do not extend to 2010 when shipments of spent nuclear fuel and high-level radioactive waste would begin to the proposed Yucca Mountain Repository. However, because it is reasonable to assume that low-level radioactive waste shipments to the Nevada Test Site could continue and occur coincidentally with shipments to the Yucca Mountain Repository, Section 8.4 analyzes the potential for cumulative impacts from the construction and operation of these two intermodal transfer stations as well as a privately owned intermodal transfer station described in the following section.

Proposed Timbisha Shoshone Reservation

The Secretary of the Interior has issued a draft report to Congress (Timbisha Shoshone and DOI 1999, all) describing a plan to establish a discontiguous reservation for people of the Timbisha Shoshone Tribe in portions of the Mojave Desert in eastern California and southwestern Nevada. The plan recommends a reservation that includes land at Furnace Creek in Death Valley National Park, four separated nearby parcels of Federally held land, two parcels of lands formerly allotted to Native Americans in the Saline Valley, California, and private lands near Lida, Nevada. The plan also proposes creating cooperative management and tribal use opportunities on other portions of the Tribe’s ancestral homelands. Congress would have to pass legislation to create the reservation as proposed. The National Park Service of the U.S. Department of the Interior has issued a Notice of Scoping for environmental analysis on the proposal (64 *FR* 19193, April 19, 1999).

One of the parcels of land proposed for inclusion in the Timbisha reservation is near Scotty’s Junction along U.S. 95 in Nevada, which is within 80 kilometers (50 miles) of the Yucca mountain site. The Carlin and Caliente rail corridor implementing alternatives follow a common course in this area and would overlap a portion of the parcel. Similarly, the Caliente heavy-haul implementing alternative, which would use U.S. 95, would pass through one part of the parcel and along the edge of another part.

The creation of a reservation is uncertain. The timing and final form of any reservation are speculative. There is insufficient information to assess quantitatively the potential for reservation activities to affect the environment. The report (Timbisha Shoshone and DOI 1999, all) contemplates a low overall level of activity for the reservation, which would tend to minimize the potential for impacts to the environment. The report does not describe specific activities proposed for the parcel near Scotty’s Junction.

Because of the contemplated low level of use, the cumulative impacts probably would be very low. For example, the reservation proposal indicates that careful planning would occur to minimize water consumption, identifies no industrial or large-scale construction activities, and indicates that traffic patterns would not increase appreciably from the creation of the reservation. Therefore, cumulative impacts from the potential creation of this reservation do not appear to be large. Because the overall potential for cumulative impacts appears to be extremely low, the creation of a reservation would be unlikely to cause disproportionately high and adverse impacts to minority and low-income populations. If a reservation is created, DOE would work cooperatively with the Timbisha Shoshone Tribe and the government agencies directly concerned with reservation activities to minimize potential effects of transportation associated with a monitored geologic repository. The Final Yucca Mountain Repository EIS will assess information that becomes available on this project for additional impacts.

8.1.2.3 Non-Federal and Private Actions

The following paragraphs describe reasonably foreseeable future actions of non-Federal and private agencies or individuals that could result in cumulative impacts. This EIS considers the Cortez Pipeline Gold Deposit projects described below to be private actions even though they require the approval of the Bureau of Land Management.

Cortez Pipeline Gold Deposit Projects

An existing project, and two potential projects—the existing Cortez Gold Mine Pipeline Project, the proposed Pipeline Infiltration Project, and a possible Pipeline Southeast Expansion Project—are near the Carlin rail corridor of the Nevada transportation implementing rail alternative (see Chapter 2, Section 2.1.3.3). Cortez Gold Mine, Inc., operates the Pipeline Project mine and processing facility and plans to operate it through 2004. The environmental impacts of the existing mining operation are discussed in the *Cortez Pipeline Gold Deposit: Final Environmental Impact Statement* (BLM 1996, all). The proposed Pipeline Infiltration Project would expand the Pipeline Project area to add additional land for the construction and operation of infiltration ponds to support the existing mine (BLM 1999b, all). Cortez Gold Mines is studying a Pipeline Southeast Expansion Project (BLM 1996, page 5-7) that would expand mining operations southeast of the existing gold mine and would extend the life of the existing processing facility. Based on an analysis of the general area potentially affected by the Cortez Gold Mine projects, there could be cumulative land-use and ownership impacts with the Carlin branch rail line (see Figure 8-2).

Apex Bulk Commodities Intermodal Transfer Station

Apex Bulk Commodities is negotiating with BHP Copper of Ely, Nevada, to build an intermodal transfer station at Caliente near the potential intermodal transfer station site for shipping spent nuclear fuel and high-level radioactive waste to the proposed Yucca Mountain Repository. Apex anticipates one diesel truck per hour carrying 40 tons of copper concentrate, 24 hours per day, for 15 years. An improved access road and about 4,200 meters (14,000 feet) of new rail would be constructed. The transfer facility would be housed in a building 90 by 30 meters (300 by 100 feet) designed to retain dust, water, and spills generated during the transfer process. Air emission particulates would be collected in two baghouses. Apex would also need a truck maintenance facility, which would be in a building 30 by 18 meters (100 by 60 feet). An above-ground storage tank for about 45,000 liters (12,000 gallons) of diesel fuel is also planned. Apex estimates 25 new jobs for Caliente and an annual payroll of $800,000 (DOE 1998m, page 5-5).

Although a start date for Apex copper concentration intermodal transfer station and truck transportation operations is unknown, Section 8.4 analyzes the potential for cumulative impacts from the construction and operation of that station, assuming these activities would coincide with impacts from the Nevada Test Site low-level radioactive waste intermodal transfer station and the intermodal transfer station for shipments to the proposed Yucca Mountain Repository.

Shared Use of a DOE Branch Rail Line

If DOE built a branch rail line to transport spent nuclear fuel and high-level radioactive waste to the Yucca Mountain Repository, it could share the use of this line with others. A branch rail line in the Carlin corridor could provide transportation service options for mine operators in the central mountain valleys of Nevada and could provide freight service options for southwestern Nevada communities such as Tonopah, Beatty, Goldfield, and Pahrump. A branch rail line in the Caliente corridor could serve those communities plus Warm Springs, along with mine operators in the interior of Nevada. A Caliente-Chalk Mountain branch line could provide rail service to Nevada mines in the interior. A branch rail line in the Valley Modified or Jean corridors would provide freight service access to farms, industries, and businesses in the Amargosa Valley and Pahrump communities. A Valley Modified branch line would also provide rail service to the Indian Springs community. Any of the potential branch rail lines to the Yucca Mountain site (see Chapter 6, Figure 6-10) would provide rail access to the Nevada Test Site. The shared use of a branch rail line would have positive economic benefits, but could produce cumulative impacts due to increased operations and traffic.

8.2 Cumulative Short-Term Impacts in the Proposed Yucca Mountain Repository Region

This section describes short-term cumulative impacts during the construction, operation and monitoring, and closure of the repository in the regions of influence for the resources the repository could affect. DOE has organized the analysis of cumulative impacts by resource area. As necessary, the discussion of each resource area includes cumulative impacts from Inventory Module 1 or 2; from other Federal, non-Federal, and private actions; and from the combination of Inventory Modules 1 and 2 and other Federal, non-Federal, and private actions. Table 8-5 summarizes these impacts. The impacts listed for the Proposed Action in Table 8-5 include the combined effects of the potential repository and transportation activities.

There would be essentially no difference in the design and operation of the repository for Inventory Modules 1 and 2. As described in Appendix A, the radioactive inventory for Greater-Than-Class-C waste and for Special-Performance-Assessment-Required waste is much less than that for spent nuclear fuel and high-level radioactive waste. The subsurface emplacement of the material in Inventory Module 2, in comparison with the inventory for Module 1, would not greatly increase radiological impacts to workers or the public (TRW 1999b, page 6-44). For the surface facilities, the number of workers and the radiological exposure levels would be the same for Inventory Modules 1 and 2 (TRW 1999a, Tables 6-1, 6-2, 6-4, and 6-5). Therefore, DOE did not perform separate analyses for Modules 1 and 2 to estimate the short-term impacts. This section identifies the short-term impacts as being for Modules 1 and 2, indicating that the impacts for the two modules would not differ greatly.

DOE performed quantitative calculations for long-term impacts for both modules (see Section 8.3.1). The conclusion from these quantitative estimates was that the long-term impacts for Modules 1 and 2 would not differ greatly.

8.2.1 LAND USE AND OWNERSHIP

The ownership, management, and use of the analyzed land withdrawal area described in Chapter 4, Section 4.1.1 for the Proposed Action would not change for Inventory Module 1 or 2. The amount of land required for surface facilities would increase somewhat for Module 1 or 2 because of the larger storage area for excavated rock and an additional ventilation shaft for the intermediate thermal load scenario (see Table 8-4). This would have no substantial cumulative land-use or ownership impact.

Table 8-5. Summary of cumulative short-term impacts in the proposed Yucca Mountain Repository region (page 1 of 8).

Resource area	Proposed Action (repository and transportation)	Inventory Module 1 or 2[a]	Other Federal, non-Federal, and private actions	Total cumulative impacts
Land use and ownership	Withdraw about 600 square kilometers (150,000 acres) of land already under Federal control by DOE, U.S. Air Force, and Bureau of Land Management. Public access to about 200 square kilometers (50,000 acres) of BLM public lands would be terminated. About 3.5 square kilometers (870 acres) of withdrawn land would be disturbed. As much as 20 square kilometers (4,900 acres) of land would be disturbed along transportation routes in Nevada, a portion of which would be in the Yucca Mountain region and could include the need for rights-of-way agreements or withdrawals.	Land withdrawal impacts would be the same as those for the Proposed Action. As much as 1 square kilometer (250 acres) of additional land would be disturbed, for a total of as much as 4.5 square kilometers (1,100 acres). Land use and ownership impacts from transportation would be the same as for the Proposed Action.	No other actions were identified with potential cumulative land-use and ownership impacts in the region of influence of repository construction, operation and monitoring, and closure. An intermodal transfer station could be constructed for shipping low-level radioactive waste within the Yucca Mountain region.	Withdraw about 600 square kilometers (150,000 acres) of land already under Federal control by DOE, U.S. Air Force, and Bureau of Land Management. Public access to about 200 square kilometers (50,000 acres) of BLM public lands would be terminated. As much as 4.5 square kilometers (1,100 acres) of withdrawn land would be disturbed. As much as 20 square kilometers (4,900 acres) of land would be disturbed along transportation routes in Nevada, a portion of which would be in the Yucca Mountain region and could include the need for rights-of-way agreements or withdrawals.
Air Quality				
Nonradiological	Criteria pollutant [nitrogen dioxide, sulfur dioxide, carbon monoxide, and particulate matter ($PM_{10,}$ $PM_{2.5}$)] and cristobalite concentrations calculated at the analyzed land withdrawal area boundary would be less than 5 percent of applicable regulatory limits (see Tables 8-6, 8-7, and 8-8). Emissions associated with transportation in the proposed repository region would be low.	Criteria pollutant and cristobalite concentrations calculated at the analyzed land withdrawal area boundary would be less than 5 percent of applicable regulatory limits (see Tables 8-6, 8-7, and 8-8). Emissions associated with transportation in the proposed repository region would be low.	**Nevada Test Site:** Baseline monitoring shows that criteria pollutants at the Nevada Test Site and in the proposed repository region are well below National Ambient Air Quality Standards and would result in very small cumulative nonradiological air quality impacts. Emissions associated with the transportation of waste, people, and materials for Nevada Test Site activities in the repository region would be low.	Criteria pollutant and cristobalite concentrations calculated at the analyzed land withdrawal area boundary would be small fractions of applicable regulatory limits (generally less than 10 percent). Emissions associated with transportation in the repository region would be low.

Table 8-5. Summary of cumulative short-term impacts in the proposed Yucca Mountain Repository region (page 2 of 8).

Resource area	Proposed Action (repository and transportation)	Inventory Module 1 or 2[a]	Other Federal, non-Federal, and private actions	Total cumulative impacts
Air Quality (continued)				
Radiological	The maximally exposed individual in the public would receive an estimated annual radiation dose of 1.5 millirem or less (see Tables 8-9, 8-10, and 8-11), primarily from naturally occurring radon.	The maximally exposed individual in the public would receive an estimated annual dose of 2.4 millirem or less, primarily from naturally occurring radon.	**Nevada Test Site:** Activity would continue to contribute extremely small increments to the risk to the general population and should not increase injury or mortality rates. As an example, the maximally exposed individual in the public would receive an estimated annual radiation dose of 0.09 millirem from past, present and reasonably foreseeable future activities.	The maximally exposed individual in the public would receive an annual radiation dose of 2.5 millirem or less, which is well below the 40 CFR 61 limit of 10 millirem[b] from radioactive material releases from the repository and the Nevada Test Site.
Hydrology				
Surface water	About 3.5 square kilometers (870 acres) of land would be disturbed and resulting impacts would likely be small and limited to the site. Impacts from construction and use of transportation capabilities (heavy-haul and rail) in the site vicinity and region would result in small impacts to surface water. Minor changes to runoff and infiltration rates. Floodplain/wetlands assessment concluded impacts would be small. Transportation floodplain/wetlands assessments would be performed in the future as necessary.	Would be similar to impacts from the Proposed Action with an increase of as much as 1 square kilometer (250 acres) in surface disturbance for a total of as much as 4.5 square kilometers (1,100 acres). Impacts from construction and use of transportation capabilities (heavy-haul and rail) would be small. Minor changes to runoff and infiltration rates. Floodplain/wetlands assessment concluded impacts would be small. Transportation floodplain/wetlands assessments would be performed in the future as necessary.	No other actions were identified with potential cumulative surface-water impacts within the region of influence of repository construction, operation and monitoring, and closure. Transportation impacts would be small.	As much as 4.5 square kilometers (1,100 acres) of land would be disturbed and resulting impacts would likely be minor and limited to the site. Impacts from construction and use of transportation capabilities (heavy-haul and rail) in the site vicinity and region would result in small impacts to surface water. Minor changes to runoff and infiltration rates. Floodplain/wetlands assessment concluded impacts would be small. Transportation floodplain/wetlands assessments would be performed in the future as necessary.

Table 8-5. Summary of cumulative short-term impacts in the proposed Yucca Mountain Repository region (page 3 of 8).

Resource area	Proposed Action (repository and transportation)	Inventory Module 1 or 2[a]	Other Federal, non-Federal, and private actions	Total cumulative impacts
Hydrology (continued)				
Groundwater	Annual water demand (well below Nevada State Engineer's ruling on perennial yield) would be between 250 and 480 acre-feet (during emplacement) below the lowest estimate of perennial yield of the western two-thirds of the Jackass Flats basin (580 acre-feet). Water use for the construction of a rail line could be as much as 710 acre-feet from multiple wells and hydrographic areas over 2.5 years.	Anticipated annual water demand (below Nevada State Engineer's ruling on perennial yield) would be similar to that of the Proposed Action, but the highest demand, which would occur when emplacement and development activities occurred together, would extend for an additional 14 years. Water use for transportation would be the same as that for the Proposed Action.	**Nevada Test Site:** Anticipated annual water demand from Nevada Test Site activities would be about 280 acre-feet, which is less than the estimate of perennial yield of the western two-thirds of the Jackass Flats basin (580 acre-feet).	Combining the highest annual water demand of the repository of 480 acre-feet (during emplacement and development activities for the low thermal load scenario) with annual water withdrawals from the Nevada Test Site of 280 acre-feet would result in a total of 760 acre-feet, which would exceed the lowest estimate of perennial yield of the western two-thirds of the Jackass Flats basin (580 acre-feet), but would not approach the highest estimate of perennial yield, which is between 880 and 4,000 acre-feet. There is a potential for drawdown of the nearby aquifer from water withdrawal. The combined peak annual water use of a repository under an intermediate or high thermal load scenario with Nevada Test Site annual water use would result in a maximum peak cumulative use of about 530 acre-feet per year, which is below the perennial yield of the western two-thirds of the Jackass Flats basin (580 acre-feet). In addition, up to 710 acre-feet of water would be used to construct a rail line in Nevada.

Table 8-5. Summary of cumulative short-term impacts in the proposed Yucca Mountain Repository region (page 4 of 8).

Resource area	Proposed Action (repository and transportation)	Inventory Module 1 or 2[a]	Other Federal, non-Federal, and private actions	Total cumulative impacts
Biological resources and soils	About 3.5 square kilometers (870 acres) of soil, habitat, and vegetation would be disturbed, resulting in lost productivity and animal mortality and displacement. Adverse impacts to the desert tortoise and loss of individuals would occur. Wetland assessment concluded impacts would be small. Impacts from transportation would include the loss of 0 (legal-weight truck) to 20 square kilometers (4,900 acres) (rail) of habitat in Nevada. Impacts to the desert tortoise probably would occur if a rail line were constructed. Additional wetlands assessments would be performed in the future as necessary.	Inclusive of the Proposed Action, a total of as much as 4.5 square kilometers (1,100 acres) of soil, habitat, and vegetation would be disturbed, resulting in lost productivity and animal mortality and displacement. Adverse impacts to the desert tortoise would occur. Wetland assessment concluded impacts would be small. Impacts from transportation would be the same as those under the Proposed Action. Additional wetlands assessments would be performed in the future as necessary.	No other actions were identified with potential cumulative biological resource or soil impacts within the region of influence of repository construction, operation and monitoring, and closure.	As much as 4.5 square kilometers (1,100 acres) of soil, habitat, and vegetation would be disturbed, resulting in lost productivity and animal mortality and displacement. Adverse impacts to the desert tortoise and loss of individuals would occur. Impacts to potential jurisdictional wetlands would be very small and minimized. Impacts from transportation would include the loss of 0 (legal-weight truck) to 20 square kilometers (4,900 acres) (rail) of habitat in Nevada, a portion of which would be within the Yucca Mountain vicinity. Impacts to the desert tortoise and wetlands probably would occur if a rail line were constructed. Additional wetlands assessments would be performed in the future as necessary.

Table 8-5. Summary of cumulative short-term impacts in the proposed Yucca Mountain Repository region (page 5 of 8).

Resource area	Proposed Action (repository and transportation)	Inventory Module 1 or 2[a]	Other Federal, non-Federal, and private actions	Total cumulative impacts
Cultural resources	Repository development would disturb about 3.5 square kilometers (870 acres). Direct and indirect impacts (damage to archaeological and historical sites or illicit collection of artifacts) would be mitigated per applicable regulations. In addition, as much as 20 square kilometers (4,900 acres) would be disturbed along transportation routes in Nevada. Native Americans view all impacts to be adverse and immune to mitigation.	Land disturbance for repository development would increase to a total of as much as 4.5 square kilometers (1,100 acres). Transportation impacts would be the same as those under the Proposed Action. Direct and indirect impacts and mitigations would be similar to the Proposed Action. Native Americans view all impacts to be adverse and immune to mitigation.	No other actions were identified with potential cumulative cultural resource impacts within the region of influence of repository construction, operation and monitoring, and closure. Native Americans view all impacts to be adverse and immune to mitigation.	Repository development would disturb as much as 4.5 square kilometers (1,100 acres). As much as 20 square kilometers (4,900 acres) would be disturbed if a rail line was constructed in Nevada. Direct and indirect impacts (damage to archaeological and historical sites or illicit collection of artifacts) would be mitigated per applicable regulations. Native Americans view all impacts to be adverse and immune to mitigation.
Socioeconomics	Estimated peak direct employment of 1,800 occurring in 2006 would result in less than a 1 percent increase in direct and indirect regional employment. Employment increases would range from less than 1 percent to 5.7 percent (use of intermodal transfer station or rail line in Lincoln County, Nevada) of total employment by county.	Estimated peak employment would be the same as for the Proposed Action, but would be extended by the longer time (14 years) for emplacement and development activities. Impacts to Lincoln County would be the same as for the Proposed Action.	**Nevada Test Site:** Estimated total of approximately 4,550 direct jobs by 2005 would occur prior to construction of the repository and small cumulative impacts would be expected.	Estimated peak employment increase of about 6,350 occurring in 2005-2006 would result in less than a 4- to 9-percent increase in direct and indirect regional employment (with as much as a 5.7-percent change if intermodal transfer station or rail line were located in Lincoln County, Nevada).
Occupational and public health and safety				
Industrial hazards (nonradiological)	1 to 2 fatalities during construction, operation and monitoring, and closure. Exposures well below regulatory limits. Also, between 11 and 16 fatalities from commuting, and transportation of material.	3 or less fatalities during construction, operation and monitoring, and closure. Exposures well below regulatory limits. Also, between 11 and 16 fatalities from commuting, and transportation of material.	No other actions were identified with potential cumulative industrial hazard impacts.	13 to 19 fatalities during construction, operation and monitoring, and closure (including transportation). Exposures well below regulatory limits.

Table 8-5. Summary of cumulative short-term impacts in the proposed Yucca Mountain Repository region (page 6 of 8).

Resource area	Proposed Action (repository and transportation)	Inventory Module 1 or 2[a]	Other Federal, non-Federal, and private actions	Total cumulative impacts
Occupational and public health and safety (continued)				
Radiological health impacts				
Workers	3 to 4 latent cancer fatalities from repository construction, operation and monitoring, and closure. Up to 3 or up to 11 latent cancer fatalities to workers from shipping material by rail and truck, respectively.	3 to 6 latent cancer fatalities from repository construction, operation and monitoring, and closure. Impacts from transportation would be similar to those from the Proposed Action.	No other actions were identified with potential cumulative radiological health impacts to repository workers.	About 6 to 17 latent cancer fatalities from repository construction, operation and monitoring, and closure (including transportation)
Public	Estimated doses would result in less than 1 latent cancer fatality to the public from repository construction, operation and monitoring, and closure. Up to 3 or up to 18 latent cancer fatalities would result from shipping material by rail and truck, respectively.	Estimated doses would result in less than one latent cancer fatality to the public from repository construction, operation and monitoring, and closure. Impacts from transportation would be similar to those from the Proposed Action.	**Nevada Test Site:** Estimated doses and associated health effects from the Nevada Test Site would be about 0.0055 latent cancer fatalities over 10 years.	About 3 to 18 latent cancer fatalities from repository construction, operation and monitoring, and closure (including transportation); and Nevada Test Site activities.
Accidents	No latent cancer fatalities would be likely from the maximum reasonably foreseeable repository accident scenarios. Between 5 and 31 latent cancer fatalities would result from a maximum reasonably foreseeable transportation accident scenario that has 1.9 chances in 10 million of occurring.	The accident risk (probability of occurrence times consequence) is essentially the same as that for the Proposed Action. Impacts of a maximum reasonably foreseeable transportation accident scenario would be the same as those for the Proposed Action.	No other actions were identified with potential cumulative accident risk impacts.	No latent cancer fatalities would be likely from the maximum reasonably foreseeable repository accident scenario. Between 5 and 31 latent cancer fatalities would result from a maximum reasonably foreseeable transportation accident scenario that has a 1.9 in 10 million potential of occurring.

Table 8-5. Summary of cumulative short-term impacts in the proposed Yucca Mountain Repository region (page 7 of 8).

Resource area	Proposed Action (repository and transportation)	Inventory Module 1 or 2[a]	Other Federal, non-Federal, and private actions	Total cumulative impacts
Noise	Impacts from construction, operation and monitoring, and closure of a repository would result in low noise impacts. Noise levels would be transient, less than 90 dBA[c]. New intermittent noise source if a rail line was used in Nevada, including in the Yucca Mountain region.	Same as the Proposed Action.	No other actions were identified with potential cumulative noise impacts within the region of influence of repository construction, operation and monitoring, and closure.	Impacts from construction, operation and monitoring, and closure of a repository would result in low noise impacts. Noise levels would be transient, less than 90 dBA[c]. New intermittent noise source if a rail line was used in Nevada, including in the Yucca Mountain.
Aesthetics	Low. Additional structures at the repository and rail line if rail was used in Nevada. Possible conflict with visual resource management goals for Jean rail corridor.	Same as the Proposed Action.	No other actions were identified with potential cumulative aesthetic impacts within the region of influence of repository construction, operation and monitoring, and closure.	Low. Additional structures at Yucca Mountain and potential rail line in rural areas in Nevada. Possible conflict with visual resource management goals for Jean rail corridor.
Utilities, energy, materials, and site services	Peak electrical power demand would require an upgrade to the electric transmission and distribution system. No adverse impacts on energy and material supplies or to site services would be expected, including materials needed for transportation capabilities in the Yucca Mountain vicinity.	Peak electrical power demand would require upgrade to the electric transmission and distribution system. Although requirements for electricity, fossil fuels, concrete, steel, and copper would increase, no adverse impacts to energy and material supplies or to site services would be expected, including materials needed for transportation capabilities in the Yucca Mountain vicinity.	No other actions were identified with potential substantial cumulative utilities, energy, materials, and site services impacts within the region of influence of repository construction, operation and monitoring, and closure.	Peak electrical power demand would require upgrade to the electric transmission and distribution system. No adverse impacts on energy and material supplies or to site services would be expected, including materials needed for transportation capabilities in the Yucca Mountain vicinity.
Waste management	Disposal of repository-generated low-level waste would represent less than 3 percent of the reserve capacity of the Nevada Test Site. If nonradioactive, nonhazardous solid waste would be disposed of at the Nevada Test Site, existing landfills would need to be expanded.	Disposal of repository-generated low-level waste would represent less than 6 percent of the reserve capacity of the Nevada Test Site. If nonradioactive, nonhazardous solid waste would be disposed of at the Nevada Test Site, the larger quantity of this waste would require even further landfill expansion at the Nevada Test Site.	**Nevada Test Site:** The total low-level radioactive waste disposal capacity of the Nevada Test Site is sufficient and would not be exceeded by the combined actions of repository development and selection of the Nevada Test Site as a regional disposal site for DOE-complex-wide low-level radioactive and mixed wastes.	The Nevada Test Site has sufficient capacity for low-level radioactive waste from all reasonably foreseeable future actions. If nonradioactive, nonhazardous solid waste would be disposed of at the Nevada Test Site, existing landfills would need to be expanded.

Table 8-5. Summary of cumulative short-term impacts in the proposed Yucca Mountain Repository region (page 8 of 8).

Resource area	Proposed Action (repository and transportation)	Inventory Module 1 or 2[a]	Other Federal, non-Federal, and private actions	Total cumulative impacts
Environmental justice	No disproportionately high and adverse impacts to minority or low-income populations would occur for repository or transportation activities. DOE recognizes that Native American people living in the region near Yucca Mountain have concerns about the protection of traditions and the spiritual integrity of the land that extend to the propriety of the Proposed Action, and that implementing the Proposed Action would continue restrictions on free access to the proposed site.	No disproportionately high and adverse impacts to minority or low-income populations would occur for repository or transportation activities. DOE recognizes that Native American people living in the region near Yucca Mountain have concerns about the protection of traditions and the spiritual integrity of the land that extend to the propriety of the Proposed Action, and that implementing the Proposed Action would continue restrictions on free access to the proposed site.	No other actions were identified with potential cumulative impacts within the region of influence of repository construction, operation and monitoring, and closure that would create environmental justice concerns. DOE recognizes that Native American people living in the region near Yucca Mountain have concerns about the protection of traditions and the spiritual integrity of the land that extend to the propriety of the Proposed Action, and that implementing the Proposed Action would continue restrictions on free access to the proposed site.	No disproportionately high and adverse cumulative impacts to minority or low-income populations would occur for repository or transportation activities. DOE recognizes that Native American people living in the region near Yucca Mountain have concerns about the protection of traditions and the spiritual integrity of the land that extend to the propriety of the Proposed Action, and that implementing the Proposed Action would continue restrictions on free access to the proposed site.

a. As described in Section 8.1.2.1, there would be essentially no difference in the design and operation of the repository for Inventory Module 1 or 2. Therefore, the analysis considered cumulative impacts from Inventory Module 2 to be the same as those from Inventory Module 1.

b. The 40 CFR Part 61 limit of 10 millirem per year is used as a point of reference even though this limit does not apply to releases of radon that would be the predominant contributor to the dose from the proposed Yucca Mountain Repository. The 10 millirem per year dose limit was established by EPA for a member of the public from emissions to the air from manmade sources.

c. dBA = A-weighted decibels, a common sound measurement. A-weighting accounts for the fact that the human ear responds more effectively to some pitches than to others. Higher pitches receive less weighting than lower ones.

8.2.2 AIR QUALITY

8.2.2.1 Inventory Module 1 or 2 Impacts

This section addresses potential nonradiological and radiological cumulative impacts to air quality from emplacement in a repository at Yucca Mountain of the additional quantities of spent nuclear fuel and high-level radioactive waste above those evaluated for the Proposed Action, Greater-Than-Class-C waste, and Special-Performance-Assessment-Required waste (that is, Inventory Modules 1 and 2). It compares potential nonradiological and radiological cumulative impacts to applicable regulatory limits, including the new U.S. Environmental Protection Agency National Ambient Air Quality Standard for particulate matter with a diameter of less than 2.5 micrometers. A Federal appeals court recently struck down these new standards (American Trucking v. EPA 1999, all). The EIS use these standards, among other standards that were not at issue in that case, in analyzing air quality impacts. The Environmental Protection Agency has announced that it will appeal the Court's decision. Sources of nonradiological air pollutants at the proposed repository could include fugitive dust emissions from land disturbances, excavated rock handling, and concrete batch plant operations and emissions from fossil fuel consumption.

8.2.2.1.1 *Nonradiological Air Quality*

The construction, operation and monitoring, and closure of the proposed Yucca Mountain Repository for Inventory Module 1 or 2 would result in increased releases of criteria pollutants (nitrogen dioxide, sulfur dioxide, carbon monoxide, and particulate matter) and cristobalite as described in the following sections. The types of activities producing these releases would be the same as those described for the Proposed Action (see Chapter 4, Section 4.1.2).

Construction. The repository construction phase for Inventory Module 1 or 2 (2005 to 2010) would produce the higher air concentrations of criteria pollutants and cristobalite listed in Table 8-6, but these concentrations would still be small fractions of the applicable regulatory limits.

Operation and Monitoring. Table 8-7 lists estimated air quality impacts from criteria pollutants and cristobalite for Inventory Module 1 or 2. The concentrations in this table are for the period of continuing subsurface development and emplacement activities. During the subsequent monitoring and maintenance activities these concentrations would decrease considerably. While somewhat higher than those produced under the Proposed Action, all concentrations would still be small fractions of the applicable regulatory limits for Module 1 or 2. Because the development of the emplacement drifts for Module 1 or 2 would take an additional 14 years (see Table 8-3), these releases of criteria pollutants would occur over a longer period than those from the Proposed Action. In general, the values in Table 8-7 for operation and monitoring are smaller than the values in Table 8-6 for construction because there would be more land surface disturbance during construction.

Closure. Continuing the closure of the repository for either Inventory Module 1 or 2 would produce concentrations of criteria pollutants and cristobalite higher than those estimated for the Proposed Action, but they would still be small fractions of the applicable regulatory limits (see Table 8-8). With Inventory Module 1 or 2, the amount of backfill required to close the ramps, main tunnels, and ventilation shafts would be larger than that for the Proposed Action, and the size of the excavated rock pile to reclaim would be larger. In addition, the duration of the closure period for Inventory Module 1 or 2 would increase over that of the Proposed Action from 6 to 13 years, 6 to 17 years, and 15 to 27 years for the high, intermediate, and low thermal load scenarios, respectively.

Table 8-6. Estimated construction phase (2005 to 2010) criteria pollutant and cristobalite concentrations at the public maximally exposed individual location (micrograms per cubic meter).

Pollutant	Averaging time	Regulatory limit[a]	Maximum concentration[b,c,d]			Percent of regulatory limit[d]		
			High	Intermediate	Low	High	Intermediate	Low
	Proposed Action							
Nitrogen dioxide[e]	Annual	100	0.36	0.36	0.39	0.36	0.36	0.39
Sulfur dioxide[e]	Annual	80	0.088	0.088	0.091	0.11	0.11	0.12
	24-hour	365	1.0	1.0	1.0	0.28	0.28	0.29
	3-hour	1,300	6.3	6.3	6.5	0.49	0.49	0.50
Carbon monoxide[e,f]	8-hour	10,000	3.8	3.8	4.1	0.037	0.037	0.040
	1-hour	40,000	23	23	25	0.058	0.058	0.062
PM_{10} ($PM_{2.5}$)[e,f]	Annual	50 (15)	0.66	0.70	0.65	1.3	1.4	1.3
	24-hour	150 (65)	6.1	6.4	6.0	4.0	4.3	4.0
Cristobalite	Annual[g]	10	0.021	0.026	0.011	0.21	0.26	0.11
	Inventory Module 1 or 2							
Nitrogen dioxide[e]	Annual	100	0.70	0.70	0.70	0.71	0.71	0.71
Sulfur dioxide[e]	Annual	80	0.12	0.12	0.12	0.16	0.16	0.16
	24-hour	365	1.3	1.3	1.3	0.35	0.35	0.35
	3-hour	1,300	8.2	8.2	8.2	0.63	0.63	0.63
Carbon monoxide[e]	8-hour	10,000	6.6	6.6	6.6	0.065	0.065	0.065
	1-hour	40,000	39	39	39	0.099	0.099	0.099
PM_{10} ($PM_{2.5}$)[e,f]	Annual	50 (15)	0.73	0.77	0.83	1.5	1.5	1.7
	24-hour	150 (65)	6.6	6.9	7.2	4.4	4.6	4.8
Cristobalite	Annual[g]	10	0.025	0.025	0.011	0.25	0.25	0.11

a. Regulatory limits for criteria pollutants from 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391 (see Chapter 3, Table 3-5).

b. Sum of highest concentrations at the accessible land withdrawal boundary, regardless of direction.

c. Source: Chapter 4, Section 4.1.2 and Appendix G, Section G.1.4.

d. Numbers are rounded to two significant figures; therefore, the percent of regulatory limit might not equal the percent calculated from the numbers listed in the table.

e. These values would increase by a small percentage should a Cask Maintenance Facility be collocated at the proposed repository.

f. Data on $PM_{2.5}$ not being collected at time of analysis. However, overall PM_{10} numbers are well below standard for both.

g. There are no regulatory limits for public exposure to cristobalite, a form of crystalline silica. An Environmental Protection Agency health assessment (EPA 1996a, all) states that the risk of silicosis is less than 1 percent for a cumulative exposure to 1,000 micrograms per cubic meter-year. Using a 70-year lifetime, an approximate annual average concentration of 10 micrograms per cubic meter was established as a benchmark for comparison.

8.2.2.1.2 *Radiological Air Quality*

Inventory Module 1 or 2 would require more subsurface excavation and a longer closure phase leading to increased radon releases compared to the Proposed Action. The increased quantity of spent nuclear fuel that repository facilities would receive and package would also result in additional releases of krypton-85 from failed spent nuclear fuel cladding but, as for the Proposed Action, naturally occurring radon-222 and its radioactive decay products would still be the dominant dose contributors.

The following paragraphs discuss the estimated radiological air quality impacts in terms of the potential radiation dose to members of the public and workers for the construction, operation and monitoring, and closure phases of Inventory Module 1 or 2. For these estimates, workers exposed through the air pathway would be noninvolved workers.

Construction. Table 8-9 lists estimated doses to members of the public and workers for the construction phase. These values resulting from radon releases during the 5-year construction phase would be similar to those for the Proposed Action because the subsurface volume excavated would be about the same.

Operation and Monitoring. The doses from krypton-85 from receipt and packaging activities during the operation and monitoring phase would be very low and would be about one one-millionth (0.000001) or less of the dose from naturally occurring radon-222 and its radioactive decay products, as discussed

Table 8-7. Estimated operation and monitoring phase (2010 to 2110) criteria pollutant and cristobalite concentrations at the public maximally exposed individual location (micrograms per cubic meter).

Pollutant	Averaging time	Regulatory limit[a]	Maximum concentration[b,c,d]			Percent of regulatory limit[d]		
			High	Intermediate	Low	High	Intermediate	Low
			Proposed Action[e]					
Nitrogen dioxide	Annual	100	0.45	0.45	0.82	0.46	0.46	0.83
Sulfur dioxide	Annual	80	0.14	0.14	0.16	0.18	0.18	0.23
	24-hour	365	1.8	1.8	2.1	0.50	0.50	0.57
	3-hour	1,300	11	11	13	0.87	0.87	1.0
Carbon monoxide	8-hour	10,000	4.2	4.2	7.3	0.041	0.041	0.072
	1-hour	40,000	28	28	46	0.070	0.070	0.11
PM_{10} ($PM_{2.5}$)[f]	Annual	50 (15)	0.22	0.22	0.27	0.43	0.44	0.54
	24-hour	150 (65)	3.0	3.1	3.4	2.0	2.1	2.3
Cristobalite	Annual[g]	10	0.0097	0.012	0.015	0.097	0.12	0.15
			Inventory Module 1 or 2[e]					
Nitrogen dioxide	Annual	100	0.49	0.56	0.82	0.49	0.56	0.82
Sulfur dioxide	Annual	80	0.15	0.15	0.18	0.19	0.20	0.23
	24-hour	365	1.8	1.9	2.1	0.51	0.52	0.57
	3-hour	1,300	12	12	13	0.89	0.92	1.0
Carbon monoxide	8-hour	10,000	4.5	5.2	7.2	0.044	0.051	0.070
	1-hour	40,000	30	33	45	0.074	0.084	0.11
PM_{10} ($PM_{2.5}$)[f]	Annual	50 (15)	0.23	0.24	0.27	0.46	0.48	0.55
	24-hour	150 (65)	3.2	3.2	3.5	2.1	2.1	2.3
Cristobalite	Annual[g]	10	0.013	0.014	0.017	0.13	0.14	0.17

a. Regulatory limits for criteria pollutants from 40 CFR 50.4 through 50.11, and Nevada Administrative Code 445B.391 (see Chapter 3, Table 3-5).
b. Sum of highest concentrations at accessible land withdrawal boundary, regardless of direction.
c. Source: Chapter 4, Section 4.1.2 and Appendix G, Section G.1.5.
d. Numbers are rounded to two significant figures; therefore, the percent of regulatory limit might not equal the percent calculated from the numbers listed in the table.
e. These values would increase by less than 4 percent if a Cask Maintenance Facility was located at the proposed repository.
f. Data on $PM_{2.5}$ not being collected at time of analysis. However, overall PM_{10} numbers are well below standard for both.
g. There are no regulatory limits for public exposure to cristobalite, a form of crystalline silica. An Environmental Protection Agency health assessment (EPA 1996a, all) states that the risk of silicosis is less than 1 percent for a cumulative exposure to 1,000 micrograms per cubic meter-year. Using a 70-year lifetime, an approximate annual average concentration of 10 micrograms per cubic meter was established as a benchmark for comparison.

below. The annual dose from krypton-85 would be the same as that for the Proposed Action, but would occur for 38 rather than 24 years.

Table 8-10 lists doses to individuals and populations for the operation and monitoring phase. In all cases, naturally occurring radon-222 would be the dominant contributor to the doses, which would increase based on the additional excavation required for Inventory Module 1 or 2. Average annual doses would be higher to members of the public and higher to noninvolved workers during the 38 years of development and emplacement activities when the South Portal would be open and used for exhaust ventilation. The analysis estimated collective doses for public and worker populations for the 100 years of the operation and monitoring phase, including the 38 years of development and emplacement activities and 62 years of monitoring and maintenance activities. The dose to the maximally exposed member of the public is for 38 years of operations and 32 years of monitoring (that is, a 70-year lifetime). The dose to the maximally exposed noninvolved worker is for 50 years at the South Portal during development, emplacement, and monitoring activities.

Closure. Table 8-11 lists estimated doses to populations and maximally exposed individuals during the closure phase. Radiation doses would increase over those for the Proposed Action not only because of the larger excavated volume but also the longer time required for closure (13 to 27 years) in comparison to 6 to 15 years. The annual radon emissions and doses during closure would be the same as those for

Table 8-8. Estimated closure phase[a] criteria pollutant and cristobalite concentrations at the public maximally exposed individual location (micrograms per cubic meter).

Pollutant	Averaging time	Regulatory limit[b]	Maximum concentration[c,d,e]			Percent of regulatory limit[d]		
			High	Intermediate	Low	High	Intermediate	Low
			Proposed Action					
Nitrogen dioxide[f]	Annual	100	0.080	0.13	0.12	0.080	0.13	0.12
Sulfur dioxide[f]	Annual	80	0.0076	0.013	0.011	0.0097	0.016	0.014
	24-hour	365	0.057	0.093	0.082	0.016	0.025	0.022
	3-hour	1,300	0.45	0.74	0.66	0.035	0.057	0.050
Carbon monoxide[f]	8-hour	10,000	0.67	1.1	0.98	0.0065	0.011	0.0095
	1-hour	40,000	4.1	6.6	5.9	0.010	0.017	0.015
PM_{10} ($PM_{2.5}$)[f,g]	Annual	50 (15)	0.52	0.56	0.53	1.0	1.1	1.1
	24-hour	150 (65)	6.5	6.8	6.6	4.3	4.5	4.4
Cristobalite	Annual[h]	10	0.010	0.014	0.0053	0.10	0.14	0.053
			Inventory Module 1 or 2					
Nitrogen dioxide[f]	Annual	100	0.11	0.12	0.14	0.11	0.12	0.14
Sulfur dioxide[f]	Annual	80	0.011	0.011	0.013	0.014	0.014	0.016
	24-hour	365	0.079	0.081	0.093	0.021	0.022	0.026
	3-hour	1,300	0.63	0.65	0.75	0.048	0.050	0.057
Carbon monoxide[f]	8-hour	10,000	0.94	0.97	1.1	0.0092	0.0094	0.011
	1-hour	40,000	5.7	5.8	6.7	0.014	0.015	0.017
PM_{10} ($PM_{2.5}$)[f,g]	Annual	50 (15)	0.55	0.60	0.68	1.1	1.2	1.4
	24-hour	150 (65)	6.8	7.1	7.6	4.5	4.7	5.1
Cristobalite	Annual[h]	10	0.013	0.013	0.0056	0.13	0.13	0.056

a. Duration of closure phase would be 6 years for high and intermediate thermal load scenarios and 15 years for low thermal load scenario.

b. Regulatory limits for criteria pollutants from 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391 (see Chapter 3, Table 3-5).

c. Sum of highest concentrations at accessible land withdrawal boundary, regardless of direction.

d. Source: Chapter 4, Section 4.1.2 and Appendix G, Section G.1.6.

e. Numbers are rounded to two significant figures; therefore, the percent of regulatory limit might not equal the percent calculated from the numbers listed in the table.

f. These values would increase by a small percentage should a cask maintenance facility be co-located at the proposed repository.

g. Data on $PM_{2.5}$ not being collected at time of analysis. However, overall PM_{10} numbers are well below standard for both.

h. There are no regulatory limits for public exposure to cristobalite, a form of crystalline silica. An Environmental Protection Agency health assessment (EPA 1996a, all) states that the risk of silicosis is less than 1 percent for a cumulative exposure to 1,000 micrograms per cubic meter-year. Using a 70-year lifetime, an approximate annual average concentration of 10 micrograms per cubic meter was established as a benchmark for comparison.

monitoring and maintenance activities because the release points would be the same and because the quantities released would depend on the excavated volume. No reduction in radon releases from backfilling the main tunnels is assumed. The collective dose to the repository worker population would vary with the packaging scenario, because labor for the closure of the surface facilities would differ among these scenarios.

Summary. Based on the analysis of radiological air quality impacts from repository construction, operation and monitoring, and closure for Inventory Module 1 or 2, the highest estimated average annual dose to the maximally exposed individual member of the public would be 2.5 millirem for the low thermal load scenario during development and emplacement activities in the operation and monitoring phase. As a point of reference, this dose would be 25 percent of the 10-millirem-per-year regulatory limit in 40 CFR Part 61, even though this limit does not apply to releases of radon that are the predominant contributor to this dose. The radiation dose is 0.7 percent of the annual 340-millirem natural background dose to individuals in Amargosa Valley. Section 8.2.7 discusses human health impacts to the public that

Table 8-9. Estimated construction phase (2005 to 2010) radon-222 radiation doses to maximally exposed individuals and populations.[a,b]

	Thermal load					
	High		Intermediate		Low	
Dose	Total	Annual average[c]	Total	Annual average	Total	Annual average
	Proposed Action					
Public						
MEI[d] (millirem)	2.1	0.43	2.5	0.49	2.5	0.49
Population[e] (person-rem)	11	2.3	13	2.6	13	2.6
Noninvolved workers (surface)						
Maximally exposed noninvolved worker[f] (millirem)	23	4.7	27	5.4	27	5.4
Worker population[g](person-rem)						
Uncanistered	9.0	1.8	10	2.0	10	2.0
Noninvolved Nevada Test Site workers						
Worker population[h] (person-rem)	0.012	0.0025	0.014	0.0028	0.014	0.0028
	Inventory Module 1 or 2					
Public						
MEI[d] (millirem)	2.4	0.48	2.4	0.48	2.4	0.48
Population[e] (person-rem)	13	2.6	13	2.6	13	2.6
Noninvolved workers (surface)						
Maximally exposed noninvolved worker[f] (millirem)	26	5.2	26	5.2	26	5.2
Worker population[g] (person-rem)	10	2.0	10	2.0	10	2.0
Noninvolved Nevada Test Site workers						
Worker population[h] (person-rem)	0.014	0.0027	0.014	0.0027	0.014	0.0027

a. Source: Chapter 4, Section 4.1.2 and Appendix G, Section G.2.

b. Totals might differ from sums due to rounding.

c. Annual average doses reflect the increasing repository volume and resulting increasing radon-222 releases during subsurface construction.

d. MEI is the maximally exposed individual of the public, 20 kilometers (12 miles) south of the repository.

e. The population includes about 28,000 individuals within about 80 kilometers (50 miles) of the repository (see Section 3.1.8).

f. Maximally exposed noninvolved worker would be in the South Portal Operations Area.

g. Values vary slightly (less than 2 percent) by packaging scenario due to differences in the number of surface workers.

h. DOE workers at the Nevada Test Site [about 6,600 workers (DOE 1996f, Volume I, page A-69) 50 kilometers (30 miles) east-southeast near Mercury, Nevada].

could result from radiation exposures during construction, operation and monitoring, and closure for Inventory Module 1 or 2.

8.2.2.2 Cumulative Impacts from Inventory Module 1 or 2 and Other Federal, Non-Federal, and Private Actions

This section addresses potential nonradiological and radiological cumulative impacts to air quality from activities at the repository for the Proposed Action or Inventory Module 1 or 2 and other Federal, non-Federal, and private actions that would coincide with repository operations and potentially affect the air quality within the geographic boundaries of repository air quality impacts.

8.2.2.2.1 *Nonradiological Air Quality*

Construction, operation and monitoring, and closure of the proposed Yucca Mountain Repository would have very small impacts on regional air quality for the Proposed Action or for Inventory Module 1 or 2. Annual average concentrations of criteria pollutants at the land withdrawal boundary would be 1 percent or less of applicable regulatory limits except for PM$_{10}$, which the analysis estimated would be as much as 5 percent

Table 8-10. Estimated operation and monitoring phase (2010 to 2110) total radiation doses to maximally exposed individuals and populations.[a,b]

	Thermal load					
	High		Intermediate		Low	
Dose	Total	Annual average[c]	Total	Annual average	Total	Annual average
	Proposed Action					
Public						
MEI[d] (millirem)	38	0.55	45	0.65	100	1.5
Population[e] (person-rem)	260	2.6	310	3.1	710	7.1
Noninvolved workers (surface)						
Maximally exposed noninvolved worker[f] (millirem)	82	3.4	82	3.4	82	3.4
Worker population (person-rem)						
Uncanistered	64	0.64	76	0.74	140	1.4
Disposable canister	62	0.62	74	0.73	130	1.3
Dual-purpose canister	62	0.62	74	0.73	130	1.3
Nevada Test Site noninvolved workers						
Worker population[g] (person-rem)	0.39	0.0039	0.46	0.0046	1.1	0.011
	Inventory Module 1 or 2					
Public						
MEI[h] (millirem)	68	0.97	67	0.96	170	2.4
Population[e] (person-rem)	470	4.7	460	4.6	1,200	12
Noninvolved workers (surface)						
Maximally exposed noninvolved worker[h] (millirem)	130	3.4	130	3.4	130	3.4
Worker population[i] (person-rem)	140	1.4	140	1.4	330	3.3
Nevada Test Site noninvolved workers						
Worker population[h] (person-rem)	0.67	0.0067	0.68	0.0068	1.7	0.017

a. Source: Chapter 4, Section 4.1.2 and Appendix G, Section G.2.
b. Totals might differ from sums due to rounding.
c. Annual average doses reflect radon releases from the increasing repository volume and varying ventilation flows during subsurface development.
d. MEI is the maximally exposed individual of the public, 20 kilometers (12 miles) south of the repository. Dose estimate is based on 24 years of operations and 46 years of monitoring for a total of 70 years.
e. The population includes about 28,000 individuals within about 80 kilometers (50 miles) of the repository (see Section 3.1.8).
f. Maximally exposed noninvolved worker would be in the South Portal Operations Area (from radon-222 exposure) for a 50-year working lifetime including 24 years of operations activities and 26 years of monitoring activities.
g. DOE workers at the Nevada Test Site [about 6,600 workers (DOE 1996f, Volume I, page A-69) 50 kilometers (30 miles) east-southeast near Mercury, Nevada].
h. Dose estimate is based on 38 years of operations and 12 years of monitoring for a total of 50 years.
i. Values vary slightly (less than 2 percent) by packaging scenario due to differences in the number of surface workers.

of the regulatory limit at the land withdrawal boundary. This estimate does not consider standard dust suppression activities (such as wetting), so actual concentrations probably would be much lower.

DOE has monitored particulate matter concentrations in the Yucca Mountain region since 1989; gaseous criteria pollutants were monitored from October 1991 through September 1995. Concentrations were well below applicable National Ambient Air Quality Standards (see Section 3.1.2.1). In 1990, DOE also measured ambient air quality in several Nevada Test Site areas for short-term concentrations of sulfur dioxide, carbon monoxide, and PM_{10} (DOE 1996f, Volume I, pages 4-146 and 4-148). The measurements were all lower than the applicable short-term (1-hour, 3-hour, 8-hour, and 24-hour) limits.

Table 8-11. Estimated closure phase radon-222 radiation doses to maximally exposed individuals and populations.[a,b]

	Thermal load					
	High		Intermediate		Low	
Dose	Total	Annual[c]	Total	Annual	Total	Annual
	Proposed Action					
Public						
MEI[d] (millirem)	2.6	0.43	3.1	0.5	19	1.2
Population[e] (person-rem)	13	2.1	15	2.5	93	6.2
Noninvolved workers (surface)						
Maximally exposed noninvolved worker[f] (millirem)	0.24	0.039	0.28	0.047	1.7	0.12
Worker population[g] (person-rem)						
Uncanistered	0.041	0.0068	0.049	0.0082	0.12	0.020
Disposable canister	0.029	0.0049	0.035	0.0058	0.086	0.014
Dual-purpose canister	0.032	0.0053	0.038	0.0063	0.092	0.016
Nevada Test Site noninvolved workers						
Worker population[h] (person-rem)	0.021	0.0035	0.025	0.0042	0.16	0.010
	Inventory Module 1 or 2					
Public						
MEI[d] (millirem)	10	0.78	14	0.80	58	2.1
Population[e] (person-rem)	51	3.9	68	4.0	290	11
Noninvolved workers (surface)						
Maximally exposed noninvolved worker[f] (millirem)	0.94	0.072	1.3	0.074	1.9	0.07
Worker population[g] (person-rem)						
Uncanistered	0.073	0.012	0.075	0.012	0.15	0.026
Disposable canister	0.051	0.0086	0.053	0.0088	0.11	0.018
Dual-purpose canister	0.055	0.0093	0.057	0.0094	0.12	0.019
Nevada Test Site noninvolved workers						
Worker population[h] (person-rem)	0.085	0.0065	0.11	0.0067	0.48	0.018

a. Source: Chapter 4, Section 4.1.2 and Appendix G, Section G.2.
b. Totals might differ from sums due to rounding.
c. For purposes of analysis, annual radon-222 releases remain constant over the closure phase.
d. MEI is the maximally exposed individual of the public, 20 kilometers (12 miles) south of the repository.
e. The population includes about 28,000 individuals within about 80 kilometers (50 miles) of the repository (see Section 3.1.8).
f. Maximally exposed noninvolved worker would be in the South Portal Operations Area.
g. Values vary slightly by packaging scenario due to differences in the number of surface workers.
h. DOE workers at the Nevada Test Site [about 6,600 workers (DOE 1996f, Volume I, page A-69) 50 kilometers (30 miles) east-southeast near Mercury, Nevada].

Pollutant concentrations related to Nevada Test Site activities would be well below ambient air quality standards and would not increase ambient pollutant concentrations above standards in Nye County (DOE 1996f, Volume I, page 4-146). Therefore, DOE expects the cumulative impacts from proposed repository and Nevada Test Site operations to be very small.

Repository activities would have no effect on air quality in the Las Vegas Valley air basin, which is a nonattainment area for carbon monoxide and PM_{10}, because the Las Vegas Valley air basin lies approximately 120 kilometers (75 miles) southeast of the proposed repository site.

8.2.2.2.2 *Radiological Air Quality*

Past activities at the Nevada Test Site are responsible for the seepage of radioactive gases from underground testing areas and slightly increased krypton-85 levels on Pahute Mesa in the northwest corner of the Nevada Test Site (see Figure 8-2). Some radioactivity on the site is attributable to the resuspension of soils contaminated from past above-ground nuclear weapons testing (DOE 1996f, Volume I, page 4-149). Current Nevada Test Site defense program activities have not resulted in detectable offsite levels of radioactivity. Estimated radiation doses to the public during 1997 were 0.089 millirem to the maximally exposed individual [a hypothetical resident of Springdale, Nevada, which is about 18 kilometers (11 miles) west of the Nevada Test Site (see Figure 8-2)] and 0.26 person-rem to the population within 80 kilometers (50 miles) of Nevada Test Site airborne emission sources (Bechtel 1998, page 7-1). The radiation dose estimates from repository construction, operation and monitoring, and closure (see Tables 8-9, 8-10, and 8-11) would add to these estimates assuming the exposed individuals and population were the same (they are not). Conservatively adding the 1997 maximally exposed individual dose from the Nevada Test Site to the highest estimated average annual dose to the maximally exposed individual from repository operations [hypothetical individual located 20 kilometers (12 miles) south of the repository] (2.4 millirem) results in a cumulative dose of 2.5 millirem. This is about 40 percent of the 40 CFR Part 61 limit of 10 millirem and about 0.7 percent of the annual 340 millirem natural background radiation dose to individuals in Amargosa Valley. Conservatively adding the 1997 Nevada Test Site and highest estimated annual repository population dose (12 person-rem) results in a cumulative dose of 12 person-rem. No latent cancer fatalities to the population would be expected from this cumulative exposure (see Section 8.2.7).

The only other activity identified in the 80-kilometer (50-mile)-radius region of influence that could affect radiological air quality is a low-level radioactive disposal site near Beatty, Nevada, which was officially closed on January 1, 1993. The physical work of a State-approved Stabilization and Closure Plan ended in July 1994. Custodianship of the site has been transferred to the State of Nevada. Monitoring is continuing at the site to ensure that any radioactive material releases to the air continue to be low (NSHD 1999, Section on the Bureau of Health Protection Services).

8.2.3 HYDROLOGY

8.2.3.1 Surface Water

Potential impacts to surface waters from the Proposed Action would be relatively minor and limited to the immediate vicinity of land disturbances associated with the action (see Chapter 4, Section 4.1.3.2, and the floodplain/wetlands assessment in Appendix L). Surface-water impacts of primary concern would include the following:

- Introduction and movement of contaminants
- Changes to runoff or infiltration rates
- Alterations of natural drainage

This section addresses these impact areas in a discussion of possible increases or other changes that could occur as a result of the emplacement of Inventory Module 1 or 2. To be cumulative, other Federal, non-Federal, or private action effects would have to occur in the immediate area. No currently identified actions have affected meeting this criterion.

Introduction and Movement of Contaminants

For Inventory Module 1 or 2, there would be essentially no change in the potential for soil contamination during the construction, operation and monitoring, and closure phases. There would be no change in the types of contaminants present nor would there be changes in operations that would make spills or releases more likely. Similarly, there would be no change in the threat of flooding to cause contaminant releases beyond that described for the Proposed Action.

Changes to Runoff or Infiltration Rates

Compared to the estimated area of land disturbed under the Proposed Action, Inventory Module 1 or 2 would require the disturbance of additional land for the corresponding thermal load scenario (see Table 8-4). A maximum of about 2.8 square kilometers (1.1 square miles) of land would be disturbed for Module 1 or 2 for the low thermal load scenario. This increase in disturbed land would still be a relatively small portion of the natural drainage areas and would make little difference in the amount of water that soaked into the ground or reached the intermittently flowing drainage channels. Disturbed areas not covered by structures would slowly return to conditions more similar to those of the surrounding undisturbed ground.

Alterations of Natural Drainage

No additional actions or land disturbances associated with Inventory Module 1 or 2 would involve a potential to alter noteworthy natural drainage channels in the area. The excavated rock pile and its increased size for Module 1 or 2 would be in an area that would obstruct a very small portion of overland drainage. Potential impacts to floodplains would be the same as those described for the Proposed Action (see Chapter 4, Section 4.1.3.4). The construction, operation, and maintenance of a rail line, roadways, and bridges in the Yucca Mountain vicinity could affect the 100- and 500-year floodplains of Fortymile Wash, Busted Butte Wash, Drill Hole Wash, and Midway Valley Wash at Yucca Mountain. The floodplains affected and the extent of activities in the floodplains would depend on which routes DOE selected. Appendix L contains a floodplain/wetlands assessment that describes the actions DOE could take to construct, operate, and maintain a branch rail line or highway route in the Yucca Mountain vicinity.

8.2.3.2 Groundwater

8.2.3.2.1 *Inventory Module 1 or 2 Impacts*

Potential groundwater impacts would be related to the following:

- The potential for a change in infiltration rates that could increase the amount of water in the unsaturated zone and adversely affect the performance of waste containment in the repository, or decrease the amount of recharge to the aquifer

- The potential for contaminants to migrate to the unsaturated or saturated groundwater zones during the active life of the repository

- The potential for water demands associated with the repository to deplete groundwater resources to an extent that could affect downgradient groundwater use or users

Changes to Infiltration and Aquifer Recharge. If DOE emplaced Inventory Module 1 or 2, changes related to infiltration and recharge rates would be limited to two areas: a possible increase in the size of the excavated rock pile and an extended scope for subsurface activities. The following paragraphs discuss these items.

Additional land disturbance anticipated during the operation and monitoring phase would be the continued growth of the excavated rock pile. Depending on the thermal load scenario, this could involve an additional 0.15 to 0.85 square kilometer (0.06 to 0.33 square mile) of land over that required for the

Proposed Action (see Table 8-4). Although the excavated rock pile could have different infiltration rates than undisturbed ground, it probably would not be a recharge location because of the extended depth of unconsolidated material, nor would it be likely to cause a large change in the amount of water that would otherwise reach recharge areas such as drainage channels.

Underground activities and their associated potential to contribute to the deep infiltration of water would be basically the same as those described for the Proposed Action, except emplacement drift construction would take an estimated 36 years to complete with either Inventory Module 1 or 2, compared to 22 years for the Proposed Action (see Table 8-3). As described for the Proposed Action, the quantities of water in the subsurface not removed to the surface by ventilation or pumping and thus available for infiltration would be small and primarily limited to the duration of drift development when the largest quantities of water would be used in the subsurface for dust control.

Potential for Contaminant Migration to Groundwater Zones. Neither Inventory Module 1 nor 2 would involve additional actions likely to increase the potential for contaminant releases to the environment. The only possible exception to this could be the extended period of subsurface excavation activities to accommodate the additional inventory. However, this exception would be an extension of activities with minimal potential to involve substantial contaminant releases.

Potential to Deplete Groundwater Resources. Anticipated annual water demand for Inventory Module 1 or 2 would be the same or very similar to that projected for the Proposed Action. Table 8-12 summarizes estimated annual water demands for both the Proposed Action and Inventory Module 1 or 2. The table indicates only small variations in water demand during construction, with the minor differences attributable to slight changes in the rate at which subsurface development would occur.

Projected annual water demand during emplacement and development activities of the operation and monitoring phase (as listed in Table 8-12) would be very similar under Inventory Module 1 or 2 and would actually decrease under the low thermal load scenario. However, a decrease in annual demand would be the direct result of extending the duration of drift development from 22 to 36 years. [While the total quantity of water consumed during emplacement and development activities would increase by 40 to 60 percent (depending on the thermal load) over the Proposed Action, it would be withdrawn over more years.]

Projected annual water demand during monitoring activities of the operation and monitoring phase would be the same under either the Proposed Action or Inventory Module 1 or 2. In either case, the demands listed in Table 8-12 represent the highest projected during monitoring, which would last only about 3 years during surface facility decontamination. There would be very minimal water demand during the remaining monitoring activities. The closure phase for Module 1 or 2 shows there would be a decrease in projected annual water demand in comparison to the Proposed Action. This would be due to the closure phase being longer under Module 1 or 2. That is, the annual water demand would decrease, but the total amount that would be used over the entire phase would increase.

Potential impacts to water resources under Inventory Module 1 or 2 would be very similar to those under the Proposed Action because the annual water demand would change little, and the best understanding of the groundwater resource is that it is replenished on an annual basis as gauged by the perennial yield of the groundwater basin. Under Module 1 or 2, the repository’s annual water demand from the western two-thirds of the Jackass Flats basin would remain below the lowest estimated value for its perennial yield of [720,000 cubic meters (580 acre-feet)] (see Chapter 3, Table 3-11).

Table 8-12. Estimated annual water demand (acre-feet) for the Proposed Action and Inventory Module 1 or 2.[a,b]

Phase	Thermal Load High	Thermal Load Intermediate	Thermal Load Low
	Proposed Action		
Construction (2005 to 2010)	150	170	170
Operation and monitoring (2010 to 2110)			
Emplacement and development activities[c]			
Uncanistered	250	260	480
Disposable canister	220	230	450
Dual-purpose canister	220	230	450
Monitoring activities (first 3 years)[d,e]			
Uncanistered	200	200	200
Disposable canister	160	160	160
Dual-purpose canister	160	160	160
Closure			
Uncanistered	80	90	90
Disposable canister	80	90	90
Dual-purpose canister	80	90	90
	Inventory Module 1 or 2		
Construction (2005 to 2010)	150	150	150
Operation and monitoring (2010 to 2110)			
Emplacement and development activities[c]			
Uncanistered	250	260	430
Disposable canister	220	230	400
Dual-purpose canister	220	230	400
Monitoring activities (first 3 years)[d,e]			
Uncanistered	200	200	200
Disposable canister	160	160	160
Dual-purpose canister	160	160	160
Closure			
Uncanistered	60	60	70
Disposable canister	60	60	70
Dual-purpose canister	60	60	70

a. Source: TRW (1999a, pages 73, 76, and 80); TRW (1999b, pages 6-3, 6-14, 6-21, 6-25, 6-26, 6-37, 6-45, 6-53, 6-61, 6-65, and 6-77).

b. To convert acre-feet to cubic meters, multiply by 1,233.49.

c. A collocated Cask Maintenance Facility would increase these values by 2 to 5 percent.

d. Values shown for monitoring activities are applicable only to the first 3 years when decontamination of surface facilities would be performed. Water demand for the 73 years that follow would be low.

e. A collocated Cask Maintenance Facility would increase these values by 5 to 7 percent.

8.2.3.2.2 *Cumulative Impacts from Inventory Module 1 or 2 and Other Federal, Non-Federal, and Private Actions*

Potential impacts to groundwater, as described in Chapter 4, Section 4.1.3.3, and in Section 8.2.3.2.1, for the Proposed Action and Inventory Module 1 or 2 would be small and limited to the immediate vicinity of land disturbances associated with the action. The exception to this would be the potential impact from water demands on groundwater resources. With this single exception, other Federal, non-Federal, or private action effects would have to occur in the same region of influence to be cumulative with those resulting from the Proposed Action or Inventory Module 1 or 2, and no currently identified actions meet this criterion.

The remainder of this discussion addresses the exception to this statement—potential impacts to groundwater resources from water demand.

The discussion of impacts to groundwater resources in Chapter 4, Section 4.1.3.3, includes ongoing water demands from Area 25 of the Nevada Test Site. Area 25 is the proposed location of the primary repository surface facilities. It is also the location of wells J-12 and J-13, which would provide water for the Proposed Action and for ongoing Nevada Test Site activities in this area. The estimated water demand for these ongoing activities is 340,000 cubic meters (280 acre-feet) a year (DOE 1998n, Table 11-2, page 11-6).

As with the Proposed Action, water demand during emplacement and development activities of the operation and monitoring phase under Inventory Module 1 or 2 combined with the baseline demands from Nevada Test Site activities would exceed the lowest perennial yield estimate under the low thermal load scenario. The combined water demands under either the high or intermediate thermal load scenario, and with any of the packaging scenarios, would be below the lowest estimates of perennial yield for the western two-thirds of Jackass Flats. None of the water demand estimates would approach the high estimate of perennial yield for the entire Jackass Flats hydrographic basin, which is 4.9 million cubic meters (4,000 acre-feet) (see Chapter 3, Table 3-11). Potential impacts to groundwater resources from this combined demand would be no different than those described in Chapter 4, Section 4.1.3.3. That is, some decline in the water level would be likely near the production wells, but not extensively over the Jackass Flats basin, and general groundwater flow patterns could shift very slightly to accommodate the withdrawals. Changes in general flow patterns probably would be too small for estimation or detection.

The Nevada Test Site EIS (DOE 1996f, pages 3-18, 3-19, and 3-34) indicates that the potential construction and operation of a Solar Enterprise Zone facility would represent the only action that would cause water withdrawals on the Test Site to exceed past levels. That EIS estimates that this demand would be greater than the highest estimates of the basin’s perennial yield. Therefore, cumulative impacts from the Solar Enterprise Zone facility are likely. DOE is considering several locations for the Solar Enterprise Zone facility, one of which is Area 25. If DOE built this facility in Area 25, it would obtain water from the Jackass Flats hydrologic area, and possibly from other hydrologic areas.

Cumulative demands on the Jackass Flats hydrographic area could have long-term impacts on water availability in the downgradient aquifers beneath Amargosa Desert. The groundwaters in these areas are hydraulically linked, but the exact nature and extent of that link is still a matter of study and some speculation. However, the amount of water already being withdrawn in the Amargosa Desert [averaging about 18 million cubic meters (15,000 acre-feet) of water per year from 1995 through 1997 (see Chapter 3, Table 3-10)] is much greater than the quantities being considered for withdrawal from Jackass Flats. If water pumpage from Jackass Flats were to affect water levels in Amargosa Desert, the impacts would be small in comparison to those caused by local pumping in the Amargosa Desert.

A report from the Nye County Nuclear Waste Repository Office (Buqo 1999, pages 39 to 53) provides a perspective of potential cumulative impacts with that County as the center of interest. The Nye County report evaluates impacts to all water resources potentially available in the entire county, whereas this EIS focuses principally on impacts to the Jackass Flats groundwater basin (the source of water that DOE would use for the repository) and the groundwater system that could become contaminated thousands of years in the future. Nye County reports that the potential cumulative impacts would include additive contamination as radionuclides ultimately reached the groundwater, constraints on development of groundwater due to land withdrawal, and reduction of water available for Nye County development because of use by Federal agencies (Buqo 1999, pages 49 to 51).

8.2.4 BIOLOGICAL RESOURCES

Impacts to biological resources from Inventory Module 1 or 2 would be similar to impacts that would occur as a result of the Proposed Action evaluated in Chapter 4, Section 4.1.4. Those impacts would occur primarily as a result of site clearing, placement of material in the excavated rock pile, habitat loss, and the loss of individuals of some animal species during site clearing and from vehicle traffic.

Inventory Module 1 or 2 would require disturbing biological resources in a larger area under each thermal load scenario than would be disturbed under the Proposed Action, primarily because the excavated rock pile would be larger (Table 8-13).

Table 8-13. Area of land cover types in analyzed withdrawal area disturbed by construction and the excavated rock pile (square kilometers).[a,b,c]

	Total area		Disturbed area		
Land cover	Nevada	Withdrawal area[d]	High thermal load	Intermediate thermal load	Low thermal load[e]
			Proposed Action		
Blackbrush	9,900	140	0.02	0.02	0.36
Creosote-bursage	15,000	290	0.62	0.72	1.1
Mojave mixed scrub	5,600	120	0.8	0.86	0.03
Sagebrush	67,000	16	0	0	0
Salt desert scrub	58,000	20	0	0	0
Previously disturbed[f]	NA[g]	4	0.37	0.37	0.48
Totals	**NA**	**590**	**1.82**	**1.97**	**1.98**
			Inventory Module 1 or 2		
Blackbrush	9,900	140	0.02	0.02	0.31
Creosote-bursage	15,000	290	0.72	0.87	2.0
Mojave mixed scrub	5,600	120	0.86	0.95	0.03
Sagebrush	67,000	16	0	0	0
Salt desert scrub	58,000	20	0	0	0
Previously disturbed[f]	NA	4	0.37	0.37	0.48
Totals	**NA**	**590**	**1.97**	**2.21**	**2.83**

a. Source: Facility diagrams from TRW (1999b; Figures 6.1.7-1, 6.1.7-2, 6.2.7-1, and 6.2.7-2; pages 6-42, 6-43, 6-84, and 6-85) overlain on the land cover types map (Utah State University 1996, GAP data; TRW 1998c, page 9 as adapted) using a Geographic Information System.

b. To convert square kilometers to acres, multiply by 247.1.

c. Totals might differ from sums due to rounding.

d. A small area [0.016 square kilometer (4 acres)] of the pinyon-juniper-2 land cover type occurs in the analyzed land withdrawal area, but would not be affected.

e. As described in Chapter 2, the excavated rock pile would be in a different location for a low thermal load scenario.

f. Estimate.

g. NA = not applicable.

Repository construction and the excavated rock pile to support Inventory Module 1 or 2 would disturb about 3.5 square kilometers (870 acres) of vegetation under any of the thermal load scenarios. For the low thermal load scenario, about 2 square kilometers (500 acres) of the disturbed area would result from the excavated rock pile. Disturbances would occur in areas dominated by Mojave mixed scrub and salt desert scrub land cover types. These cover types are widespread in the withdrawal area and in Nevada. Although this disturbed area is larger than that for the Proposed Action, it still would affect vegetation on less than 1 percent of the land withdrawal area.

Releases of radioactive materials would not adversely affect biological resources. Routine releases would consist of noble gases, primarily krypton-85 and radon-222. These gases would not accumulate in the environment around Yucca Mountain and would result in low doses to plants or animals.

Overall impacts to biological resources from Inventory Module 1 or 2 would be very small. Species at the repository site are generally widespread throughout the Mojave or Great Basin Deserts and repository activities would affect a very small percentage of the available habitat in the region. Changes in the regional population of any species would be undetectable and no species would be threatened with extinction. The removal of vegetation from the small area required for Module 1 or 2 or the local loss of small numbers of individuals of some species due to site clearing and vehicle traffic would not affect regional biodiversity and ecosystem function. The loss of desert tortoise habitat and small numbers of tortoises under Module 1 or 2 would have no impact on recovery efforts for this threatened species.

Activities associated with other Federal, non-Federal, and private actions in the region should not add measurable impacts to the overall impact on biological resources. However, as stated in the Nevada Test Site EIS (DOE 1996f, page 6-16), cumulative impacts to the desert tortoises would occur throughout the region, although the intensity of the impacts would vary from location to location. The largest impact to the habitat probably would occur in the Las Vegas Valley region. The Clark County Desert Conservation Plan authorizes the taking of all tortoises on 445 square kilometers (110,000 acres) of non-Federal land in the County, and on 12 square kilometers (3,000 acres) disturbed by Nevada Department of Transportation activities in Clark and adjacent counties. The plan also authorizes several recovery units designed to optimize the survival and recovery of this threatened species. Potential land disturbance activities at the Nevada Test Site under the expanded use alternative represent a small amount of available desert tortoise habitat and will not add measurably to the loss of this species (DOE 1996f, page 6-16). As discussed in Chapter 4, Section 4.1.4, repository construction activities would involve the loss of an amount of desert tortoise habitat that would be small in comparison to its range. Yucca Mountain is at the northern end of the range of this species. DOE anticipates that small numbers of tortoises would be killed inadvertently by vehicle traffic during the repository construction, operation and monitoring, and closure phases.

8.2.5 CULTURAL RESOURCES

The only identified actions that could result in cumulative cultural resource impact in the Yucca Mountain site vicinity are Inventory Module 1 or 2. The emplacement of either module would require small additional disturbances to land in areas already surveyed during site characterization activities (see Table 8-4). Because repository construction, operation and monitoring, and closure would be Federal actions, DOE would identify and evaluate cultural resources, as required by Section 106 of the National Historic Preservation Act, and would take appropriate measures to avoid or mitigate adverse impacts to such resources. As a consequence, archaeological information gathered from artifact retrieval during land disturbance would contribute additional cultural resources information to the regional data base for understanding past human occupation and use of the land. However, there would be a potential for illicit or incidental vandalism of archaeological or historic sites and artifacts as a result of increased activities in the repository area, which would be extended for Module 1 or 2 (see Table 8-3), and this could contribute to an overall loss of regional cultural resources information.

The Native American view of resource management and preservation is holistic in its definition of cultural resources, incorporating all elements of the natural and physical environment in an interrelated context (AIWS 1998, all). The Native American perspective on cultural resources is further discussed in Chapter 3, Section 3.1.6. Potential impacts resulting from the Proposed Action described in Chapter 4, Section 4.1.5, would also apply to Inventory Module 1 or 2.

8.2.6 SOCIOECONOMICS

8.2.6.1 Inventory Modules 1 and 2 Impacts

This section addresses potential impacts associated with Inventory Module 1 or 2 on socioeconomic indicators that would be above the impacts estimated for the Proposed Action (Section 4.1.6). As described in Chapter 4, Section 4.1.6, DOE established a bounding case to examine the maximum potential workforces it would need to implement thermal load scenarios and packaging scenarios and to identify the scenario combination that would have the highest employment—low thermal load with uncanistered packaging. The analysis of Inventory Modules 1 and 2 assumes the same combination. Table 8-14 summarizes the peak direct employment levels during all phases for the Proposed Action and Module 1 or 2.

Table 8-14. Estimated peak direct employment level impacts from repository phases.

		Peak direct employment levels[a,b]	
Phase	Years	Proposed Action	Module 1 or 2
Construction	2005-2010	2,400	1,600
Operation and monitoring	2010-2110		
Development and emplacement		1,800	1,800
Monitoring and maintenance		120	120
Closure	2110-varies	520	520

a. Sources: TRW (1999a, all); TRW (1999b, all).

b. Cask Maintenance Facility-related construction, operation and monitoring, and closure activities would result in an increase to peak employment of approximately 4 percent.

Construction

DOE expects the construction phase to last from 2005 until 2010. In relation to employment, the construction phase for Inventory Module 1 or 2 would require the same peak number of workers as the Proposed Action (see Table 8-14). The impacts for Module 1 or 2 would therefore be the same as those for the Proposed Action.

Operation and Monitoring

DOE expects the operation and monitoring phase to last from 2010 until 2110. Employment levels during the continuing development of the emplacement drifts and emplacement activities and during monitoring and maintenance activities would be similar to those during the Proposed Action (see Table 8-14). Although the overall duration of the operation and monitoring phase would be 100 years, the primary difference between Inventory Module 1 or 2 and the Proposed Action is the increased duration of development and emplacement activities and the reduced duration of monitoring and maintenance activities. (Under Module 1 or 2, DOE would require an additional 14 years to complete the emplacement of the waste packages. Monitoring and maintenance would still end in 2110, which would shorten the duration of these activities by 14 years).

The annualized impacts during development and emplacement activities for Inventory Module 1 or 2 would be similar to those for the Proposed Action continued an additional 14 years. Cumulative impacts would occur primarily between 2033 (the last year of Proposed Action emplacement) and 2047 (when Module 1 or 2 emplacement would end). As with the Proposed Action, direct and indirect increases in regional employment, population, personal income, Gross Regional Product, and government expenditures for Module 1 or 2 would be small. No substantial impacts would be likely during operation and monitoring for Module 1 or 2.

Closure

DOE expects the closure phase to last from 2110 until 2125 for the Proposed Action with the low thermal load scenario. Although the staffing level for Inventory Module 1 or 2 would be the same as that for the Proposed Action (see Table 8-14), it would require more time. Closure would last 27 years for Module 1 or 2. Annualized impacts for about 520 repository workers would remain the same, carried forward for 12 more years. Cumulative impacts could occur between 2125 (the last year of Proposed Action closure) and 2137 (when Module 1 or 2 closure would be completed). However, as with the Proposed Action, because workforce demands would be considerably less than the peak during operation and monitoring, impacts to regional employment (direct and indirect), population, personal income, Gross Regional Product, and government expenditures for Module 1 or 2 probably would increase less than one-half of 1 percent. No substantial impacts would be likely during closure for Module 1 or 2.

8.2.6.2 Cumulative Impacts from Inventory Module 1 or 2 and Other Federal, Non-Federal, and Private Actions

Reasonably foreseeable future actions at the Nevada Test Site could affect the socioeconomic region of influence (Nye, Clark, and Lincoln Counties). The *Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada* (DOE 1996f, all) presents various scenarios for Nevada Test Site actions. The Record of Decision for that EIS states that DOE would implement a combination of three alternatives: Expanded Use, No Action (continue operations at current levels) regarding mixed and low-level radioactive waste management, and Alternate Use of Withdrawn Lands regarding public education (61 *FR* 65551, December 13, 1996). Under this combination of alternatives, the Nevada Test Site could generate an increase of approximately 4,550 direct jobs, and most of these workers would be likely to live in Clark County (DOE 1996f, page 5-17). Because the Nevada Test Site jobs would be created by 2005, repository peak employment levels would occur later than the peak for Nevada Test Site employment and provide the communities affected with more time to assimilate any new residents that relocated to the region. Thus, no substantial impacts would be likely to occur.

8.2.7 OCCUPATIONAL AND PUBLIC HEALTH AND SAFETY

This section discusses the short-term health and safety impacts to workers and to members of the public (radiological only) associated with construction, operation and monitoring, and closure activities at the Yucca Mountain site for Inventory Module 1 or 2 (Sections 8.2.7.1 through 8.2.7.3). Section 8.2.7.4 provides a summary of these impacts. Appendix F contains the approach and methods used to estimate the health and safety impacts and additional detailed results for Module 1 or 2 health and safety impacts to workers.

With one exception, no other Federal, non-Federal, or private actions were identified with spatially or temporally coincident short-term impacts in the region of influence that would result in cumulative health and safety impacts with those of the proposed Yucca Mountain Repository. Estimated radioactive releases from past activities at the Nevada Test Site resulted in very small radiation doses to the public (see Section 8.2.2.2.2); even combined with estimated radiation doses from a repository at Yucca Mountain, less than 1 latent cancer fatality would be likely (Section 8.2.7.4). With the increased number of persons living and working in the region, the number of injuries and fatalities from nonrepository-related activities would increase. However, injury and mortality incidence should remain unchanged or decrease, assuming the continued enforcement of occupational and public health and safety regulations.

Regarding the health and safety impact analysis for Inventory Module 1 or 2, the radiological characteristics of the spent nuclear fuel and high-level radioactive waste would be the same as those for the Proposed Action; there just would be more material to emplace. As described in Appendix A, the radioactive inventory (and radiological properties) of the Greater-Than-Class-C waste and

Special-Performance-Assessment-Required waste is much less than that for spent nuclear fuel and high-level radioactive waste. Therefore, the subsurface emplacement of the material in Inventory Module 2 would not greatly increase radiological impacts to workers over those estimated for Module 1. For the surface facility evaluation, the number of workers would be the same for Inventory Module 1 or 2 (TRW 1999a, Section 3.3, third paragraph). Therefore, DOE did not perform separate impact analyses for Modules 1 and 2.

The primary changes in the parameters that would affect the magnitude of the worker health and safety impacts between the Proposed Action and Inventory Module 1 or 2 would be the periods required to perform the work (see Table 8-3) and the numbers of workers for the different phases. Appendix F (Table F-29) contains a detailed breakdown of the estimates for the involved and noninvolved workforce for the repository phases for Inventory Module 1 or 2 in terms of full-time equivalent worker-years.

For the public, the principal changes in parameters that would affect the magnitude of the health impact estimates would be the length of the various phases (see Table 8-3) and the rate at which air would be exhausted from the repository. The exhaust rate of the subsurface ventilation system would affect both the radon-222 concentrations to which subsurface workers would be exposed and the quantity of radon-222 released to the environment. Appendix G discusses radon-222 concentrations in the subsurface environment and release rates to the environment from the various project phases.

8.2.7.1 Construction

This section presents estimates of health and safety impacts to repository workers and members of the public for the 5-year construction phase. The values are similar to those for the Proposed Action because the length of the construction phase would be the same and activities would be similar.

Industrial Hazards

Table 8-15 lists health and safety hazards to workers common to the workplace. They are based on the health and safety loss statistics listed in Appendix F, Tables F-2 and F-3. For Inventory Module 1 or 2 these impacts would be independent of the thermal load scenarios because the number of workers would be the same for all three thermal load scenarios (see Appendix F, Table F-31).

Radiological Health Impacts

This analysis presents radiological health impacts in terms of doses and resultant latent cancer fatalities. Estimated doses were converted to estimates of latent cancer fatality using a dose-to-risk conversion factor of 0.0004 and 0.0005 latent cancer fatality per person-rem for workers and the public, respectively (see Appendix F, Section F.1.1.5).

Workers. Spent nuclear fuel and high-level radioactive waste would not be present during the construction phase. Potential radiological impacts to surface workers during this phase would be limited to those from releases of naturally occurring radon-222 and its decay products with the subsurface ventilation exhaust (these impacts are presented in Section 8.2, Table 8-9). Subsurface workers would incur exposure from radiation resulting from radionuclides in the walls of the drifts and from inhalation of radon-222 in the subsurface atmosphere. Surface worker exposure would be very small compared to those for subsurface workers. The radiological doses and health impacts for Inventory Module 1 or 2 are listed in Table 8-16. The Module 1 or 2 impacts would be independent of both thermal load and packaging scenarios because the subsurface workforce would not change.

Public. Potential radiological impacts to the public during the construction phase would be limited to those from the release of naturally occurring radon-222 with the exhaust from subsurface ventilation. For

Table 8-15. Construction phase (2005 to 2010) impacts to workers from industrial hazards.[a]

	Proposed Action[b]								
	High thermal load			Intermediate thermal load			Low thermal load		
Group	UC[c]	DISP[d]	DPC[e]	UC	DISP	DPC	UC	DISP	DPC
Involved									
Total recordable cases	290	250	240	300	250	260	300	250	260
Lost workday cases	140	120	120	140	120	120	140	120	120
Fatalities	0.14	0.11	0.12	0.14	0.12	0.12	0.14	0.12	0.12
Noninvolved									
Total recordable cases	50	41	42	50	41	42	50	41	42
Lost workday cases	24	20	21	24	20	21	24	20	21
Fatalities	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
All workers (total)[f]									
Total recordable cases	340	290	280	350	290	300	350	290	300
Lost workday cases	160	140	140	170	140	140	170	140	140
Fatalities	0.18	0.15	0.16	0.18	0.16	0.16	0.18	0.16	0.16

	Inventory Module 1 or 2[g]		
	UC	DISP	DPC
Involved			
Total recordable cases	300	250	260
Lost workday cases	140	120	120
Fatalities	0.14	0.12	0.12
Noninvolved			
Total recordable cases	50	41	42
Lost workday cases	24	20	21
Fatalities	0.04	0.04	0.04
All workers (total)[f]			
Total recordable cases	350	290	300
Lost workday cases	170	140	140
Fatalities	0.18	0.16	0.16

a. The analysis assumes that construction would last 44 months for surface activities and 60 months for subsurface activities.
b. Source: Chapter 4, Table 4-20.
c. UC = uncanistered packaging scenario.
d. DISP = disposable canister packaging scenario.
e. DPC = dual-purpose canister packaging scenario.
f. Totals might differ from sums due to rounding.
g. Source: Appendix F, Tables F-7 and F-33.

Inventory Module 1 or 2, the construction phase and the subsurface exhaust system ventilation rate would be essentially the same as those for the Proposed Action. Thus, radiological health impacts to the public would be the same as those for the Proposed Action, as listed in Chapter 4, Table 4-22.

8.2.7.2 Operation and Monitoring

This section presents estimates of health and safety impacts to workers and members of the public during the operation and monitoring phase. The primary differences between Inventory Module 1 or 2 and the Proposed Action would be the longer durations for development and emplacement activities and the shorter duration for monitoring and maintenance activities (see Table 8-3). Under Module 1 or 2, it would take DOE 14 more years to complete drift development (36 years total) than for the Proposed Action and 14 more years to complete emplacement (38 years total) than for the Proposed Action. Because the analysis assumed that monitoring would end 100 years after the start of emplacement (or in 2110), the duration of the monitoring period would be shortened by 14 years (a total of 62 years) for Module 1 or 2 compared to the Proposed Action.

Table 8-16. Construction phase (2005 to 2010) radiological doses and health impacts to subsurface workers.[a]

Group	High thermal load	Intermediate thermal load	Low thermal load
		Proposed Action[b]	
Involved			
MEI[c] (millirem)	770	860	860
LCF[d] probability	0.0003	0.0003	0.0003
CD[e] (person-rem)	350	420	420
LCF incidence	0.14	0.17	0.17
Noninvolved			
MEI (millirem)	580	640	640
LCF probability	0.0002	0.0003	0.0003
CD (person-rem)	70	78	78
LCF incidence	0.03	0.03	0.03
All workers (total)[f]			
CD (person-rem)	420	500	500
LCF incidence	0.17	0.20	0.20
		Inventory Module 1 or 2[g]	
Involved			
MEI (millirem)		830	
LCF probability		0.0003	
CD (person-rem)		410	
LCF incidence		0.16	
Noninvolved			
MEI (millirem)		620	
LCF probability		0.0002	
CD (person-rem)		75	
LCF incidence		0.33	
All workers (total)[f]			
CD (person-rem)		480	
LCF incidence		0.19	

a. The construction phase would last 5 years. Results are for subsurface workers.
b. Source: Chapter 4, Table 4-21.
c. MEI = dose to maximally exposed individual worker.
d. LCF = latent cancer fatality.
e. CD = collective dose.
f. Totals might differ from sums due to rounding.
g. Source: Appendix F, Table F-34.

Industrial Hazards

Table 8-17 lists health and safety impacts to workers from industrial hazards common to the workplace. These impacts would be about 40 percent greater than those calculated for the Proposed Action.

Radiological Impacts

Workers. Table 8-10 lists radiation doses to workers and the public for this phase. Table 8-18 lists radiological doses and health impacts to workers during the operation and monitoring phase for Inventory Module 1 or 2. Appendix F contains additional detail and presents the radiological impacts for surface workers, subsurface workers, and monitoring activities. Radiological impacts to workers for Module 1 or 2 would be about 40 percent greater than those for the Proposed Action. The dominant factors in dose to workers are direct exposure and inhalation.

Public. Potential radiological impacts to the public from the operation and monitoring phase would result from the release of naturally occurring radon-22 and its decay products with the subsurface exhaust

Table 8-17. Operation and monitoring phase (2010 to 2110) impacts to workers from industrial hazards.

	High thermal load			Intermediate thermal load			Low thermal load		
Group	UC[a]	DISP[b]	DPC[c]	UC	DISP	DPC	UC	DISP	DPC
	Proposed Action[d]								
Involved									
TRC[e]	1,360	1,150	1,160	1,360	1,150	1,160	1,400	1,180	1,200
LWC[f]	710	610	620	710	610	620	730	640	640
Fatalities	1.1	0.88	0.89	1.1	0.88	0.89	1.1	0.90	0.92
Noninvolved									
TRC	500	450	450	500	450	450	500	450	450
LWC	250	220	220	250	220	220	250	220	220
Fatalities	0.49	0.43	0.43	0.49	0.43	0.43	0.49	0.42	0.43
All workers (total)[g]									
TRC	1,860	1,590	1,610	1,860	1,590	1,610	1,890	1,630	1,650
LWC	950	840	840	950	840	840	950	860	870
Fatalities	1.6	1.3	1.3	1.6	1.3	1.3	1.6	1.3	1.3
	Inventory Module 1 or 2[h]								
Involved									
TRC	1,850	1,530	1,550	1,890	1,570	1,590	1,990	1,670	1,690
LWC	970	840	840	1,000	860	870	1,060	920	930
Fatalities	1.5	1.1	1.2	1.5	1.2	1.2	1.5	1.2	1.3
Noninvolved									
TRC	760	680	690	760	680	690	790	710	720
LWC	380	340	340	380	340	340	390	350	360
Fatalities	0.72	0.64	0.65	0.72	0.64	0.65	0.75	0.68	0.68
All workers (total)[g]									
TRC	2,610	2,210	2,240	2,650	2,250	2,280	2,780	2,380	2,410
LWC	1,350	1,170	1,180	1,380	1,200	1,210	1,400	1,270	1,280
Fatalities	2.2	1.8	1.8	2.2	1.8	1.8	2.3	1.9	1.9

a. UC = uncanistered packaging scenario.
b. DISP = disposable canister packaging scenario.
c. DPC = dual-purpose canister packaging scenario.
d. Source: Chapter 4, Table 4-23.
e. TRC = total recordable cases.
f. LWC = lost workday cases.
g. Totals might differ from sums due to rounding.
h. Source: Appendix F, sum of Tables F-35, F-36, and F-37.

ventilation air and from radioactive gases, principally krypton-85, that could be released from the Waste Handling Building during spent nuclear fuel handling operations.

Table 8-19 lists the total radiological doses and radiological health impacts to the public from releases to the atmosphere of krypton-85 and radon-222 during the operation and monitoring phase. Radon-222 and its decay products would be the dominant dose contributors (greater than 99 percent). Radiological health impacts would be 50 to 80 percent higher than those calculated for the Proposed Action.

8.2.7.3 Closure

This section contains estimates of health and safety impacts to workers and members of the public for the closure phase. The length of this phase would depend on the thermal load scenario (see Table 8-3).

Table 8-18. Operation and monitoring phase (2010 to 2110) radiological doses and health impacts to workers.

	High thermal load			Intermediate thermal load			Low thermal load		
Group	UC[a]	DISP[b]	DPC[c]	UC	DISP	DPC	UC	DISP	DPC
	Proposed Action[d]								
Involved									
MEI[e] (millirem)	16,240	16,240	16,240	18,940	18,940	18,940	17,610	17,610	17,610
LCF[f] probability	0.006	0.006	0.006	0.008	0.008	0.008	0.007	0.007	0.007
CD[g] (person-rem)	8,120	5,330	5,380	8,450	5,660	5,710	8,530	5,740	5,790
LCF incidence	3.2	2.1	2.2	3.4	2.3	2.3	3.4	2.3	2.3
Noninvolved									
MEI (millirem)	6,200	6,200	6,200	7,550	7,550	7,550	8,000	8,000	8,000
LCF probability	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003
CD (person-rem)	350	330	330	380	360	360	400	390	390
LCF incidence	0.14	0.13	0.13	0.15	0.14	0.14	0.16	0.15	0.15
All workers (total)[h]									
CD (person-rem)	8,470	5,660	5,710	8,830	6,020	6,070	8,930	6,130	6,180
LCF incidence	3.4	2.3	2.3	3.5	2.4	2.4	3.6	2.5	2.5
	Inventory Module 1 or 2[i]								
Involved									
MEI (millirem)	19,240	19,240	19,240	15,200	15,200	15,200	16,710	16,710	16,710
LCF probability	0.008	0.008	0.008	0.006	0.006	0.006	0.007	0.007	0.007
CD (person-rem)	11,690	7,320	7,390	11,420	7,050	7,120	12,280	7,910	7,980
LCF incidence	4.7	2.9	3.0	4.6	2.8	2.8	4.9	3.2	3.2
Noninvolved									
MEI (millirem)	7,700	7,700	7,700	5,450	5,450	5,450	7,550	7,550	7,550
LCF probability	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003
CD (person-rem)	480	460	460	440	420	420	650	630	630
LCF incidence	0.19	0.18	0.18	0.18	0.17	0.17	0.26	0.25	0.25
All workers (total)[h]									
CD (person-rem)	12,180	7,780	7,850	11,860	7,470	7,530	12,930	8,540	8,610
LCF incidence	4.9	3.1	3.1	4.7	3.0	3.0	5.2	3.4	3.4

a. UC = uncanistered packaging scenario.
b. DISP = disposable canister packaging scenario.
c. DPC = dual-purpose canister packaging scenario.
d. Source: Chapter 4, Table 4-24.
e. MEI = dose to maximally exposed individual worker over a 50-year period. The subsurface facility workers during monitoring would incur the dose listed.
f. LCF = latent cancer fatality.
g. CD = collective dose.
h. Totals might differ from sums due to rounding.
i. Source: Sum of Appendix F, Tables F-39, F-40, F-41, and F-42.

Industrial Hazards

Table 8-20 lists health and safety impacts to workers from hazards common to the workplace. These impacts would be about 50 percent greater than those for the Proposed Action.

Radiological Impacts

Workers. Table 8-21 lists radiological doses and health impacts to workers during the closure phase. During the closure phase, the primary source of radiation exposure for surface workers would be inhalation of radon-222 released through the subsurface ventilation system. Subsurface workers would be exposed to radon-222 from inhalation of air in the drifts, to external radiation from radionuclides in the rock in the drift walls, and to external radiation emanating from the waste packages. Surface worker exposures would be much smaller than those to subsurface workers, so essentially all of the exposure and

Table 8-19. Operation and monitoring phase (2010 to 2110) radiological doses and health impacts to the public.

Dose[a]/impact	High thermal load	Intermediate thermal load	Low thermal load
		Proposed Action[b]	
Individual MEI[c] dose (millirem)	38	46	100
LCF[d] probability	1.9×10^{-5}	2.3×10^{-5}	5.1×10^{-5}
Population collective dose[e] (person-rem)	260	310	710
LCF incidence	0.13	0.15	0.35
		Inventory Module 1 or 2[f]	
Individual MEI dose (millirem)	68	67	170
LCF probability	3.4×10^{-5}	3.3×10^{-5}	8.4×10^{-5}
Population collective dose (person-rem)	470	460	1,200
LCF incidence	0.23	0.23	0.59

a. From releases of radon-222 and krypton-85 to the atmosphere.
b. Source: Chapter 4, Table 4-28.
c. MEI = the maximally exposed individual of the public, 20 kilometers (12 miles) south of the repository for 24 years of operation and 46 years of monitoring for the Proposed Action and 38 years of operation and 32 years of monitoring for Inventory Module 1 or 2, for a total of 70 years.
d. LCF = latent cancer fatality.
e. Collective dose is for population within about 80 kilometers (50 miles) of Yucca Mountain.
f. Source: Table 8-10.

Table 8-20. Closure phase impacts to workers from industrial hazards.

	High thermal load			Intermediate thermal load			Low thermal load		
Group	UC[a]	DISP[b]	DPC[c]	UC	DISP	DPC	UC	DPC	DISP
					Proposed Action[d]				
Involved									
TRC[e]	180	150	150	180	150	150	300	270	270
LWC[f]	85	71	74	85	71	74	140	130	130
Fatalities	0.08	0.07	0.07	0.08	0.07	0.07	0.14	0.13	0.13
Noninvolved									
TRC	28	23	24	28	23	24	41	36	37
LWC	14	11	12	14	11	12	20	18	18
Fatalities	0.03	0.02	0.02	0.03	0.02	0.02	0.04	0.03	0.03
All workers (total)[g]									
TRC	200	170	180	200	170	180	340	300	310
LWC	99	83	85	99	83	85	160	150	150
Fatalities	0.11	0.09	0.09	0.11	0.09	0.09	0.18	0.16	0.16
					Inventory Module 1 or 2[h]				
Involved									
TRC	270	240	250	320	300	300	460	430	440
LWC	130	120	120	160	140	140	220	210	210
Fatalities	0.13	0.12	0.11	0.15	0.14	0.14	0.22	0.20	0.21
Noninvolved									
TRC	38	33	34	44	38	40	59	53	54
LWC	19	16	17	22	19	19	29	26	27
Fatalities	0.03	0.03	0.03	0.04	0.03	0.03	0.05	0.05	0.05
All workers (total)[g]									
TRC	310	280	280	370	330	340	520	480	490
LWC	150	130	140	180	160	160	250	230	240
Fatalities	0.16	0.14	0.15	0.19	0.17	0.18	0.27	0.25	0.25

a. UC = uncanistered packaging scenario.
b. DISP = disposable canister packaging scenario.
c. DPC = dual-purpose canister packaging scenario.
d. Source: Chapter 4, Table 4-29.
e. TRC = total recordable cases.
f. LWC = lost workday cases.
g. Totals might differ from sums due to rounding.
h. Source: Sum of Appendix F, Tables F-43 and F-44.

Table 8-21. Closure phase radiological doses and health impacts to workers.

Group	High thermal load	Intermediate thermal load	Low thermal load
	Proposed Action[a]		
Involved			
MEI[b] (millirem)	2,040	2,370	5,520
LCF[c] probability	0.0008	0.0009	0.002
CD[d] (person-rem)	380	450	1,100
LCF incidence	0.15	0.18	0.44
Noninvolved			
MEI (millirem)	1,090	1,340	3,540
LCF probability	0.0004	0.0005	0.001
CD (person-rem)	48	59	160
LCF incidence	0.02	0.02	0.06
All workers (total)[e]			
CD (person-rem)	430	510	1,260
LCF incidence	0.17	0.20	0.50
	Inventory Module 1 or 2[f]		
Involved			
MEI (millirem)	5,200	5,280	9,450
LCF probability	0.002	0.002	0.004
CD (person-rem)	990	960	1,880
LCF incidence	0.40	0.38	0.75
Noninvolved			
MEI (millirem)	2,950	2,710	6,010
LCF probability	0.001	0.001	0.002
CD (person-rem)	130	120	260
LCF incidence	0.05	0.05	0.11
All workers (total)[e]			
CD (person-rem)	1,120	1,080	2,150
LCF incidence	0.45	0.43	0.86

a. Source: Chapter 4, Table 4-30.
b. MEI = dose to maximally exposed individual worker; a subsurface facilities worker could potentially incur the dose listed.
c. LCF = latent cancer fatality.
d. CD = collective dose.
e. Totals might differ from sums due to rounding.
f. Source: Full-time equivalent work years from Appendix F, Table F-21; exposure rates from radon inhalation, Table F-32, from waste package exposure, Table F-6, and from ambient exposure, Table F-5.

health impacts would be to subsurface workers. The primary source of exposure would be from inhalation of radon-222 and its decay products. Radiological impacts to workers from Inventory Module 1 or 2 would be greater than those for the Proposed Action by approximately 100 percent.

Public. Potential radiation-related health impacts to the public from closure activities would result from releases of radon-222 in the subsurface ventilation flow. Section 8.2.2.1.2 describes radiation doses to the public for this phase and they are listed in Table 8-11. Table 8-22 lists radiological dose and health impacts for the closure phase. Radiological health impacts to the public for the inventory module case would be approximately 300 to 400 percent greater than those for the Proposed Action and would be independent of the packaging scenario.

8.2.7.4 Summary

This section contains three summary tables:

- A summary of health impacts to workers from industrial hazards common to the workplace for all phases (Table 8-23)

Table 8-22. Closure phase radiological doses and health impacts to the public.

Dose[a]/impact	High thermal load	Intermediate thermal load	Low thermal load
	Proposed Action [b]		
Individual			
MEI[c] dose (millirem)	2.6	3.1	19
LCF[d] probability	1.3×10^{-6}	2.0×10^{-6}	9.4×10^{-6}
Population			
Collective dose[e] (person-rem)	13	15	93
LCF incidence	0.006	0.008	0.05
	Inventory Module 1 or 2[f]		
Individual			
MEI dose (millirem)	10	14	58
LCF probability	5.1×10^{-6}	6.8×10^{-6}	2.9×10^{-5}
Population			
Collective dose (person-rem)	51	68	290
LCF incidence	0.025	0.034	0.14

a. From releases of radon-222 and krypton-85 to the atmosphere.
b. Source: Chapter 4, Table 4-31.
c. MEI = maximally exposed individual of the public, 20 kilometers (12 miles) south of the repository for total closure period.
d. LCF = latent cancer fatality.
e. Collective dose is for population within about 80 kilometers (50 miles) of Yucca Mountain.
f. Source: Table 8-11.

- A summary of radiological doses and health impacts to workers for all phases (Table 8-24)
- A summary of radiological doses and health impacts to the public for all phases (Table 8-25)

Industrial Hazards to Workers

Table 8-23 summarizes health and safety impacts to workers from industrial hazards common to the workplace for all phases. The calculated health impacts from industrial hazards common to the workplace would be in the range of 2 to 3 fatalities for Inventory Module 1 or 2. Most of the impacts would come from surface facility operations during the operation and monitoring phase. The next biggest contributor would be from emplacement drift development during the operation and monitoring phase. These two activities would account for more than 80 percent of the health and safety impacts from industrial hazards (see Appendix F, Table F-31). Industrial safety impacts for Module 1 or 2 are about 40 percent greater than those for the Proposed Action.

Radiological Health

Workers. Table 8-24 summarizes radiological doses and health impacts to workers for the Proposed Action and Inventory Module 1 or 2. It lists these impacts as the likelihood of a latent cancer fatality for the maximally exposed individual worker over a 50-year working career, and as the number of latent cancer fatalities. The calculated values for latent cancer fatalities for repository workers during the construction, operation and monitoring, and closure phases for Module 1 or 2 are in the range of 4 to 6 fatalities for Module 1 or 2. These are higher than those for the Proposed Action (2.5 to 4 fatalities) and would be about double those from normal workplace industrial hazards (see Table 8-23).

About 50 percent of the total worker radiation dose would be from the receipt and handling of spent nuclear fuel in the surface facilities. Radiation exposure from inhalation of radon-222 and its decay products by workers in the subsurface facilities would account for about 25 percent of total worker dose, with another 10 to 15 percent of the dose coming from subsurface worker exposure to radiation emanating from the waste packages.

Public. Table 8-25 summarizes radiological doses and health impacts to the public during all phases for the Proposed Action and Inventory Module 1 or 2. The radiological doses and health impacts would

Table 8-23. Estimated impacts to workers from industrial hazards during all phases.

	High thermal load			Intermediate thermal load			Low thermal load		
Group	UC[a]	DISP[b]	DPC[c]	UC	DISP	DPC	UC	DISP	DPC
					Proposed Action[d]				
Involved									
TRC[e]	1,820	1,540	1,560	1,830	1,550	1,570	1,990	1,700	1,730
LWC[f]	930	800	810	930	810	820	1,010	890	900
Fatalities	1.3	1.1	1.1	1.3	1.1	1.1	1.4	1.2	1.2
Noninvolved									
TRC	570	510	520	570	510	520	590	520	530
LWC	280	250	260	280	250	260	290	260	260
Fatalities	0.54	0.48	0.49	0.54	0.48	0.49	0.55	0.50	0.50
All workers (total)[g]									
TRC	2,400	2,050	2,080	2,410	2,060	2,090	2,580	2,230	2,260
LWC	1,210	1,065	1,070	1,220	1,060	1,070	1,280	1,140	1,160
Fatalities	1.8	1.5	1.6	1.8	1.5	1.6	1.9	1.6	1.7
					Inventory Module 1 or 2[h]				
Involved									
TRC	2,420	2,020	2,060	2,510	2,120	2,150	2,740	2,350	2,380
LWC	1,240	1,070	1,090	1,500	1,120	1,140	1,420	1,250	1,260
Fatalities	1.7	1.4	1.4	1.8	1.4	1.5	1.9	1.6	1.6
Noninvolved									
TRC	850	750	760	850	760	770	900	800	810
LWC	420	370	380	420	380	380	450	400	400
Fatalities	0.79	0.71	0.72	0.80	0.72	0.72	0.84	0.76	0.77
All workers (total)[g]									
TRC	3,260	2,780	2,820	3,360	2,880	2,920	3,640	3,160	3,200
LWC	1,670	1,450	1,460	1,720	1,500	1,520	1,820	1,650	1,670
Fatalities	2.5	2.1	2.1	2.6	2.1	2.2	2.7	2.3	2.4

a. UC = uncanistered packaging scenario.
b. DISP = disposable canister packaging scenario.
c. DPC = dual-purpose canister packaging scenario.
d. Source: Chapter 4, Table 4-32.
e. TRC = total recordable cases.
f. LWC = lost workday cases.
g. Totals might differ from sums due to rounding.
h. Source: Sum of Tables 8-15, 8-17, and 8-20.

result from exposure of the public to naturally occurring radon-222 and decay products released from the subsurface facilities in ventilation exhaust air. The calculated likelihood for Module 1 or 2 that the maximally exposed individual would experience a latent cancer fatality is less than 0.00005. The estimated increase in the number of latent cancer fatalities is less than 1 for the exposed population within about 80 kilometers (50 miles) over the period of more than 100 years of repository activities.

For purposes of comparison, the number of latent cancer fatalities calculated for the public for the Yucca Mountain construction, operation and monitoring, and closure phases for Inventory Module 1 or 2 would be less than 0.75. The average annual age-adjusted rate for cancer deaths is 185 per 100,000 Nevada residents (ACS 1998, page 6). Assuming this mortality rate is a baseline that would remain unchanged for the estimated population of 28,000 people living within about 80 kilometers of Yucca Mountain, the expected annual cancer death rate in the population would be about 50 per year. Therefore, there would be more than 5,000 cancer deaths from other causes over the period of repository operations.

Table 8-24. Estimated radiological doses and health impacts to workers during all phases.

	High thermal load			Intermediate thermal load			Low thermal load		
Group	UC[a]	DISP[b]	DPC[c]	UC	DISP	DPC	UC	DISP	DPC
	Proposed Action[d]								
Involved									
MEI[e] (millirem)	16,240	16,240	16,240	18,940	18,940	18,940	17,610	17,610	17,610
LCF[f] probability	0.006	0.006	0.006	0.008	0.008	0.008	0.007	0.007	0.007
CD[g] (person-rem)	8,850	6,060	6,110	9,320	6,530	6,580	10,060	7,270	7,320
LCF[h] incidence	3.5	2.4	2.4	3.7	2.6	2.6	4.0	2.9	2.9
Noninvolved									
MEI (millirem)	6,200	6,200	6,200	7,550	7,550	7,550	8,000	8,000	8,000
LCF probability	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003
CD (person-rem)	460	450	450	510	500	500	640	620	620
LCF incidence	0.19	0.18	0.18	0.21	0.20	0.20	0.25	0.25	0.25
All workers (total)[i]									
CD (person-rem)	9,320	6,510	6,560	9,830	7,030	7,080	10,690	7,890	7,940
LCF incidence	3.7	2.6	2.6	3.9	2.8	2.8	4.3	3.2	3.2
	Inventory Module 1 or 2[j]								
Involved									
MEI (millirem)	19,240	19,240	19,240	15,200	15,200	15,200	16,710	16,710	16,710
LCF probability	0.008	0.008	0.008	0.006	0.006	0.006	0.007	0.007	0.007
CD (person-rem)	13,090	8,720	8,790	12,780	8,420	8,480	14,570	10,200	10,270
LCF incidence	5.2	3.5	3.5	5.1	3.4	3.4	5.8	4.1	4.1
Noninvolved									
MEI (millirem)	7,700	7,700	7,700	5,450	5,450	5,450	7,550	7,550	7,550
LCF probability	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003
CD (person-rem)	690	660	660	640	610	610	990	970	970
LCF incidence	0.28	0.27	0.27	0.26	0.24	0.24	0.40	0.39	0.39
All workers (total)[i]									
CD (person-rem)	13,780	9,380	9,450	13,420	9,030	9,100	15,560	11,170	11,240
LCF incidence	5.5	3.8	3.8	5.4	3.6	3.6	6.2	4.5	4.5

a. UC = uncanistered packaging scenario.
b. DISP = disposable canister packaging scenario.
c. DPC = dual-purpose canister packaging scenario.
d. Source: Chapter 4, Table 4-33.
e. MEI = dose to maximally exposed individual worker over a 50-year period; subsurface facility workers during the monitoring phase would incur the listed impacts.
f. LCF = latent cancer fatality.
g. CD = collective dose.
h. LCF = latent cancer fatality incidence.
i. Totals might differ from sums due to rounding.
j. Source: Sum of Tables 8-16, 8-18, and 8-21.

Table 8-25. Estimated radiological doses and health impacts to the public during all phases.

Dose[a]/impact	High thermal load	Intermediate thermal load	Low thermal load
	Proposed Action[b]		
Individual MEI[c] dose (millirem)	38	46	100
LCF[d] probability	1.9×10^{-5}	2.3×10^{-5}	5.1×10^{-5}
Population collective dose[e] (person-rem)	280	340	810
LCF incidence	0.14	0.17	0.41
	Inventory Module 1 or 2[f]		
Individual MEI dose (millirem)	68	67	170
LCF probability	3.4×10^{-5}	3.3×10^{-5}	8.5×10^{-5}
Population collective dose (person-rem)	530	540	1,500
LCF incidence	0.27	0.27	0.74

a. From releases of radon-222 and krypton-85 to the atmosphere.
b. Source: Chapter 4, Table 4-34.
c. MEI = the maximally exposed individual of the public, 20 kilometers (12 miles) south of the repository. Over a 70-year lifetime of an individual, this maximum dose occurs during the operation and monitoring phase.
d. LCF = latent cancer fatality.
e. Collective dose is for the population within about 80 kilometers (50 miles) of Yucca Mountain over all phases [that is, over a period from 118 to 132 years for Inventory Module 1 or 2].
f. Source: Sum of Tables 8-19 and 8-22, and Chapter 4, Table 4-22.

8.2.8 ACCIDENTS

Disposal in the proposed repository of the additional spent nuclear fuel and high-level radioactive waste along with the Greater-Than-Class-C waste and Special-Performance-Assessment-Required waste in Inventory Module 1 or 2 would result in a very small increase in the estimated risk from accidents described in Chapter 4, Section 4.1.8, for the Proposed Action. The potential hazards and postulated accident scenarios identified and evaluated in Chapter 4, Section 4.1.8, would be the same as those for Module 1 or 2 because there would be no change to the basic repository design or operation. The time required for receipt, packaging, and emplacement of the additional waste would extend from 24 to 38 years, but the probability of an accident scenario (likelihood per year) would be essentially unaffected. The accident scenario consequences evaluated for the Proposed Action would bound those that could occur for Inventory Module 1 or 2 because the spent nuclear fuel and high-level radioactive waste, except the Greater-Than-Class-C waste and the Special-Performance-Assessment-Required waste, would be the same. DOE has not determined the final disposition method for Greater-Than-Class-C and Special-Performance-Assessment-Required waste but, based on the characteristics and expected packaging of these wastes (type and quantity of radionuclides; see Appendix A), the accident scenario consequences calculated in Chapter 4, Section 4.1.8 for spent nuclear fuel and high-level radioactive waste would be bounding. Therefore, substantial cumulative accident impacts would be unlikely for Inventory Module 1 or 2.

In addition, the analysis identified no other Federal, non-Federal, or private action that could affect either the occurrence probability in consequences of the accident scenarios evaluated above.

8.2.9 NOISE

The emplacement of Inventory Module 1 or 2 would have noise levels associated with the construction and operation of the repository similar to those for the Proposed Action. An increase in potential noise impacts from Module 1 or 2 would result only from the increased number of shipments to the site. The expected rate of receipt would be about the same as that for the Proposed Action; therefore, the impact would be an extended period (approximately 14 years) that shipping would continue beyond the Proposed Action.

DOE does not expect other Federal, non-Federal, or private actions in the region to add measurable noise impacts to those of the Proposed Action or Inventory Module 1 or 2.

8.2.10 AESTHETICS

There would be no impacts for Inventory Module 1 or 2 beyond those described in Chapter 4, Section 4.1.10, because the profile of the repository facility would not be visible beyond the analyzed land withdrawal area boundary. DOE does not expect other Federal, non-Federal, and private industry actions in the region to add measurable aesthetic impacts to those of the Proposed Action or Inventory Module 1 or 2.

8.2.11 UTILITIES, ENERGY, MATERIALS, AND SITE SERVICES

This section discusses potential impacts to utilities, energy, materials, and site services from the construction, operation and monitoring, and closure of the repository for Inventory Module 1 or 2. The scope of the analysis includes electricity use, fossil-fuel consumption, and consumption of construction materials. Chapter 4, Section 4.1.11, evaluates special services such as emergency medical support, fire protection, and security and law enforcement, which would not change for Module 1 or 2. The material in this section parallels Section 4.1.11, which addresses impacts from the Proposed Action. DOE has not identified any other Federal, non-Federal, or private actions that would result in cumulative impacts to utilities, energy, materials, and site services.

To determine the potential impacts of Inventory Module 1 or 2, DOE evaluated the projected uses of electricity, fuel, and construction materials for each repository phase and compared them to those for the Proposed Action. The following paragraphs describe these evaluations.

Construction

As in the Proposed Action, the major impact during the construction phase for Inventory Module 1 or 2 would be the estimated demand for electric power. The peak demand for electricity for the Proposed Action would be 24 megawatts during construction (Table 8-26). During the construction required for Module 1 or 2, the peak demand for electricity would be about the same (24 to 25 megawatts). The tunnel boring machines would account for more than half of the demand for electricity during the 5-year construction phase, but power would also be required to operate ventilation equipment and to support the construction of surface facilities. As for the Proposed Action, the existing electric transmission and distribution system at the Nevada Test Site could not support this increased demand. DOE is evaluating modifications to the site electrical system, as discussed in Chapter 4, Section 4.1.11.

Table 8-26. Peak electric power demand (megawatts).[a,b]

Phase[c]	Time (years)	High thermal load UC[d]	High thermal load DISP[e]	High thermal load DPC[f]	Intermediate thermal load UC	Intermediate thermal load DISP	Intermediate thermal load DPC	Low thermal load UC	Low thermal load DISP	Low thermal load DPC
	Proposed Action[g]									
Construction	*2005-2010*	*24*	*24*	*24*	*24*	*24*	*24*	*24*	*24*	*24*
Operation and monitoring	*2010-2033*	*41*	*38*	*38*	*41*	*38*	*38*	*41*	*38*	*38*
Development	2010-2032	19	19	19	19	19	19	19	19	19
Emplacement	2010-2033	22	18	19	22	18	19	22	18	19
Decontamination	2034-2037	14	10	11	14	10	11	14	10	11
Monitoring	2034-2110	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
	2034-2060	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
	2034-2310	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
Closure	*2110+6-15*	*9.2*	*8.9*	*8.9*	*9.2*	*8.9*	*8.9*	*9.2*	*8.9*	*8.9*
	Inventory Module 1 or 2[g]									
Construction	*2005-2010*	*25*	*24*	*24*	*25*	*24*	*24*	*25*	*24*	*24*
Operation and monitoring	*2010-2048*	*41*	*37*	*38*	*41*	*37*	*38*	*41*	*37*	*38*
Development	2010-2046	19	19	19	19	19	19	27	27	27
Emplacement	2010-2048	22	18	19	22	18	19	22	18	19
Decontamination	2048-2051	14	10	11	14	10	11	14	10	11
Monitoring	2048-2110	8	8	8	8	8	8	8	8	8
Closure	*2110+11-27*	*9.5*	*9.2*	*9.2*	*9.5*	*9.2*	*9.2*	*9.5*	*9.2*	*9.2*

a. Sources: TRW (1999a, Section 6); TRW (1999b, Section 6).
b. Totals might differ from sums due to rounding.
c. Approximate periods for each phase would be as follows: construction, 5 years; operation and monitoring, 100 years; closure, 6 to 15 years for the Proposed Action and 11 to 27 years for Inventory Module 1 or 2.
d. UC = uncanistered packaging scenario.
e. DISP = disposable canister packaging scenario.
f. DPC = dual-purpose canister packaging scenario.
g. The estimated electric power demand from a collocated Cask Maintenance Facility would be within the repository's capacity.

The use of electricity for Inventory Module 1 or 2 would be about 240,000 megawatt-hours during the construction phase, compared to 180,000 to 240,000 megawatt-hours for the Proposed Action (see Table 8-27). This is about 30 percent above the Proposed Action. All thermal load scenarios for Module 1 or 2 would involve the construction of main drifts longer than those for the Proposed Action.

Table 8-27. Electricity use (1,000 megawatt-hours)[a,b]

Phase[c]	Time (years)	High thermal load UC[d]	High thermal load DISP[e]	High thermal load DPC[f]	Intermediate thermal load UC	Intermediate thermal load DISP	Intermediate thermal load DPC	Low thermal load UC	Low thermal load DISP	Low thermal load DPC
					Proposed Action[g]					
Construction	*2005-2010*	*180*	*180*	*180*	*230*	*230*	*230*	*240*	*240*	*240*
Operation and monitoring	*2010-2110*	*5,500*	*4,900*	*5,000*	*6,100*	*5,600*	*5,600*	*8,600*	*8,000*	*8,100*
Development	2010-2032	650	650	650	890	890	890	2,200	2,280	2,200
Emplacement	2010-2033	2,600	2,100	2,100	2,600	2,100	2,100	2,600	2,100	2,200
Decontamination	2034-2037	250	190	200	250	190	200	250	190	200
Monitoring	2034-2110	2,000	2,000	2,000	2,400	2,400	2,400	3,500	3,500	3,500
	2034-2060	680	680	680	810	810	810	1,200	1,200	1,200
	2034-2310	7,200	7,200	7,200	8,600	8,600	8,600	13,000	13,000	13,000
Closure	*2110+6-15*	*250*	*240*	*240*	*370*	*370*	*370*	*560*	*560*	*560*
					Inventory Module 1 or 2[g]					
Construction	*2005-2010*	*240*	*240*	*240*	*240*	*240*	*240*	*240*	*240*	*240*
Operation and monitoring	*2010-2110*	*8,400*	*7,500*	*7,600*	*9,200*	*8,400*	*8,500*	*17,000*	*16,000*	*16,000*
Development	2010-2046	1,400	1,400	1,400	1,700	1,700	1,700	6,100	6,100	6,100
Emplacement	2010-2048	4,100	3,300	3,400	4,200	3,400	3,500	4,400	3,600	3,700
Decontamination	2048-2051	250	190	200	250	190	200	250	190	200
Monitoring	2048-2110	2,600	2,600	2,600	3,100	3,100	3,100	6,200	6,200	6,200
Closure	*2110+11-27*	*480*	*470*	*480*	*620*	*620*	*620*	*1,800*	*1,700*	*1,700*

a. Sources: TRW (1999a, Section 6); TRW (1999b, Section 6).

b. Totals might differ from sums due to rounding.

c. Approximate periods for each phase would be as follows: construction, 5 years; operation and monitoring, 100 years; closure, 6 to 15 years for the Proposed Action and 11 to 27 years for Inventory Module 1 or 2.

d. UC = uncanistered packaging scenario.

e. DISP = disposable canister packaging scenario.

f. DPC = dual-purpose canister packaging scenario.

g. The additional electricity used as a result of Cask Maintenance Facility construction, operation and monitoring, and closure activities would be no greater than approximately 10 percent of that for the repository.

The use of liquid fossil fuel during the construction phase would include diesel fuel and fuel oil. The estimated liquid petroleum use would be 24 to 25 million liters (6.3 to 6.6 million gallons) compared to 7.1 to 14 million liters (1.9 to 3.7 million gallons) for the Proposed Action (see Table 8-28). The usage rate should be well within the regional supply capacity and, therefore, would not result in substantial impacts.

The primary materials needed to support construction would be concrete, steel, and copper. Concrete would be used for tunnel liners. Concrete also would be used in the construction of the surface facilities. The quantity of concrete required for the surface facilities and initial emplacement drift construction would be about 400,000 cubic meters (523,000 cubic yards). Sand and gravel needs would be met from materials excavated from the repository. The value would be about 5 to 20 percent higher than that for the Proposed Action. As much as 190,000 metric tons (210,000 tons) of steel for a variety of uses including rebar, piping, vent ducts, and track, and 100 metric tons (110 tons) of copper for electrical cable also would be required. These quantities would not be likely to affect the regional supply capacity.

Operation and Monitoring

The event that would indicate the start of the operation and monitoring phase would be the beginning of emplacement of spent nuclear fuel and high-level radioactive waste. During this phase the construction of emplacement drifts would continue in parallel with emplacement activities at about the same rate as during the construction phase. As a result, the peak electric power demand would increase to between about 37 and 41 megawatts. The peak demand of 41 megawatts would be about the same as that for the Proposed Action. As was the case for the Proposed Action, DOE would have to upgrade or revise the

Table 8-28. Fossil-fuel use (million liters).[a,b,c]

Phase[d]	Time (years)	High thermal load			Intermediate thermal load			Low thermal load		
		UC[e]	DISP[f]	DPC[g]	UC	DISP	DPC	UC	DISP	DPC
		Proposed Action[h]								
Construction	*2005-2010*	*8.1*	*7.1*	*7.3*	*12*	*11*	*12*	*14*	*13*	*13*
Operation and monitoring	*2010-2110*	*290*	*240*	*240*	*290*	*250*	*250*	*360*	*310*	*310*
Development	2010-2032	19	19	19	20	20	20	83	83	83
Emplacement	2010-2033	230	180	190	230	180	190	230	180	190
Decontamination	2034-2037	33	26	27	33	26	27	33	26	27
Monitoring	2034-2110	11	11	11	15	15	15	15	15	15
	2034-2060	3.9	3.9	3.9	5.0	5.0	5.0	5.0	5.0	5.0
	2034-2310	41	41	41	53	53	53	53	53	53
Closure	*2110+6-15*	*5.1*	*4.5*	*4.6*	*9.4*	*8.8*	*8.9*	*15*	*14*	*15*
		Inventory Module 1 or 2[h]								
Construction	*2005-2010*	*25*	*24*	*24*	*25*	*24*	*24*	*25*	*24*	*24*
Operation and monitoring	*2010-2110*	*450*	*370*	*380*	*470*	*410*	*400*	*580*	*500*	*510*
Development	2010-2046	45	45	45	70	70	70	170	170	170
Emplacement	2010-2048	360	290	300	360	290	300	360	290	300
Decontamination	2048-2051	33	26	27	33	26	27	33	26	27
Monitoring	2048-2110	12	12	12	12	12	12	12	12	12
Closure	*2110+11-27*	*13*	*12*	*12*	*17*	*16*	*16*	*32*	*31*	*31*

a. Sources: TRW (1999a, Section 6); TRW (1999b, Section 6).
b. To convert liters to gallons, multiply by 0.26418.
c. Totals might differ from sums due to rounding.
d. Approximate periods for each phase would be as follows: construction, 5 years; operation and monitoring, 100 years; closure, 6 to 15 years for the Proposed Action and 11 to 27 years for Inventory Module 1 or 2.
e. UC = uncanistered packaging scenario.
f. DISP = disposable canister packaging scenario.
g. DPC = dual-purpose canister packaging scenario.
h. The additional fossil fuel used as a result of Cask Maintenance Facility construction, operation and monitoring, and closure activities would be no greater than approximately 10 percent of that for the repository.

transmission and distribution system on the Nevada Test Site to meet this demand. However, the upgrade or revision for the Proposed Action would accommodate the similar increase for Inventory Module 1 or 2.

The demand for electricity for Inventory Module 1 or 2 would be well within the regional capacity for power generation. Nevada Power Company, for example, plans to maintain a reserve capacity of about 12 percent. For the beginning of the operation and monitoring phase in 2010, Nevada Power projects a net peak load of about 6,000 megawatts and plans a reserve of about 710 megawatts (NPC 1997, Figure 4, page 9). The repository peak demand of 41 megawatts would be less than 1 percent of the Nevada Power Company planned capacity and about 7 percent of planned reserves. The repository would not affect the regional availability of electric power to any extent.

Fossil-fuel use during the operation and monitoring phase would be for onsite vehicles and for heating. It should range between 370 million and 580 million liters (98 million and 153 million gallons) during repository operations. The annual usage rates would be highest during the first half of the operation and monitoring phase (emplacement and continued construction of drifts) and would decrease substantially during the monitoring period (see Table 8-28). The projected annual usage rates of liquid fossil fuels would be higher than those for the Proposed Action but would still be within the regional supply capacity.

Additional construction materials would be required to support the continued construction of emplacement drifts for Inventory Module 1 or 2. About 3,300,000 cubic meters (4,300,000 cubic yards) of concrete would be required for the low thermal load scenario, and 910,000 cubic meters (1,200,000 cubic yards) would be required for the high thermal load scenario (see Table 8-29). The requirement for

Table 8-29. Concrete use (1,000 cubic meters).[a,b,c]

		High thermal load			Intermediate thermal load			Low thermal load		
Phase[d]	Time (years)	UC[e]	DISP[f]	DPC[g]	UC	DISP	DPC	UC	DISP	DPC
Proposed Action[h]										
Construction	*2005-2010*	*330*	*330*	*330*	*390*	*380*	*380*	*390*	*390*	*390*
Operation and monitoring	*2010-2110*	*450*	*450*	*450*	*510*	*510*	*510*	*1,800*	*1,800*	*1,800*
Development	2010-2032	420	420	420	480	480	480	1,700	1,700	1,700
Emplacement	2010-2033	27	27	27	27	27	27	27	27	27
Closure	*2110+6-15*	*2*	*2*	*2*	*2*	*2*	*2*	*4*	*4*	*4*
Totals		***780***	***780***	***780***	***900***	***890***	***890***	***2,200***	***2,200***	***2,200***
Inventory Module 1 or 2[h]										
Construction	*2005-2010*	*400*	*400*	*400*	*400*	*400*	*400*	*400*	*400*	*400*
Operation and monitoring	*2010-2110*	*910*	*910*	*910*	*1,200*	*1,200*	*1,200*	*3,300*	*3,300*	*3,300*
Development	2010-2046	870	870	870	1,100	1,100	1,100	3,200	3,200	3,200
Emplacement	2010-2048	45	45	45	45	45	45	110	110	110
Closure	*2110+11-27*	*3*	*3*	*3*	*5*	*5*	*5*	*8*	*8*	*8*
Totals		***1,300***	***1,300***	***1,300***	***1,600***	***1,600***	***1,600***	***3,700***	***3,700***	***3,700***

a. Sources: TRW (1999a, Section 6); TRW (1999b, Section 6); TRW (1999c, pages 6-17 to 6-24).

b. To convert cubic meters to cubic yards, multiply by 1.3079.

c. Totals might differ from sums due to rounding.

d. Approximate periods for each phase would be as follows: construction, 5 years; operation and monitoring, 100 years; closure, 6 to 15 years for the Proposed Action and 11 to 24 years for Inventory Modules 1 or 2.

e. UC = uncanistered packaging scenario.

f. DISP = disposable canister packaging scenario.

g. DPC = dual-purpose canister packaging scenario.

h. The additional concrete used as a result of Cask Maintenance Facility construction, operation and monitoring, and closure activities would be no greater than approximately 10 percent of that for the repository.

steel would be between 300,000 and 1,400,000 metric tons (330,000 and 1,540,000 tons), and for copper it would be about 300 and 1,600 metric tons (330 and 1,800 tons) (see Tables 8-30 and 8-31). These quantities, while 2 or 3 times those required for the Proposed Action, would be unlikely to affect the regional supply capacity because the annual usage rate would be only about 20 to 30 percent higher than that for the Proposed Action.

Closure

The peak electric power required during the closure phase for Inventory Module 1 or 2 would be only slightly higher than that for the Proposed Action and would be less than 10 megawatts for all three thermal load scenarios. This would be much less than the peak levels predicted for the earlier phases, so impacts would be small.

Fossil-fuel use would be between 12 million and 32 million liters (3.2 million and 8.5 million gallons). A small amount of concrete and steel would be used for closure. An estimated maximum of 8,000 cubic meters (10,000 cubic yards) of concrete would be required for the low thermal load scenario and about 3,000 cubic meters (3,900 cubic yards) for the high thermal load scenario. Similarly, an estimated 3,700 metric tons (4,100 tons) of steel would be required for the low thermal load scenario and about 1,400 metric tons (1,500 tons) for the high thermal load scenario. The fossil-fuel and material quantities required for closure would not be large and would not result in substantial impacts.

Table 8-30. Steel use (1,000 metric tons).[a,b,c]

Phase[d]	Time (years)	High thermal load			Intermediate thermal load			Low thermal load		
		UC[e]	DISP[f]	DPC[g]	UC	DISP	DPC	UC	DISP	DPC
		Proposed Action[h]								
Construction	*2005-2010*	*70*	*68*	*67*	*83*	*81*	*80*	*83*	*81*	*80*
Operation and monitoring	*2010-2110*	*130*	*130*	*130*	*180*	*180*	*180*	*720*	*720*	*720*
Development	2010-2032	90	90	90	140	140	140	610	610	610
Emplacement	2010-2033	42	42	42	42	42	42	110	110	110
Closure	*2110+6-15*	*0.71*	*0.71*	*0.71*	*0.92*	*0.92*	*0.92*	*2.0*	*2.0*	*2.0*
Totals		***200***	***200***	***200***	***260***	***260***	***260***	***800***	***800***	***800***
		Inventory Module 1 or 2[h]								
Construction	*2005-2010*	*190*	*190*	*190*	*190*	*190*	*190*	*190*	*190*	*190*
Operation and monitoring	*2010-2110*	*300*	*300*	*300*	*370*	*370*	*370*	*1,400*	*1,400*	*1,400*
Development	2010-2046	230	230	230	300	300	300	1,200	1,200	1,200
Emplacement	2010-2033	70	70	70	70	70	70	180	180	180
Closure	*2110+11-27*	*1.4*	*1.4*	*1.4*	*2.1*	*2.1*	*2.1*	*3.7*	*3.7*	*3.7*
Totals		***490***	***490***	***490***	***560***	***560***	***560***	***1,600***	***1,600***	***1,600***

a. Sources: TRW (1999a, Section 6); TRW (1999b, Section 6); TRW (1999c, pages 6-17 to 6-24)
b. To convert metric tons to tons, multiply by 1.1023.
c. Totals might differ from sums due to rounding.
d. Approximate periods for each phase would be as follows: construction, 5 years; operation and monitoring, 100 years; closure, 6 to 15 years for the Proposed Action and 11 to 27 years for Inventory Modules 1 or 2.
e. UC = uncanistered packaging scenario.
f. DISP = disposable canister packaging scenario.
g. DPC = dual-purpose canister packaging scenario.
h. The additional steel used as a result of Cask Maintenance Facility construction, operation and monitoring, and closure activities would be no greater than approximately 10 percent of that for the repository.

Table 8-31. Copper use (1,000 metric tons).[a,b,c]

Phase[d]	Time (years)	High thermal load			Intermediate thermal load			Low thermal load		
		UC[e]	DISP[f]	DPC[g]	UC	DISP	DPC	UC	DISP	DPC
		Proposed Action[h]								
Construction	2005-2010	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Operation and monitoring										
Development[i]	2010-2032	0.1	0.1	0.1	0.1	0.1	0.1	0.9	0.9	0.9
Closure	2110+6-15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Totals		***0.2***	***0.2***	***0.2***	***0.2***	***0.2***	***0.2***	***1.0***	***1.0***	***1.0***
		Inventory Module 1 or 2[h]								
Construction	2005-2010	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Operation and monitoring										
Development	2010-2046	0.3	0.3	0.3	0.3	0.3	0.3	1.6	1.6	1.6
Closure	2110+11-27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Totals		***0.4***	***0.4***	***0.4***	***0.4***	***0.4***	***0.4***	***1.7***	***1.7***	***1.7***

a. Sources: TRW (1999a, Section 6); TRW (1999b, Section 6).
b. To convert metric tons to tons, multiply by 1.1023.
c. Totals might differ from sums due to rounding.
d. Approximate periods for each phase would be as follows: construction, 5 years; operation and monitoring, 100 years; closure, 6 to 15 years for the Proposed Action and 11 to 27 years for Inventory Module 1 or 2.
e. UC = uncanistered packaging scenario.
f. DISP = disposable canister packaging scenario.
g. DPC = dual-purpose canister packaging scenario.
h. The additional copper used as a result of Cask Maintenance Facility construction, operation and monitoring, and closure activities would be no greater than approximately 10 percent of that for the repository.
i. Copper would not be consumed during other portions of the operation and monitoring phase.

8.2.12 MANAGEMENT OF REPOSITORY-GENERATED WASTE AND HAZARDOUS MATERIALS

8.2.12.1 Inventory Module 1 or 2 Impacts

Activities for the emplacement of Inventory Module 1 or 2 would generate waste totals beyond the quantities estimated for the Proposed Action (see Chapter 4, Section 4.1.12). The waste types and the treatment and disposal of each waste type would be the same as those described for the Proposed Action.

The quantities of most waste types for Inventory Module 1 or 2 would not change in comparison to the Proposed Action during the construction phase. Sanitary sewage and industrial wastewater would have small fluctuations in comparison to the Proposed Action (TRW 1999a, page 73; TRW 1999b, pages 6-8, 6-9, 6-48, and 6-49).

The emplacement of Inventory Module 1 or 2 would require an additional 14 years of activities, which would reduce the number of maintenance and monitoring years from 76 to 62 years. Table 8-32 lists the waste quantities generated for the Proposed Action and Inventory Modules 1 and 2 for the operation and monitoring phase.

The closure of the repository after the emplacement of the Inventory Module 1 or 2 inventory would require more time than the Proposed Action. The number of years needed for closure would also increase with the lower thermal load scenarios. (Table 8-33 lists the difference in time sequences.) The additional time would lead to an increase in waste quantities.

Sanitary and industrial solid waste, sanitary sewage, and industrial wastewater would be disposed of in facilities at the repository site. These facilities would be designed to accommodate the additional waste from Inventory Module 1 or 2. However, DOE could use existing Nevada Test Site landfills to dispose of nonrecyclable construction and demolition debris and sanitary and industrial solid waste. If Nevada Test Site landfills were used, about 290,000 cubic meters (10.2 million cubic feet) to 440,000 cubic meters (15.5 million cubic feet) would be disposed of from construction through closure (TRW 1999a, Section 6; TRW 1999b, Section 6). Disposal of the Proposed Action waste quantities would require the Nevada Test Site landfills to operate past their projected operating lives and to expand as needed (Chapter 4, Section 4.1.12.2). Disposal of the larger waste quantities under Inventory Module 1 or 2 would require the availability of additional disposal capacity in future landfill expansions.

Impacts from the treatment and disposal of hazardous waste off the site would be the same for the Proposed Action and Inventory Module 1 or 2. At present, commercial facilities are available for hazardous waste treatment and disposal, and DOE expects similar facilities to be available until the closure of the repository. The National Capacity Assessment Report (EPA 1996b, pages 32, 33, 36, 46, 47, and 50) indicates that the estimated 20-year (1993 to 2013) available capacity for incineration of solids and liquids at permitted treatment, storage, and disposal facilities in the western states is about 7 times more than the demand for these services. The estimated landfill capacity is about 50 times the demand. Given the current outlook for the capacity versus demand for hazardous waste treatment and disposal, the treatment and disposal of repository-generated hazardous waste would not present a large cumulative impact.

The Nevada Test Site has an estimated total disposal capacity of 3.15 million cubic meters (110 million cubic feet). The DOE analysis of demand for low-level radioactive waste disposal at the Nevada Test Site through 2070 projects a need for about 670,000 cubic meters (24 million cubic feet or 2.8 percent) of the total disposal capacity (DOE 1998l, page 2-23). The reserve capacity at the Nevada Test Site is about 2.5 million cubic meters (88 million cubic feet). The disposal of repository-generated waste would

Table 8-32. Estimated operation and monitoring phase (2010 to 2110) waste quantities.[a]

Waste type	High thermal load			Intermediate thermal load			Low thermal load		
	UC[b]	DISP[c]	DPC[d]	UC	DISP	DPC	UC	DISP	DPC
	Proposed Action								
Low-level radioactive (cubic meters)[e]	68,000	19,000	26,000	68,000	19,000	26,000	68,000	19,000	26,000
Hazardous (cubic meters)	6,100	2,400	2,300	6,100	2,400	2,300	6,100	2,400	2,300
Sanitary and industrial solid (cubic meters)	70,000	60,000	61,000	70,000	60,000	61,000	90,000	80,000	81,000
Sanitary sewage (million liters)[f]	1,800	1,500	1,600	1,800	1,500	1,600	1,800	1,600	1,600
Industrial wastewater (million liters)	900	780	780	930	810	810	1,400	1,300	1,300
	Inventory Module 1								
Low-level radioactive (cubic meters)	110,000	37,000	42,000	110,000	37,000	42,000	110,000	37,000	42,000
Hazardous (cubic meters)	9,800	3,800	3,500	9,800	3,800	3,500	9,800	3,800	3,500
	Inventory Module 2								
Low-level radioactive (cubic meters)	130,000	41,000	46,000	130,000	41,000	46,000	130,000	41,000	46,000
Hazardous (cubic meters)	12,000	4,600	4,300	12,000	4,600	4,300	12,000	4,600	4,300
	Inventory Module 1 or 2								
Sanitary and industrial solid (cubic meters)	92,000	79,000	80,000	92,000	79,000	80,000	120,000	110,000	110,000
Sanitary sewage (million liters)	2,300	2,000	2,000	2,300	2,000	2,000	2,500	2,100	2,200
Industrial wastewater (million liters)	1,400	1,300	1,300	1,500	1,300	1,300	2,200	2,000	2,000

a. Sources: Chapter 4, Section 4.1.12; TRW (1999a, pages 78, 80, and 81); TRW (1999b, pages 6-56, 6-62, 6-67, and 6-68).
b. UC = uncanistered packaging scenario.
c. DISP = disposable canister packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. To convert cubic meters to cubic feet, multiply by 35.314.
f. To convert liters to gallons, multiply by 0.26418.

require about 2.8 percent of the reserve capacity for the Proposed Action, about 4.7 percent for Inventory Module 1, and about 5.4 percent for Inventory Module 2.

The emplacement of Inventory Module 1 or 2 would require the same types and annual quantities of hazardous materials as the Proposed Action, as described in Chapter 4, Section 4.1.12.3. These materials would be used for the additional years associated with the emplacement of the module inventory. As with the Proposed Action, no cumulative impact would be likely from the procurement and use of hazardous materials at the repository.

8.2.12.2 Cumulative Impacts from Inventory Module 1 or 2 and Other Federal, Non-Federal, and Private Actions

A reasonably foreseeable action that could result in waste management impacts that could add to those of the Proposed Action and Inventory Module 1 or 2 would be the selection of the Nevada Test Site as a regional DOE low-level radioactive waste disposal site, as discussed in the Final Waste Management

Table 8-33. Estimated closure phase waste quantities.[a]

	High thermal load			Intermediate thermal load			Low thermal load		
Waste type	UC[b]	DISP[c]	DPC[d]	UC	DISP	DPC	UC	DISP	DPC
	Proposed Action								
Low-level radioactive (cubic meters)[e]	3,500	2,100	2,500	3,500	2,100	2,500	3,500	2,100	2,500
Hazardous (cubic meters)	630	440	480	630	440	480	630	440	480
Sanitary and industrial solid (cubic meters)	5,300	4,400	4,600	5,400	4,400	4,600	10,000	9,100	9,300
Sanitary sewage (million liters)[f]	87	83	84	87	83	84	200	200	200
Industrial wastewater (million liters)	42	42	42	42	42	42	110	110	110
Demolition debris (cubic meters)	150,000	100,000	120,000	150,000	100,000	120,000	150,000	100,000	120,000
	Inventory Module 1 or 2								
Low-level radioactive (cubic meters)	3,500	2,100	2,500	3,500	2,100	2,500	3,500	2,100	2,500
Hazardous (cubic meters)	630	440	480	630	440	480	630	440	480
Sanitary and industrial solid (cubic meters)	7,700	6,700	6,900	9,100	6,800	8,300	16,000	15,000	15,000
Sanitary sewage (million liters)	150	150	150	150	150	150	350	340	350
Industrial wastewater (million liters)	27	27	27	34	34	34	150	150	150
Demolition debris (cubic meters)	150,000	100,000	120,000	150,000	100,000	120,000	150,000	100,000	120,000

a. Sources: TRW (1999a, page 73); TRW (1999b, pages 6-79 and 6-80).
b. UC = uncanistered packaging scenario.
c. DISP = disposable canister packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. To convert cubic meters to cubic feet, multiply by 35.314.
f. To convert liters to gallons, multiply by 0.26418.

Programmatic Environmental Impact Statement (DOE 1997b, page 7-23). The repository (under the uncanistered packaging scenario) which has the largest estimated waste quantities and the other DOE sites that would use Nevada Test Site facilities for disposal under the regional disposal concept would generate about 14,000 cubic meters (490,000 cubic feet) annually (TRW 1999a, page 76; DOE 1997b, pages 7-23 and I-38).

8.2.13 ENVIRONMENTAL JUSTICE

As discussed in Chapter 4, Section 4.1.13, the environmental justice analysis brings together the results of all resource and feature analyses to determine (1) if an activity would have substantial environmental impacts and (2) if those substantial impacts would have disproportionately high and adverse human health or environmental effects on minority or low-income populations. DOE determined that cumulative impacts from Inventory Module 1 or 2 along with those expected from other Federal, non-Federal, and private actions would not produce cumulative adverse impacts to any surrounding populations, which would include minority and low-income populations. Evaluation of subsistence lifestyles and cultural values has confirmed that these factors would not change the conclusion that the absence of high and adverse impacts for the general population means there would be no disproportionately high and adverse impacts on minority or low-income communities. No substantial impacts were identified; therefore, cumulative impacts from Inventory Module 1 or 2 and other Federal, non-Federal, and private actions would not cause environmental justice concerns.

DOE recognizes that Native American people living in areas near Yucca Mountain have concerns about the protection of traditions and the spiritual integrity of the land that extend to the propriety of the Proposed Action, and that the implementation of the Proposed Action would continue restrictions on free access to the site. Chapter 4, Section 4.1.3.4, discusses these views and beliefs.

8.3 Cumulative Long-Term Impacts in the Proposed Yucca Mountain Repository Vicinity

This section describes results from the long-term cumulative impact analysis that DOE conducted for Inventory Modules 1 and 2 (Section 8.3.1) and for past, present, and reasonably foreseeable future actions at the Nevada Test Site, and past actions at the Beatty low-level radioactive waste site (Section 8.3.2).

8.3.1 INVENTORY MODULE 1 OR 2 IMPACTS

The long-term performance assessment of Inventory Modules 1 and 2 used the same methodology described in Chapter 5 and Appendix I for the Proposed Action to estimate potential human health impacts from radioactive and chemically toxic material releases through waterborne and airborne pathways. Section 8.3.1.1 presents the radioactive and chemically toxic material source terms for Inventory Modules 1 and 2, and Sections 8.3.1.2 and 8.3.1.3 present the results of the analysis for Inventory Modules 1 and 2, respectively.

In addition to long-term human health impacts from radioactive and chemically toxic material releases, the other potential long-term impact identified following repository closure involve biological resources. Though the surface area affected by heat rise would be larger for Inventory Module 1 or 2, the thermal load (expressed in metric tons of heavy metal per acre) would be constant, and, therefore, the ground surface temperature increase would be the same. Thus, long-term biological effects of Module 1 or 2 from heat generated by waste packages that would slightly raise ground surface temperatures would be the same as those described in Chapter 5, Section 5.8 for the Proposed Action.

8.3.1.1 Radioactive and Chemically Toxic Material Source Terms for Inventory Modules 1 and 2

For calculations of long-term performance impacts, the radioactive material inventory of individual waste packages for commercial spent nuclear fuel, high-level radioactive waste, and DOE spent nuclear fuel under Inventory Modules 1 and 2 would be identical to the radioactive material inventory under the Proposed Action for the same waste categories. Inventory Module 2 includes an additional waste category for Greater-Than-Class-C and Special-Performance-Assessment-Required wastes. This category includes a different category of waste package with its own radioactive material inventory. This waste would be emplaced in 608 “naval spent nuclear fuel long waste” packages (TRW 1999c, page 6-9), of which approximately 55 would contain waste from naval reactors and the remainder would contain waste from DOE and commercial reactors. The inventory used for each modeled waste package is an averaged radioactive material inventory of each waste category (commercial spent nuclear fuel, DOE spent nuclear fuel, high-level radioactive waste, and Greater-Than-Class-C and Special-Performance-Assessment-Required wastes). More waste packages would be used for Inventory Modules 1 and 2 than for the Proposed Action to accommodate the expanded inventories. Table 8-34 lists the number of waste packages used in long-term performance assessment calculations for the Proposed Action and Modules 1 and 2.

Table 8-34. Number of waste packages used in long-term performance assessment calculations.[a]

Inventory	Commercial SNF[b]	HLW[c]	DOE SNF	GTCC and SPAR[d]	Total
Proposed Action	7,760	1,663	2,546	0	11,969
Inventory Module 1	12,933	4,456	4,341	0	21,730
Inventory Module 2	12,933	4,456	4,341	1,642	23,372

a. The number of waste packages represented in RIP model simulations would not exactly match the number of actual waste packages. Refer to Appendix I, Section I.3 for a detailed description of waste package abstraction.
b. SNF = spent nuclear fuel.
c. HLW = high-level radioactive waste.
d. GTCC = Greater-Than-Class-C, SPAR = Special-Performance-Assessment-Required.

As listed in Table 8-34, Inventory Module 2 differs from Inventory Module 1 only by the addition of 1,642 Greater-than-Class-C and Special-Performance-Assessment-Required waste packages [the abstracted number of packages for this category of waste (1,642) differs substantially from the actual number (608), but the total radionuclide inventory is identical; the difference concerns only the number of packages modeled for waste package degradation calculations in RIP and is not expected to impact results appreciably]. Table 8-35 lists the inventory of the Greater-than-Class-C and Special-Performance-Assessment-Required waste packages under Inventory Module 2.

Table 8-35. Average radionuclide inventory (curies) per waste package for Greater-Than-Class-C and Special-Performance-Assessment-Required wastes used in performance assessment calculations under Inventory Module 2.

Isotope	Inventory
Carbon-14	38
Iodine-129	1.2×10^{-8}
Neptunium-237	5.2×10^{-8}
Protactinium-231	7.00×10^{-8}
Plutonium-239	48
Plutonium-242	4.0×10^{-6}
Selenium-79	1.0×10^{-6}
Technetium-99	2.6
Uranium-234	6.2×10^{-7}

Table 8-36 lists the total inventory of elemental uranium (that is, all isotopes of uranium) for consideration as a chemically toxic material for the Proposed Action and for Inventory Module 1 or 2. The total uranium inventory for Module 1 or 2 would be about 70 percent greater than for the Proposed Action.

Table 8-36. Total inventory (kilograms)[a] of uranium in the repository under the Proposed Action and Inventory Module 1 or 2.[b]

Inventory	Commercial SNF[c]	HLW[d]	DOE SNF	Total
Proposed Action	63,000,000	4,700,000	2,300,000	70,000,000
Inventory Module 1 or 2 [e]	105,000,000	12,600,000	2,500,000	120,000,000

a. To convert kilograms to pounds, multiply by 2.2046.
b. The uranium content in high-level radioactive waste was set to the MTHM equivalent for this analysis, even though much of the uranium would have been removed during reprocessing operations.
c. SNF = spent nuclear fuel.
d. HLW = high-level radioactive waste.
e. Inventory Modules 1 and 2 would have the same total uranium inventory because Greater-Than-Class-C and Special-Performance-Assessment-Required wastes, (the only additional inventory in Module 2 over Module 1) does not contain a substantial quantity of uranium.

Table 8-37 lists the total chromium inventory for the Proposed Action and Inventory Modules 1 and 2 from waste packages. The analysis used this inventory to calculate the potential impacts to human health from chemically toxic chromium in the waste package materials and in the pressurized- and boiling-water reactor fuel assemblies. The inventory does not include the chromium content of stainless steel that would be stored with the waste in the waste packages. Further information on the chromium inventory is provided in Chapter 5 and in more detail in Appendix I.

Table 8-37. Total chromium in the Proposed Action and Inventory Modules 1 and 2 (kilograms).[a,b]

Inventory	Commercial SNF[c]	HLW[d]	DOE SNF	GTCC and SPAR[e]	Total
Proposed Action	11,000,000	2,100,000	380,000	0	14,000,000
Inventory Module 1	18,000,000	4,400,000	400,000	0	23,000,000
Inventory Module 2	18,000,000	4,400,000	400,000	730,000	24,000,000

a. To convert kilograms to pounds, multiply by 2.2046.
b. Totals might differ from sums due to rounding.
c. SNF = spent nuclear fuel.
d. HLW = high-level radioactive waste.
e. GTCC = Greater-Than-Class-C waste; SPAR = Special-Performance-Assessment-Required waste.

The only radionuclide that would have a relatively large inventory and a potential for gas transport is carbon-14. Iodine-129 can exist in a gas phase, but it is highly soluble and, therefore, would be likely to dissolve in groundwater rather than migrate as a gas. After the carbon-14 escaped from the waste package, it could flow through the fractured and porous rock in the form of carbon dioxide. About 2 percent of the carbon-14 in commercial spent nuclear fuel is in gas in the space (or gap) between the fuel and the cladding around the fuel (Oversby 1987, page 92). The gaseous inventory consists of 0.234 curie of carbon-14 per commercial spent nuclear fuel waste package. The additional carbon-14 activity associated with Inventory Module 2, in relation to Module 1, would be the core shrouds. The carbon-14 would result from neutron irradiation of the core shroud metal. The carbon-14 would be unlikely to be present as gaseous carbon dioxide that could be released to the environment (see Table 8-38).

Table 8-38. Total carbon-14 in the repository for the Proposed Action and Inventory Modules 1 and 2 (curies).[a]

Inventory	Solid[b]	Gaseous[c]	Total
Proposed Action	92,000	1,800	93,000
Inventory Module 1	150,000	3,200	160,000
Inventory Module 2	240,000	3,200	240,000

a. Totals might differ from sums due to rounding.
b. Impacts of carbon-14 in solid form are addressed as waterborne radioactive material impacts.
c. Based on 0.234 curies of carbon-14 per commercial spent nuclear fuel waste package.

8.3.1.2 Impacts for Inventory Module 1

The analysis included human-health impacts from Inventory Module 1 for radioactive materials and chemically toxic materials, as discussed in the following sections.

8.3.1.2.1 *Waterborne Radioactive Material Impacts*

The analysis used the modeling methods described for the Proposed Action in Chapter 5 (and in greater detail in Appendix I) to calculate the impacts for a maximally exposed individual and population resulting from groundwater releases of radioactive material for 10,000 years and 1 million years following repository closure for Inventory Module 1.

8.3.1.2.1.1 High Thermal Load Scenario. Table 8-39 lists the estimated impacts for a maximally exposed individual for the high thermal load scenario under the Proposed Action and Inventory Module 1. In general, the impacts from Module 1 would be higher by a factor ranging from 3 to 5 times the values calculated for this scenario under the Proposed Action. This increase is higher than the ratio of inventories between Module 1 and the Proposed Action. Reasons for the higher impacts include different

Table 8-39. Impacts for a maximally exposed individual from groundwater releases of radionuclides during 10,000 years after repository closure for the high thermal load scenario under the Proposed Action and Inventory Module 1.[a]

		Mean		95th-percentile	
Inventory	Maximally exposed individual	Peak dose rate[b] (millirem/year)	Probability of a LCF[c]	Peak dose rate[b] (millirem/year)	Probability of a LCF[c]
Proposed Action	At 5 kilometers[d]	0.32	1.1×10^{-5}	1.3	4.4×10^{-5}
	At 20 kilometers	0.22	7.6×10^{-6}	0.58	2.0×10^{-5}
	At 30 kilometers	0.12	4.2×10^{-6}	0.28	1.0×10^{-5}
	At 80 kilometers	0.03	1.1×10^{-6}	0.0029	1.0×10^{-7}
Inventory Module 1	At 5 kilometers	1.6	5.6×10^{-5}	5.5	1.9×10^{-4}
	At 20 kilometers	1.1	3.7×10^{-5}	2.4	8.2×10^{-5}
	At 30 kilometers	0.48	1.7×10^{-5}	0.77	2.7×10^{-5}
	At 80 kilometers	0.15	5.3×10^{-6}	0.012	3.7×10^{-7}

a. Based on 100 simulations of total system performance for each location, using random samples of uncertain parameters.

b. All peaks occur at or near 10,000 years, indicating that the dose rate would still be rising at the end of the simulation period.

c. LCF = latent cancer fatality; incremental lifetime (70 years) risk of contracting a fatal cancer, assuming a risk of 0.0005 latent cancer fatality per rem for members of the public (NCRP 1993a, page 31).

d. To convert kilometers to miles, multiply by 0.62137.

water percolation fluxes in different areas of the repository and the percolation flux impacts on the dissolution and transport of radionuclides. Appendix I, Section I.5.2, discusses these effects further.

Table 8-40 lists the impacts to the population during the first 10,000 years after repository closure for both the Proposed Action and Inventory Module 1 for the high thermal load scenario. The population impacts would be higher than the impacts for the Proposed Action under the same thermal load scenario. For example, the population dose in the 70-year period of maximum impacts would be about 5 times greater for Module 1 than for the Proposed Action at the 95th-percentile level and the same 70-year period. However, the 10,000-year integrated doses for the 95th-percentile level would be only about 2 times greater for Module 1 than for the Proposed Action.

Table 8-40. Population impacts from groundwater releases of radionuclides during 10,000 years after repository closure for the high thermal load scenario under the Proposed Action and Inventory Module 1.[a]

		Mean		95th-percentile	
Inventory	Case	Population dose (person-rem)	Population LCFs[b]	Population dose (person-rem)	Population LCFs[b]
Proposed Action	Peak 70-year lifetime	0.015	7.5×10^{-6}	0.035	1.8×10^{-5}
	Integrated over 10,000 years	0.37	1.8×10^{-4}	1.2	5.8×10^{-4}
Inventory Module 1	Peak 70-year lifetime	0.11	5.5×10^{-5}	0.18	9.0×10^{-5}
	Integrated over 10,000 years	2.6	1.3×10^{-3}	2.9	1.4×10^{-3}

a. Based on 100 simulations of total system performance for each location, using random samples of uncertain parameters.

b. LCF = latent cancer fatality; expected number of cancer fatalities for populations, assuming a risk of 0.0005 latent cancer fatality per rem for members of the public (NCRP 1993a, page 31).

The range of the increase in population impacts for Inventory Module 1 compared to the Proposed Action listed in Table 8-40 differs from the range of increase in impacts for a maximally exposed individual under Module 1 listed in Table 8-39. The major factor in the difference is the amount of contaminated groundwater associated with the Proposed Action and Module 1. The Proposed Action calculations use 27,000 cubic meters (22 acre-feet) annually in the flow tubes when calculating population dose (Appendix I, Section I.4.5.3). This amount of water is diluted in 19,000,000 cubic meters (15,400 acre-feet) of water for regional population use. The calculations for increased repository size under Module 1 use 36,000 cubic meters (29 acre-feet) of water annually in the flow tubes. This difference in water use

WHY ARE THE MEAN IMPACTS SOMETIMES HIGHER THAN THE 95TH-PERCENTILE IMPACTS?

The *mean* impact is the arithmetic average of the 100 impact results from simulations of total-system performance. The mean is not the same as the 50th-percentile value (the 50th-percentile value is called the *median*) if the distribution is *skewed*.

The performance results reported in this EIS are highly skewed. In this context, skewed indicates that there are a few impact estimates that are much larger than the rest of the impacts. When a large value is added to a group of small values, it dominates the calculation of the mean. The simulations reported in this EIS have mean impacts that are often above the 90th-percentile and occasionally above the 95th-percentile.

increases the population dose by about a factor of 2 for Inventory Module 1 over that calculated for the Proposed Action.

Table 8-41 lists the peak dose rate and time of peak for 1 million years after repository closure for both Inventory Module 1 and the Proposed Action for the high thermal load scenario. The impacts would follow the same pattern as those for the first 10,000 years after repository closure listed in Table 8-40, with the impacts for Module 1 ranging from 2 to 4 times greater than those for the Proposed Action.

Table 8-41. Impacts for a maximally exposed individual from groundwater releases of radionuclides for 1 million years after repository closure for the high thermal load scenario under the Proposed Action and Inventory Module 1.[a]

		Mean		95th-percentile	
Inventory	Maximally exposed individual	Peak dose rate (millirem/year)	Time of peak (years)	Peak dose rate (millirem/year)	Time of peak (years)
Proposed Action	At 5 kilometers[b]	1,400	296,000	9,100	320,000
	At 20 kilometers	260	336,000	1,400	364,000
	At 30 kilometers	150	418,000	820	416,000
	At 80 kilometers	54	818,000	190	716,000
Inventory Module 1	At 5 kilometers	5,300	792,000	39,000	698,000
	At 20 kilometers	930	336,000	5,600	804,000
	At 30 kilometers	480	392,000	1,700	752,000
	At 80 kilometers	160	328,000	610	742,000

a. Based on 100 simulations of total system performance for each location, using random samples of uncertain parameters.

b. To convert kilometers to miles, multiply by 0.62137.

Table 8-42 lists peak radionuclide and alpha particle concentrations in water at four locations for the high thermal load scenario under the Proposed Action and Inventory Module 1. The peak concentrations would be for 10,000 years after repository closure. The concentrations and drinking water doses would follow the same pattern as those for the first 10,000 years after repository closure listed in Table 8-40, with the results for Module 1 being commensurately greater than those for the Proposed Action. The gross alpha concentration represents the amount of alpha particle radioactivity (alpha particles are positively charged particles emitted by certain radioactive material, made up of two neutrons and two protons). The analysis derived the consequences at each distance from a different set of 100 simulations. Therefore, fluctuations in the relative concentration of specific nuclides could occur at different distances. The radionuclides that would contribute the most to individual dose over 10,000 years would be iodine-129, technetium-99, and carbon-14. The analysis based the annual drinking water doses listed in Table 8-42 (and below in Tables 8-46 and 8-50) on the assumption that an individual drinks an average of 2 liters (0.5 gallon) of water a day.

Table 8-42. Radionuclide concentrations (picocuries per liter) in water at four locations for 10,000 years after repository closure for the high thermal load scenario under the Proposed Action and Inventory Module 1.[a]

		Mean				95th-percentile			
Inventory	Radionuclide	5 km[b]	20 km	30 km	80 km	5 km	20 km	30 km	80 km
Proposed Action	Carbon-14	2.1	1.1	6.4×10^{-1}	1.8×10^{-3}	8.2	1.8	3.1	2.7×10^{-2}
	Iodine-129	1.3×10^{-1}	7.0×10^{-2}	4.1×10^{-2}	1.0×10^{-4}	5.7×10^{-1}	1.2×10^{-1}	2.0×10^{-1}	2.0×10^{-3}
	Neptunium-237	6.4×10^{-4}	2.3×10^{-8}	6.1×10^{-15}	5.6×10^{-24}	6.5×10^{-4}	1.3×10^{-17}	1.3×10^{-23}	4.2×10^{-24}
	Protactinium-231	2.9×10^{-12}	4.7×10^{-26}	4.7×10^{-26}	2.4×10^{-26}	2.0×10^{-24}	2.0×10^{-24}	1.3×10^{-26}	1.3×10^{-26}
	Plutonium-239	5.7×10^{-5}	5.6×10^{-9}	4.8×10^{-10}	1.3×10^{-13}	1.8×10^{-9}	2.4×10^{-11}	8.1×10^{-10}	2.1×10^{-17}
	Plutonium-242	3.5×10^{-7}	2.9×10^{-11}	3.1×10^{-12}	8.9×10^{-16}	1.0×10^{-11}	7.8×10^{-14}	4.5×10^{-12}	1.5×10^{-19}
	Selenium-79	3.8×10^{-1}	8.2×10^{-4}	2.4×10^{-6}	1.4×10^{-21}	1.7	1.4×10^{-18}	6.8×10^{-19}	3.2×10^{-21}
	Technetium-99	4.5×10^{1}	3.0×10^{1}	1.0×10^{1}	3.3×10^{-2}	3.9×10^{2}	8.4×10^{1}	1.3×10^{2}	8.3×10^{-1}
	Uranium-234	8.8×10^{-5}	9.0×10^{-10}	1.2×10^{-16}	2.9×10^{-23}	8.3×10^{-5}	4.4×10^{-23}	3.7×10^{-23}	3.7×10^{-23}
	Drinking water dose (millirem/ year)	8.1×10^{-2}	4.8×10^{-2}	2.0×10^{-2}	5.9×10^{-5}	5.4×10^{-1}	1.2×10^{-1}	1.8×10^{-1}	1.3×10^{-3}
	Gross alpha	7.0×10^{-4}	2.9×10^{-8}	4.8×10^{-10}	1.3×10^{-13}	6.5×10^{-4}	2.4×10^{-11}	8.1×10^{-10}	2.1×10^{-17}
Inventory Module 1	Carbon-14	1.0×10^{1}	6.3	2.5	3.9×10^{-1}	2.9×10^{1}	6.9×10^{1}	3.2	1.3×10^{-1}
	Iodine-129	7.2×10^{-1}	4.4×10^{-1}	1.6×10^{-1}	2.8×10^{-2}	1.8	4.9	2.4×10^{-1}	8.9×10^{-3}
	Neptunium-237	1.8×10^{-3}	1.8×10^{-7}	4.8×10^{-14}	7.6×10^{-23}	1.9×10^{-3}	2.5×10^{-24}	1.3×10^{-21}	4.2×10^{-24}
	Protactinium-231	1.8×10^{-13}	5.9×10^{-26}	5.9×10^{-26}	6.0×10^{-26}	2.6×10^{-24}	7.7×10^{-27}	2.5×10^{-24}	1.3×10^{-26}
	Plutonium-239	3.9×10^{-4}	1.7×10^{-7}	1.2×10^{-9}	2.4×10^{-12}	3.2×10^{-10}	3.0×10^{-11}	4.0×10^{-11}	2.8×10^{-16}
	Plutonium-242	2.4×10^{-6}	1.1×10^{-9}	7.2×10^{-12}	1.5×10^{-14}	8.8×10^{-13}	1.7×10^{-13}	8.8×10^{-14}	1.7×10^{-18}
	Selenium-79	1.6	6.5×10^{-3}	2.3×10^{-5}	6.9×10^{-21}	3.2	3.0×10^{-20}	2.1×10^{-18}	1.2×10^{-19}
	Technetium-99	2.0×10^{2}	1.3×10^{2}	5.4×10^{1}	1.7×10^{1}	1.3×10^{3}	4.6×10^{2}	1.8×10^{2}	1.5
	Uranium-234	1.8×10^{-4}	2.5×10^{-9}	4.7×10^{-16}	8.3×10^{-23}	4.3×10^{-4}	2.2×10^{-23}	5.7×10^{-23}	3.7×10^{-23}
	Drinking water dose (millirem/year)	3.9×10^{-1}	2.4×10^{-1}	9.3×10^{-2}	2.4×10^{-2}	1.8	1.6	2.5×10^{-1}	3.6×10^{-3}
	Gross alpha	2.2×10^{-3}	3.5×10^{-7}	1.2×10^{-9}	2.4×10^{-12}	1.9×10^{-3}	3.1×10^{-11}	4.0×10^{-11}	2.8×10^{-16}

a. The concentrations for the mean and 95th-percentile consequences are the concentrations that yielded the mean and 95th-percentile doses.

b. To convert kilometers (km) to miles, multiply by 0.62137.

8.3.1.2.1.2 Intermediate Thermal Load Scenario. Table 8-43 lists the estimated impacts to a maximally exposed individual from groundwater releases of radionuclides during the first 10,000 years after repository closure for the intermediate thermal load scenario under the Proposed Action and Inventory Module 1. The impacts for Module 1 would generally be a factor ranging from 2 to 11 higher than those calculated for the Proposed Action. The increase is higher than the ratio of inventories between Module 1 and the Proposed Action. Reasons for the higher impacts include different water percolation fluxes in different regions of the repository and the percolation flux impacts on the dissolution and transport of radionuclides. Appendix I, Section I.5.2, discusses these effects further.

Table 8-44 lists population impacts from groundwater releases of radionuclides during the first 10,000 years after repository closure for the intermediate thermal load scenario under the Proposed Action and Inventory Module 1. The population impacts for Inventory Module 1 would be higher than those for the Proposed Action under the same thermal load scenario. For example, the population dose in the 70-year period of maximum impacts would be about 5 times greater for Module 1 than for the Proposed Action at the 95th-percentile level. In addition, the 10,000-year integrated dose for the 95th-percentile level would be about 4 times greater for Module 1 than for the Proposed Action. Again, as for the high thermal load scenario, the range of increase in population dose differs from the range of increase for the maximally exposed individual dose because of the difference in the amount of contaminated groundwater (see Section 8.3.1.2.1.1).

Table 8-43. Impacts for a maximally exposed individual from groundwater releases of radionuclides during the 10,000 years after repository closure for the intermediate thermal load scenario under the Proposed Action and Inventory Module 1.[a]

		Mean		95th-percentile	
Inventory	Maximally exposed individual	Peak dose rate[b] (millirem/year)	Probability of a LCF[c]	Peak dose rate[b] (millirem/year)	Probability of a LCF[c]
Proposed Action	At 5 kilometers[d]	0.14	4.9×10^{-6}	1.1	3.9×10^{-5}
	At 20 kilometers	0.13	4.5×10^{-6}	0.58	2.0×10^{-5}
	At 30 kilometers	0.046	1.6×10^{-6}	0.11	3.9×10^{-6}
	At 80 kilometers	0.0029	1.0×10^{-7}	0.0019	6.6×10^{-8}
Inventory Module 1	At 5 kilometers	0.74	2.6×10^{-5}	3.4	1.2×10^{-4}
	At 20 kilometers	0.44	1.6×10^{-5}	1.5	5.1×10^{-5}
	At 30 kilometers	0.19	6.5×10^{-6}	0.34	1.2×10^{-5}
	At 80 kilometers	0.03	1.1×10^{-6}	0.0034	1.2×10^{-7}

a. Based on 100 simulations of total system performance for each location, using random samples of uncertain parameters.

b. All peaks occur at or near 10,000 years, indicating that the dose rate would still be rising at the end of the simulation period.

c. LCF = latent cancer fatality; incremental lifetime (70 years) risk of contracting a fatal cancer for individuals, assuming a risk of 0.0005 latent cancer fatality per rem for members of the public (NCRP 1993a, page 31).

d. To convert kilometers to miles, multiply by 0.62137.

Table 8-44. Population impacts from groundwater releases of radionuclides during the 10,000 years after repository closure for the intermediate thermal load scenario under the Proposed Action and Inventory Module 1.[a]

		Mean		95th-percentile	
Inventory	Case	Population dose (person-rem)	Population LCFs[b]	Population dose (person-rem)	Population LCFs[b]
Proposed Action	Peak 70-year lifetime	0.007	3.3×10^{-6}	0.017	8.3×10^{-6}
	Integrated over 10,000 years	0.13	6.7×10^{-5}	0.36	1.8×10^{-4}
Inventory Module 1	Peak 70-year lifetime	0.043	2.2×10^{-5}	0.080	4.0×10^{-5}
	Integrated over 10,000 years	1.0	5.2×10^{-4}	1.4	7.2×10^{-4}

a. Based on 100 simulations of total system performance for each location, using random samples of uncertain parameters.

b. LCF = latent cancer fatality; expected number of cancer fatalities for populations, assuming a risk of 0.0005 latent cancer fatality per rem for members of the public (NCRP 1993a, page 31).

Table 8-45 lists the peak dose rate and time of peak for 1 million years after repository closure for both Inventory Module 1 and the Proposed Action for the intermediate thermal load scenario. The impacts would follow the same pattern as those for the first 10,000 years after repository closure listed in Table 8-43, with the impacts for Module 1 being about 2 to 5 times greater than those for the Proposed Action.

Table 8-46 lists peak radionuclide and alpha particle concentrations in water at four locations for the intermediate thermal load scenario under the Proposed Action and Inventory Module 1. These concentrations would occur 10,000 years after repository closure. The concentrations and the drinking water doses would follow the same pattern as those for the first 10,000 years after repository closure listed in Table 8-43, with the results for Module 1 being commensurately greater than those for the Proposed Action. The analysis derived the consequences at each distance from a different set of 100 simulations. Therefore, fluctuations in the relative concentration of specific nuclides could occur at different distances. The radionuclides that would contribute the most to individual dose in 10,000 years would be iodine-129, technetium-99, and carbon-14.

Table 8-45. Impacts for a maximally exposed individual from groundwater releases of radionuclides during the 1 million years after repository closure for the intermediate thermal load scenario under the Proposed Action and Inventory Module 1.[a]

		Mean		95th-percentile	
Inventory	Maximally exposed individual	Peak dose rate (millirem/year)	Time of peak (years)	Peak dose rate (millirem/year)	Time of peak (years)
Proposed Action	At 5 kilometers[b]	470	296,000	2,800	320,000
	At 20 kilometers	170	804,000	900	712,000
	At 30 kilometers	91	418,000	500	932,000
	At 80 kilometers	32	872,000	120	702,000
Inventory Module 1	At 5 kilometers	2,300	698,000	15,000	342,000
	At 20 kilometers	400	336,000	2,500	712,000
	At 30 kilometers	240	422,000	1,300	752,000
	At 80 kilometers	110	334,000	330	712,000

a. Based on 100 simulations of total system performance for each location, using random samples of uncertain parameters.

b. To convert kilometers to miles, multiply by 0.62137.

Table 8-46. Radionuclide concentrations (picocuries per liter) in water and doses at four locations for the 10,000 years after closure for the intermediate thermal load scenario under the Proposed Action and Inventory Module 1.[a]

		Mean				95th-percentile			
Inventory	Radionuclide	5 km[b]	20 km	30 km	80 km	5 km	20 km	30 km	80 km
Proposed Action	Carbon-14	1.2	1.1	4.4×10^{-1}	1.6×10^{-2}	9.6	5.9	6.7×10^{-1}	4.1×10^{-2}
	Iodine-129	8.0×10^{-2}	5.5×10^{-2}	2.9×10^{-2}	1.1×10^{-3}	7.2×10^{-1}	4.3×10^{-1}	4.8×10^{-2}	2.8×10^{-3}
	Neptunium-237	9.1×10^{-5}	8.0×10^{-9}	7.5×10^{-16}	2.2×10^{-23}	1.3×10^{-6}	4.2×10^{-14}	5.1×10^{-22}	2.4×10^{-24}
	Protactinium-231	1.5×10^{-14}	5.0×10^{-26}	3.8×10^{-26}	3.8×10^{-26}	1.2×10^{-26}	1.6×10^{-24}	1.6×10^{-24}	7.6×10^{-27}
	Plutonium-239	6.9×10^{-6}	3.2×10^{-9}	2.4×10^{-10}	7.0×10^{-13}	6.3×10^{-10}	3.0×10^{-10}	2.7×10^{-12}	2.5×10^{-11}
	Plutonium-242	4.8×10^{-8}	2.2×10^{-11}	1.4×10^{-12}	4.8×10^{-15}	3.5×10^{-12}	1.8×10^{-12}	9.3×10^{-15}	1.7×10^{-13}
	Selenium-79	9.4×10^{-2}	4.3×10^{-4}	2.6×10^{-6}	2.0×10^{-21}	5.0×10^{-1}	1.8×10^{-18}	1.3×10^{-18}	3.1×10^{-21}
	Technetium-99	2.1×10^{1}	1.7×10^{1}	4.5	3.7×10^{-1}	4.3×10^{2}	1.8×10^{2}	1.7×10^{1}	1.1
	Uranium-234	1.9×10^{-5}	4.0×10^{-11}	7.8×10^{-17}	2.9×10^{-23}	1.3×10^{-7}	6.3×10^{-16}	2.9×10^{-23}	2.1×10^{-23}
	Drinking water dose (millirem/ year)	4.1×10^{-2}	3.1×10^{-2}	1.1×10^{-2}	6.5×10^{-4}	6.2×10^{-1}	2.9×10^{-1}	2.9×10^{-2}	1.8×10^{-3}
	Gross alpha	9.8×10^{-5}	1.1×10^{-8}	2.4×10^{-10}	7.0×10^{-13}	1.3×10^{-6}	3.1×10^{-10}	2.7×10^{-12}	2.5×10^{-11}
Inventory Module 1	Carbon-14	4.7	3.7	1.4	1.1×10^{-1}	2.7×10^{1}	4.3×10^{1}	1.8	2.7×10^{-2}
	Iodine-129	3.1×10^{-1}	2.6×10^{-1}	9.9×10^{-2}	7.8×10^{-3}	1.9	3.1	1.3×10^{-1}	2.0×10^{-3}
	Neptunium-237	1.6×10^{-3}	5.1×10^{-8}	1.5×10^{-14}	9.3×10^{-23}	3.4×10^{-6}	8.6×10^{-24}	9.9×10^{-22}	3.4×10^{-24}
	Protactinium-231	2.2×10^{-12}	3.0×10^{-25}	7.4×10^{-26}	7.7×10^{-26}	2.7×10^{-23}	1.1×10^{-26}	3.3×10^{-24}	1.1×10^{-26}
	Plutonium-239	1.8×10^{-4}	7.1×10^{-8}	1.9×10^{-9}	1.2×10^{-12}	1.5×10^{-9}	7.4×10^{-12}	9.2×10^{-12}	3.0×10^{-12}
	Plutonium-242	1.1×10^{-6}	4.5×10^{-10}	8.7×10^{-12}	8.0×10^{-15}	8.4×10^{-12}	4.1×10^{-14}	2.5×10^{-14}	1.7×10^{-14}
	Selenium-79	1.2	2.5×10^{-3}	2.0×10^{-5}	1.0×10^{-20}	4.6	2.8×10^{-17}	3.2×10^{-18}	3.4×10^{-20}
	Technetium-99	1.0×10^{2}	4.7×10^{1}	1.5×10^{1}	3.1	1.3×10^{3}	2.9×10^{2}	7.5×10^{1}	9.0×10^{-1}
	Uranium-234	1.1×10^{-4}	8.1×10^{-10}	4.8×10^{-16}	6.1×10^{-23}	5.5×10^{-7}	3.0×10^{-23}	7.1×10^{-23}	3.0×10^{-23}
	Drinking water dose (millirem/year)	1.9×10^{-1}	1.1×10^{-1}	3.8×10^{-2}	5.0×10^{-3}	1.8	9.9×10^{-1}	1.1×10^{-1}	1.4×10^{-3}

a. The concentrations for the mean and 95th-percentile consequences are those that would yield the mean and 95th-percentile doses.

b. To convert kilometers (km) to miles, multiply by 0.62137.

8.3.1.2.1.3 Low Thermal Load Scenario. Table 8-47 lists the estimated impacts to a maximally exposed individual from groundwater releases of radionuclides during the first 10,000 years after repository closure for the low thermal load scenario under the Proposed Action and Inventory Module 1. The impacts for Module 1 would be nearly the same to 3 times greater compared to those calculated for this scenario under the Proposed Action.

Table 8-47. Impacts for a maximally exposed individual from groundwater releases of radionuclides during the 10,000 years after repository closure for the low thermal load scenario under the Proposed Action and Inventory Module 1.[a]

		Mean		95th-percentile	
Inventory	Maximally exposed individual	Peak dose rate[b] (millirem/year)	Probability of a LCF[c]	Peak dose rate[b] (millirem/year)	Probability of a LCF[c]
Proposed Action	At 5 kilometers[d]	0.13	4.7×10^{-6}	0.16	5.6×10^{-6}
	At 20 kilometers	0.059	2.1×10^{-6}	0.061	2.1×10^{-6}
	At 30 kilometers	0.040	1.4×10^{-6}	0.023	8.1×10^{-7}
	At 80 kilometers	0.00053	1.9×10^{-8}	0.0019	6.6×10^{-8}
Inventory Module 1	At 5 kilometers	0.21	7.5×10^{-6}	0.25	8.8×10^{-6}
	At 20 kilometers	0.12	4.1×10^{-6}	0.12	4.2×10^{-6}
	At 30 kilometers	0.086	3.0×10^{-6}	0.069	2.4×10^{-6}
	At 80 kilometers	0.00066	2.3×10^{-8}	0.0041	1.4×10^{-7}

a. Based on 100 simulations of total system performance for each location, using random samples of uncertain parameters.

b. All peaks occur at or near 10,000 years, indicating that the dose rate would still be rising at the end of the simulation period.

c. LCF = latent cancer fatality; incremental lifetime (70 years) risk of contracting a fatal cancer for individuals and expected number of cancer fatalities for populations, assuming a risk of 0.0005 latent cancer fatality per rem for members of the public (NCRP 1993a, page 31).

d. To convert kilometers to miles, multiply by 0.62137.

Table 8-48 lists population impacts from groundwater releases of radionuclides during the first 10,000 years after repository closure for the low thermal load scenario under the Proposed Action and Inventory Module 1. The population impacts for Module 1 would be higher than those for the Proposed Action under the same thermal load scenario. For example, the population dose in the 70-year period of maximum impacts would be about 6 times greater for Module 1 than for the Proposed Action at the 95th-percentile level. In addition, the 10,000-year integrated dose for the 95th-percentile level would be about 7 times greater for Module 1 than for the Proposed Action. Again, as for the high thermal load scenario, the range of increase in population dose differs from the range of increase for the maximally exposed individual dose because of the difference in the amount of contaminated groundwater (see Section 8.3.1.2.1.1).

Table 8-48. Population impacts from groundwater releases of radionuclides during the 10,000 years after repository closure for the low thermal load scenario under the Proposed Action and Inventory Module 1.[a]

		Mean		95th-percentile	
Inventory	Case	Population dose (person-rem)	Population LCFs[b]	Population dose (person-rem)	Population LCFs[b]
Proposed Action	Peak 70-year lifetime	0.001	5.3×10^{-6}	0.0062	3.1×10^{-6}
	Integrated over 10,000 years	0.27	1.3×10^{-4}	0.12	6.0×10^{-5}
Inventory Module 1	Peak 70-year lifetime	0.048	2.4×10^{-5}	0.039	1.9×10^{-5}
	Integrated over 10,000 years	1.0	5.2×10^{-4}	0.83	4.2×10^{-4}

a. Based on 100 simulations of total system performance for each location, using random samples of uncertain parameters.

b. LCF = latent cancer fatality; incremental lifetime (70 years) risk of contracting a fatal cancer for individuals and expected number of cancer fatalities for populations, assuming a risk of 0.0005 latent cancer per rem for members of the public (NCRP 1993a, page 31).

Table 8-49 lists the peak dose rate and time of peak for 1 million years after repository closure for both Inventory Module 1 and the Proposed Action for the low thermal load scenario. The impacts would follow the same pattern as those for the first 10,000 years after repository closure listed in Table 8-23, with the impacts for Module 1 being approximately the same to 3 times greater than those for the Proposed Action.

Table 8-49. Impacts for a maximally exposed individual from groundwater releases of radionuclides during 1 million years after repository closure for the low thermal load scenario under the Proposed Action and Inventory Module 1.[a]

		Mean		95th-percentile	
Inventory	Maximally exposed individual	Peak dose rate (millirem/year)	Time of peak (years)	Peak dose rate (millirem/year)	Time of peak (years)
Proposed Action	At 5 kilometers[b]	630	296,000	3,600	320,000
	At 20 kilometers	160	804,000	860	334,000
	At 30 kilometers	73	400,000	360	308,000
	At 80 kilometers	44	824,000	160	726,000
Inventory Module 1	At 5 kilometers	1,100	296,000	9,100	342,000
	At 20 kilometers	200	336,000	1,200	804,000
	At 30 kilometers	130	398,000	680	308,000
	At 80 kilometers	43	946,000	170	746,000

a. Based on 100 simulations of total system performance for each location, using random samples of uncertain parameters.

b. To convert kilometers to miles, multiply by 0.62137.

Table 8-50 lists peak radionuclide and alpha particle concentrations in water at four locations for the low thermal load scenario under the Proposed Action and Inventory Module 1. The peak concentrations would be for 10,000 years after repository closure. The concentrations and the drinking water doses

Table 8-50. Radionuclide concentrations (picocuries per liter) in water and doses at four locations for 10,000 years after closure for the low thermal load scenario under the Proposed Action and Inventory Module 1.

		Mean[a]				95th-percentile			
Inventory	Radionuclide	5 km[b]	20 km	30 km	80 km	5 km	20 km	30 km	80 km
Proposed Action	Carbon-14	1.6	7.9×10^{-1}	4.0×10^{-1}	6.7×10^{-3}	5.6	5.9	2.1×10^{-1}	3.1×10^{-2}
	Iodine-129	1.0×10^{-1}	5.0×10^{-2}	2.3×10^{-2}	4.8×10^{-4}	4.0×10^{-1}	1.5×10^{-1}	1.8×10^{-25}	2.4×10^{-3}
	Neptunium-237	7.3×10^{-4}	9.3×10^{-12}	2.2×10^{-16}	9.1×10^{-23}	1.4×10^{-6}	4.0×10^{-12}	7.1×10^{-25}	7.1×10^{-25}
	Protactinium-231	1.4×10^{-16}	2.6×10^{-24}	7.8×10^{-26}	7.9×10^{-26}	1.6×10^{-16}	7.7×10^{-27}	2.2×10^{-27}	2.2×10^{-27}
	Plutonium-239	9.4×10^{-5}	2.4×10^{-9}	1.1×10^{-9}	6.5×10^{-13}	2.5×10^{-13}	7.7×10^{-16}	4.0×10^{-14}	7.7×10^{-13}
	Plutonium-242	6.9×10^{-7}	1.6×10^{-11}	5.5×10^{-12}	4.5×10^{-15}	3.2×10^{-16}	4.3×10^{-18}	2.8×10^{-16}	5.5×10^{-15}
	Selenium-79	2.7×10^{-1}	4.4×10^{-6}	8.9×10^{-12}	7.8×10^{-22}	3.2	1.8×10^{-7}	1.7×10^{-21}	1.6×10^{-20}
	Technetium-99	1.7×10^{1}	7.3	4.5	7.2×10^{-2}	1.9	1.4×10^{1}	6.3	3.4×10^{-1}
	Uranium-234	3.1×10^{-6}	1.5×10^{-12}	4.1×10^{-16}	1.5×10^{-23}	2.0×10^{-7}	6.7×10^{-11}	6.2×10^{-24}	6.2×10^{-24}
	Drinking water dose (millirem/year)	4.4×10^{-2}	1.9×10^{-2}	1.0×10^{-2}	1.8×10^{-4}	9.5×10^{-2}	5.3×10^{-2}	7.0×10^{-3}	9.1×10^{-4}
	Gross alpha	8.2×10^{-4}	1.4×10^{-9}	1.1×10^{-9}	6.6×10^{-13}	1.4×10^{-6}	4.0×10^{-12}	4.0×10^{-14}	7.7×10^{-13}
Inventory Module 1	Carbon-14	2.7×10^{-0}	1.4×10^{0}	8.9×10^{-1}	1.1×10^{-2}	6.4×10^{0}	4.2	4.9×10^{-1}	5.6×10^{-2}
	Iodine-129	1.7×10^{-1}	1.0×10^{-1}	6.3×10^{-2}	7.2×10^{-4}	4.6×10^{-1}	2.9×10^{-1}	3.6×10^{-2}	2.9×10^{-3}
	Neptunium-237	1.7×10^{-3}	5.3×10^{-12}	8.5×10^{-17}	1.0×10^{-21}	1.4×10^{-9}	6.0×10^{-11}	1.7×10^{-24}	1.7×10^{-24}
	Protactinium-231	8.2×10^{-18}	8.6×10^{-25}	8.0×10^{-26}	8.3×10^{-26}	5.4×10^{-27}	5.4×10^{-27}	5.4×10^{-27}	5.4×10^{-27}
	Plutonium-239	6.1×10^{-4}	1.5×10^{-8}	1.0×10^{-9}	2.0×10^{-12}	7.8×10^{-16}	9.3×10^{-14}	9.8×10^{-14}	5.1×10^{-16}
	Plutonium-242	3.4×10^{-6}	1.2×10^{-10}	4.6×10^{-12}	1.4×10^{-14}	4.0×10^{-18}	6.3×10^{-16}	6.9×10^{-16}	3.3×10^{-18}
	Selenium-79	4.8×10^{-1}	2.2×10^{-4}	7.5×10^{-10}	1.5×10^{-21}	5.6×10^{0}	1.2×10^{-18}	2.1×10^{-21}	3.6×10^{-21}
	Technetium-99	1.5×10^{1}	9.5×10^{0}	8.9×10^{0}	1.6×10^{-1}	2.0×10^{1}	1.3×10^{1}	1.4×10^{1}	3.2×10^{-1}
	Uranium-234	9.1×10^{-6}	3.6×10^{-12}	8.3×10^{-16}	2.7×10^{-23}	6.3×10^{-8}	1.5×10^{-23}	1.5×10^{-23}	1.5×10^{-23}
	Drinking water dose (millirem/year)	6.1×10^{-2}	3.3×10^{-8}	2.3×10^{-2}	3.3×10^{-4}	1.3×10^{-1}	7.9×10^{-2}	2.3×10^{-2}	1.0×10^{-3}
	Gross alpha	2.3×10^{-3}	1.5×10^{-8}	1.0×10^{-9}	2.0×10^{-12}	1.4×10^{-9}	6.0×10^{-11}	9.9×10^{-14}	5.1×10^{-16}

a. The concentrations for the mean and 95th-percentile consequences would be those that yielded the mean and 95th-percentile doses.

b. To convert kilometers (km) to miles, multiply by 0.62137.

would follow the same pattern as for the first 10,000 years after repository closure listed in Table 8-47, with the results for Module 1 being commensurately greater than those for the Proposed Action. The analysis derived the consequences at each distance from a different set of 100 simulations. Therefore, fluctuations in the relative concentration of specific nuclides could occur at different distances. The radionuclides that would contribute the most to individual dose in 10,000 years would be iodine-129, technetium-99, and carbon-14.

8.3.1.2.2 *Waterborne Chemically Toxic Material Impacts*

The Proposed Action impacts described in Chapter 5, Section 5.6.3, for uranium would be about 100,000 times smaller than a threshold concentration based on the reference dose for elemental uranium of 0.003 milligram per kilogram per day (EPA 1999d, all). The Environmental Protection Agency has not established a Maximum Contaminant Level Goal for elemental uranium. The 70-percent increase in uranium inventory for Inventory Module 1 (see Table 8-36) would still result in impacts that were much smaller than the threshold concentration. Therefore, uranium would not present a substantial impact as a chemically toxic material under Module 1.

Using the modeling methods described in Chapter 5 (and in greater detail in Appendix I), DOE analyzed the impacts of chromium as a chemically toxic material for Inventory Module 1. The analysis included all four receptor locations under all three thermal load scenarios for Module 1. Table 8-51 lists results for the first 10,000 years after repository closure under Module 1. The calculated chromium concentrations ranged from about the same to 8 times greater for Module 1 compared to the Proposed Action.

There are two possible comparisons for human health effects for chromium. The Environmental Protection Agency considered safe levels of contaminants in drinking water and the ability to achieve these levels with the best available technology when it established its Maximum Contaminant Level Goals. The Maximum Contaminant Level Goal for chromium is 0.1 milligram per liter (0.0000062 pound per cubic foot) (40 CFR Part 141.51). The other measure for comparison is the reference dose factor for chromium, which is 0.005 milligram per kilogram (0.0004 ounce per pound) of body mass per day (EPA 1998b, all). The reference dose factor represents a level of intake that has no adverse effect on humans. It can be converted to a threshold concentration level for drinking water. The conversion yields essentially the same concentration for the reference dose factor as the Maximum Contaminant Level Goal.

The analysis did not evaluate the groundwater concentrations listed in Table 8-51 for human health effects (for example, latent cancer fatalities) because there is insufficient epidemiological or toxicological data to determine the carcinogenic potency of hexavalent chromium by the oral route of exposure (EPA 1998a, page 48). (Soluble chromium occurs in the hexavalent form; see Appendix I.)

The Alloy-22 that would be used as a corrosion-resistant inner layer of the waste package contains 13.5 percent molybdenum. There is no established toxicity standard for molybdenum (in particular, the Environmental Protection Agency has not established a Maximum Contaminant Level Goal for molybdenum). This does not mean that molybdenum is not toxic, only that there is no standard of toxicity.

During the corrosion of the Alloy-22, molybdenum would behave almost the same as the chromium. Due to the corrosion conditions, molybdenum would dissolve in a highly soluble hexavalent form. Therefore, the source term for molybdenum would be 0.614 times the source term for chromium (the ratio of molybdenum inventory to chromium inventory). All the mechanisms and parameters would be the same

Table 8-51. Peak chromium groundwater concentrations (milligram per liter)[a] for 10,000 years after closure at four locations for high, intermediate, and low thermal load scenarios under the Proposed Action and Inventory Module 1.[b]

Inventory	Thermal load scenario	Maximally exposed individual	Mean	95th-percentile
Proposed Action	High	At 5 kilometers[c]	0.0085	0.037
		At 20 kilometers	0.0028	0.012
		At 30 kilometers	0.0018	0.0063
		At 80 kilometers	0.00022	0.00061
	Intermediate	At 5 kilometers	0.0029	0.0096
		At 20 kilometers	0.0023	0.010
		At 30 kilometers	0.00080	0.0038
		At 80 kilometers	0.000031	0.00015
	Low	At 5 kilometers	0.0046	0.016
		At 20 kilometers	0.0018	0.0083
		At 30 kilometers	0.00067	0.0033
		At 80 kilometers	0.000053	0.00034
Inventory Module 1	High	At 5 kilometers	0.032	0.14
		At 20 kilometers	0.018	0.10
		At 30 kilometers	0.0057	0.027
		At 80 kilometers	0.00029	0.00070
	Intermediate	At 5 kilometers	0.023	0.083
		At 20 kilometers	0.0089	0.042
		At 30 kilometers	0.0032	0.017
		At 80 kilometers	0.00019	0.00057
	Low	At 5 kilometers	0.0093	0.035
		At 20 kilometers	0.0050	0.022
		At 30 kilometers	0.0020	0.0084
		At 80 kilometers	0.000074	0.00026

a. To convert from milligram per liter to pounds per cubic foot, multiply by 0.0000624.

b. Based on 100 simulations of total system performance, using random samples of uncertain parameters.

c. To convert kilometers to miles, multiply by 0.62137.

as those for chromium, so modeling is unnecessary. The analysis assumed that molybdenum would be present in the water at concentrations 0.614 times those reported in Table 8-51 for chromium.

8.3.1.2.3 *Atmospheric Radioactive Material Impacts*

Using the analysis methods described in Section 5.5, DOE estimated the impacts of carbon-14 releases to the atmosphere for Inventory Module 1. Table 8-52 compares these findings to the Proposed Action

Table 8-52. Atmospheric radioactive material impacts for carbon-14.

			For local population within 84 kilometers[a]		
Inventory	Maximum release rate (microcurie per year)	Time of maximum release (years after closure)	Maximum individual dose rate (rem per year)	Maximum population dose (person-rem)	Maximum population LCFs[b]
Proposed Action	0.098	19,000	7.8×10^{-15}	2.2×10^{-10}	1.1×10^{-13}
Inventory Module 1	0.11	27,000	8.8×10^{-15}	2.4×10^{-10}	1.2×10^{-13}

a. 84 kilometers = about 52 miles.

b. LCF = latent cancer fatality; incremental lifetime (70 years) risk of contacting a fatal cancer for individuals and expected number of cancer fatalities for populations, assuming a risk of 0.0005 latent cancer fatality per rem for members of the public (NCRP 1993a, page 31).

carbon-14 impacts. The important difference in the atmospheric carbon-14 impacts for Module 1 and for the Proposed Action is that the number of waste packages containing spent nuclear fuel would increase by approximately 67 percent, providing more carbon-14 for atmospheric release.

The estimated maximum release rate to the air for gaseous-phase carbon-14 would be 0.11 microcurie a year, about 27,000 years after repository closure. This compares to a release rate of 0.098 microcurie per year about 19,000 years after repository closure for the Proposed Action. The 0.11 microcurie-per-year release corresponds to an 8.8×10^{-15} rem-per-year average dose to individuals within 80 kilometers (50 miles). The maximum population dose to the 28,000 people within 80 kilometers would be 2.4×10^{-10} person-rem. This dose rate corresponds to 1.2×10^{-13} latent cancer fatality at the maximum release rate of carbon-14. Over a 70-year period, which corresponds to a lifetime for an individual, this annual dose rate yields a dose of 1.7×10^{-8} rem, corresponding to 8.5×10^{-12} latent cancer fatality during the 70-year period of the maximum release rate. In general, the impacts would be about 13 percent higher for Inventory Module 1 than for the Proposed Action.

8.3.1.3 INCREMENTAL IMPACTS FOR INVENTORY MODULE 2

DOE addressed the long-term consequences from Inventory Module 2 by analyzing the effects of disposing waste packages containing Greater-Than-Class-C and Special-Performance-Assessment-Required wastes in addition to the material in Inventory Module 1. Table 8-35 lists the average inventory of the additional waste packages containing Greater-Than-Class-C and Special-Performance-Assessment-Required wastes. The following sections discuss these impacts in terms of waterborne radioactive releases, chemically toxic materials waterborne release, and atmospheric radioactive material releases.

8.3.1.3.1 *Waterborne Radioactive Material Impacts*

The addition of Greater-Than-Class-C and Special-Performance-Assessment-Required wastes is the only difference between Inventory Modules 1 and 2. Therefore, a complete repetition of the total systems modeling to evaluate the impacts attributable to adding these wastes was unnecessary. Rather, DOE (1998a, Volume 3, pages 2-40 to 2-41) performed a single *expected-value* simulation (using the mean of every probabilistic input parameter) for each thermal load scenario and location, specifying only the Greater-Than-Class-C and Special-Performance-Assessment-Required waste as the radionuclide inventory. The results of these expected-value simulations constitute the additional impacts of Inventory Module 2 over those of Module 1. In addition, they represent the dose attributable solely to the Greater-Than-Class-C and Special-Performance-Assessment-Required waste. By contrasting the expected-value simulation results for Module 2 to the comparable expected-value results for Module 1, the analysis estimated the incremental impact.

Table 8-53 lists the incremental (that is, the increase in) consequences for a maximally exposed individual from the Greater-Than-Class-C and Special-Performance-Assessment-Required wastes in Inventory Module 2 during 10,000 years and 1 million years following repository closure. The increases in Table 8-53 are expressed in terms of the percent increase in peak dose to the maximally exposed individual. Peak impacts from waterborne radioactive materials for Module 2 would be less than 2 percent higher for the first 10,000 years after repository closure and less than one-half of one percent higher for the first 1 million years after repository closure compared to Module 1. Therefore, the waterborne radioactive material impacts for Modules 1 and 2 are essentially equivalent in both periods.

8.3.1.3.2 *Waterborne Chemically Toxic Material Impacts*

The Proposed Action impacts described in Section 5.6.3 for uranium would be about 100,000 times smaller than a threshold concentration based on the reference dose for elemental uranium of 0.003

Table 8-53. Percentage increase in peak dose rate under Inventory Module 2 over the peak dose rate under Inventory Module 1 for a maximally exposed individual during 10,000 and 1 million years after repository closure.

Postclosure period	Maximally exposed individual	Thermal load High	Thermal load Intermediate	Thermal load Low
10,000 years	At 5 kilometers[a]	1.8	0.70	0
	At 20 kilometers	1.6	0.55	0
	At 30 kilometers	0.99	0.0033	0
	At 80 kilometers	0	0	0
1,000,000 years	At 5 kilometers	0.0015	0.0018	0.0069
	At 20 kilometers	0.0043	0.0025	0.0024
	At 30 kilometers	0.0030	0.0046	0.0044
	At 80 kilometers	0.30	0.34	0.29

a. To convert kilometers to miles, multiply by 0.62137.

milligram per kilogram per day (EPA 1999d, all). The Environmental Protection Agency has not established a Maximum Contaminant Level Goal for elemental uranium. The 70-percent increase in the uranium inventory for Inventory Module 2 (see Table 8-36) would result in impacts that would be much smaller than those for the threshold concentration. Therefore, uranium would not present a substantial impact as a chemically toxic material under Module 2.

Using the same modeling methods as those described in Chapter 5 (and in greater detail in Appendix I), the analysis calculated the impacts of chromium as a chemically toxic material for Inventory Module 2. Just as with the radioactive waterborne impacts, the chromium impacts for Module 2 were modeled as an incremental impact over Module 1 using *expected-value* simulations. Table 8-54 lists the results for the first 10,000 years after repository closure in terms of the percentage increase in chromium concentrations at the various well locations over Module 1 impacts.

Table 8-54. Percentage increase in peak chromium groundwater concentrations (milligrams per liter)[a] under Inventory Module 2 over the peak chromium groundwater concentrations for Inventory Module 1 for 10,000 years after repository closure.

Postclosure period	Maximally exposed individual	Thermal load High	Thermal load Intermediate	Thermal load Low
10,000 years	At 5 kilometers[b]	4.5	4.8	15.
	At 20 kilometers	4.5	4.5	4.4
	At 30 kilometers	4.5	4.4	4.3
	At 80 kilometers	4.1	1.5	5.4

a. To convert from milligram per liter to pounds per cubic foot, multiply by 0.0000624.

b. To convert kilometers to miles, multiply by 0.62137.

There are two possible comparisons for human health effects for chromium. The Environmental Protection Agency considered safe levels of contaminants in drinking water and the ability to achieve these levels with the best available technology when it established its Maximum Contaminant Level Goals. The Maximum Contaminant Level Goal for chromium is 0.1 milligram per liter (0.0000062 pound per cubic foot) (40 CFR Part 141.51). The other measure for comparison is the reference dose factor for chromium, which is 0.005 milligram per kilogram (0.0004 ounce per pound) of body mass per day (EPA 1998a, all). The reference dose factor represents a level of intake that has no adverse effect on humans. It can be converted to a threshold concentration level for drinking water. The conversion yields essentially the same concentration for the reference dose factor as the Maximum Contaminant Level Goal.

The analysis made no attempt to express the groundwater concentrations listed in Table 8-54 in terms of human health effects (for example, latent cancer fatalities) because there is a lack of sufficient epidemiological or toxicological data for determining the carcinogenicity of hexavalent chromium by the oral route of exposure (EPA 1998a, page 48) [soluble chromium occurs in the hexavalent form (see Appendix I)].

The Alloy-22 that would be used as a corrosion resistant inner layer of the waste package contains 13.5 percent molybdenum. There is no established toxicity standard for molybdenum (in particular, the Environmental Protection Agency has not established a Maximum Contaminant Level Goal for molybdenum). This does not mean that molybdenum is not toxic, only that there is no standard of toxicity.

During the corrosion of the Alloy-22, molybdenum would behave almost the same as the chromium. Due to the corrosion conditions, molybdenum would dissolve in a highly soluble hexavalent form. Therefore, the source term for molybdenum would be 0.614 times the source term for chromium (the ratio of molybdenum inventory to chromium inventory). All the mechanisms and parameters would be the same as those for chromium, so modeling is unnecessary. The analysis assumed that molybdenum would be present in the water at concentrations 0.614 times those listed in Table 8-54 for chromium.

8.3.1.3.3 *Atmospheric Radioactive Material Impacts*

DOE did not perform detailed analyses of impacts from atmospheric releases of carbon-14 for Inventory Module 2. While the waste packages that would be in addition to those for Module 1 would have an average carbon-14 inventory about triple that of the average waste package of commercial spent nuclear fuel, very little of the additional carbon-14 would be in gaseous form (see Table 8-38). This is because only commercial spent nuclear fuel waste packages contain a relatively large amount of gaseous carbon-14, and Module 2 includes the same number of commercial spent nuclear fuel packages as Module 1. The waste packages containing Greater-Than-Class-C waste and Special-Performance-Assessment-Required wastes that would not contain large quantities of gaseous carbon-14. Therefore, the atmospheric radioactive material impacts for Module 2 would be essentially the same as those for Module 1.

8.3.2 CUMULATIVE IMPACTS FROM INVENTORY MODULE 1 OR 2 AND OTHER FEDERAL, NON-FEDERAL, AND PRIVATE ACTIONS

This section discusses potential cumulative impacts from other Federal, non-Federal, and private actions that could contribute to doses at the locations considered in the performance assessment of the Yucca Mountain Repository. The actions identified with the potential for long-term cumulative impacts are past, present, and reasonably future actions at the Nevada Test Site and past actions at the low-level radioactive waste disposal facility near Beatty, Nevada.

8.3.2.1 Past, Present, and Reasonably Foreseeable Future Actions at the Nevada Test Site

Historically, the primary mission of the Nevada Test Site was to conduct nuclear weapons tests. Nuclear weapons testing and other activities have resulted in radioactive contamination and have the potential for radioactive and nonradioactive contamination of some areas of the Nevada Test Site. These areas and the associated contamination and the potential for contamination were evaluated for potential cumulative impacts with postclosure impacts from the proposed Yucca Mountain Repository. This section discusses these Nevada Test Site activities, the locations where these activities occurred, and the potential for cumulative long-term impacts with the repository.

Unless otherwise identified, DOE derived the information in this section from the Nevada Test Site Final EIS (DOE 1996f, all). The Yucca Mountain Repository site is in the southwestern portion of the Nevada Test Site along its western boundary, as shown in Figure 8-3.

At the Nevada Test Site, seven categories of activities have resulted in radioactive contamination or have the potential to result in radioactive and nonradioactive contamination:

1. *Atmospheric Weapons Testing.* One hundred atmospheric detonations occurred before the signing of the Limited Test Ban Treaty in August 1963. Atmospheric tests included detonations at ground level, from towers or balloons, or from airdrops.

2. *Underground Nuclear Testing.* Approximately 800 underground nuclear tests have occurred at the Nevada Test Site. Figure 8-3 shows the locations of these tests in relation to Yucca Mountain. They included deep underground tests to study weapons effects, designs, safety, and reliability, and shallow underground tests to study the peaceful application of nuclear devices for cratering.

3. *Safety Tests.* Between 1954 and 1963, 16 above-ground tests studied the vulnerability of weapons designs to possible accident scenarios.

4. *Nuclear Rocket Development Station.* Twenty-six experimental tests of reactors, nuclear engines, ramjets, and nuclear furnaces occurred between 1959 and 1973. Figure 8-3 shows the location of the Nuclear Rocket Development Station.

5. *Shallow Land Radioactive Waste Disposal.* DOE disposed of some radioactive waste generated during the testing in shallow cells, pits, and trenches. Because of the site characteristics, notably the absence of a groundwater pathway, shallow burial continues to be an important waste disposal activity at the Nevada Test Site. Section 8.3.2.1.3 discusses present and potential future low-level radioactive waste disposal activities.

6. *Crater Disposal.* DOE disposed of contaminated soils and equipment collected during the decontamination of atmospheric testing areas and the consolidation of radioactively contaminated structures, and other bulk wastes, in subsidence craters at Yucca Flat in Area 3. Figure 8-3 shows the location of the Area 3 Radioactive Waste Management Site.

7. *Greater Confinement Disposal.* In 1981, greater confinement disposal began at Area 5 for low-level radioactive wastes not suitable for shallow land disposal. Figure 8-3 shows the location of the Area 5 Radioactive Waste Management Site.

Table 8-55 lists the approximate inventory for each of these categories. The unimportance of several categories is apparent; atmospheric testing, shallow underground testing, safety testing, and nuclear rocket development all resulted in a less-than-40-curie source term. Additionally, the inventories represented by crater disposal and shallow-land disposal were determined to not be important to cumulative impact considerations. Only the deep underground testing and greater confinement disposal categories represent substantial inventories that could, when combined with the repository inventory, result in increased cumulative impacts.

8.3.2.1.1 *Underground Nuclear Testing*

Declassification of the summed radionuclide source term (total radioactivity of all radionuclides) that remains within 100 meters (330 feet) of the water table has enabled an updated estimate of the total radionuclide source term remaining below the ground surface as a result of underground testing. As of

Table 8-55. Summary of radioactivity on the Nevada Test Site (January 1996).[a]

Source	Area	Environmental media	Major known isotopes or wastes	Depth range	Approximate inventory (curies)
Atmospheric weapons testing	Aboveground nuclear weapon proving area	Surficial soils and test structures	Americium, cesium, cobalt, plutonium, europium, strontium	At land surface	20
Underground testing: shallow underground tests	Underground nuclear testing areas	Soils and alluvium	Americium, cesium, cobalt, europium, plutonium, strontium	Less than 61 meters[b]	1 at land surface; unknown at depth
Underground testing: deep underground tests	Underground nuclear testing areas	Soils, alluvium, and consolidated rock	Tritium, fission, and activation products	Typically less than 640 meters, but might be deeper	More than 300 million, approximately 110 million are below or within 100 meters (330 feet) above the water table and are available for groundwater transport
Safety tests	Aboveground experimental areas	Surficial soils	Americium, cesium, cobalt, plutonium, strontium	Less than 0.9 meter	35
Nuclear rocket development area	Nuclear rocket motor, reactor, and furnace testing area	Surficial soils	Cesium, strontium	Less than 3 meters	1
Shallow land disposal	Waste disposal landfills	Soils and alluvium	Dry-packaged low-level and mixed wastes	Less than 9 meters	500,000[c,d]
Crater disposal	Test-induced subsidence crater with sidewalls, cover, and drainage	Soils and alluvium	Bulk contaminated soils and equipment	Less than 30 meters	1,250[c,e]
Greater confinement disposal	Monitored underground waste disposal	Soils and alluvium	Tritium, americium	37 meters	9.3 million[c,f]

a. Source: DOE (1996f, page 4-6).
b. To convert meters to feet, multiply by 3.2808.
c. Inventory at time of disposal (not corrected for decay).
d. Inventory does not include prospective future low-level radioactive and mixed waste disposal (see Section 8.3.2.1.3).
e. Volume of waste considered for inventory was approximately 205,000 cubic meters (7.25 million cubic feet).
f. Volume of waste considered for inventory was approximately 300 cubic meters (10,000 cubic feet).

January 1, 1994, the estimated total radionuclide source term for all tests was 300 million curies (DOE 1996f, page 4-85). Of that amount, an estimated 110 million curies were below or within about 100 meters (330 feet) above the water table (DOE 1996f, page 4-126). There is some uncertainty related to the Nevada Test Site estimates; the Nevada Test Site EIS contains additional details on the development of the estimated total source term from underground nuclear tests (DOE 1996f, pages 4-126 to 4-130). There is recent evidence of plutonium migration from one underground test. Groundwater monitoring results indicate that plutonium has migrated about 1.3 kilometers (0.8 mile), possibly facilitated by the movement of very small and relatively mobile particles called *colloids* in the groundwater (Kersting et al.

1999, page 59). No radioactive contamination attributable to underground tests has been detected in monitoring wells off the Nevada Test Site. DOE is conducting further monitoring and research to study these and other potential radionuclide migration phenomenon.

The above information indicates that groundwater could transport radionuclides produced during underground nuclear tests at the Nevada Test Site. This transport could ultimately result in releases from underground testing at the same sites analyzed for releases from the repository in this EIS. Long-term performance assessment calculations for the underground testing inventory have not been made with the same rigor as was done for the proposed Yucca Mountain Repository. Nevertheless, DOE calculated a conservative, maximum potential individual dose that would be likely to result from the underground test inventory. The assumptions of this bounding calculation were:

- The total 300-million-curie radionuclide inventory from underground testing, excluding the tritium inventory, would be available for transport. [Tritium's short half-life (about 12.5 years) would mean that the tritium inventory would be depleted through radioactive decay to insignificant levels in about 200 years, long before any Yucca Mountain releases would occur. Tritium constitutes about 90 percent of the total underground testing inventory (DOE 1996f, Table 4-27, pages 4-128 and 4-129)].

- The total underground testing inventory available for transport would migrate through the same locations as those considered in this EIS for dose calculations for releases from the repository. [This is very conservative because much of the water migrating from the underground test locations would discharge to locations other than any releases from the proposed repository, such as Sarcobatus Flats, Oasis Valley, Ash Meadows, or the Amargosa Desert (DOE 1996f, page 4-117)].

- Conservative dilution factors would account for isotopic dilution of carbon-14 by interaction with nonradioactive carbon, removal of technetium through precipitation caused by reducing conditions along the carbonate aquifer flowpaths, dilution in uncontaminated water from the recharge over the Nevada Test Site, and aquifer mixing in transport.

Using the aforementioned conservative assumptions, the maximum potential dose from the underground testing inventory is calculated to be 0.2 millirem per year (based on calculations in the Viability Assessment for radionuclides that would influence dose in 10,000 years). Thus, the maximum cumulative impact of the Proposed Action in 10,000 years, for example [using the mean impact at 20 kilometers (12 miles); see Table 8-39], would be 0.22 millirem per year (the Yucca Mountain Repository impact) plus 0.2 millirem per year (the conservative maximum dose estimate resulting from underground testing), or 0.42 millirem per year. No estimate was made for 1 million years, but the cumulative impact contribution from underground testing is likely to be similar.

There is a high degree of uncertainty associated with this estimate, but the use of bounding assumptions ensures that any reduction in uncertainty would only lower the already low estimated impact. The uncertainty in the estimates is related to several factors. There is a relatively limited amount of information on the groundwater system between the area where underground testing occurred and the Yucca Mountain site. Therefore, the speed of groundwater travel, the relationship between aquifers (mixing), dilution rates, and other factors can only be generally approximated. In addition, the estimates of contaminant travel time from the underground tests are based on one data set from one well over a very short time (fewer than 50 years) and then extrapolated to 10,000 years. As mentioned above, these impact estimates were not performed with the same rigor as those for the long-term performance assessment for the repository.

8.3.2.1.2 *Greater Confinement Disposal*

The waste disposed of under Greater Confinement Disposal constitutes a radiological source term that is less than 10 percent of the repository radionuclide source term immediately available for groundwater transport when the first waste packages initially degrade (that is, 2 percent of the total repository radionuclide source term). Therefore, Greater Confinement Disposal wastes could result in an increase of no more than approximately 10 percent to the impacts associated with the repository.

8.3.2.1.3 *Future Nevada Test Site Low-Level Waste Disposal*

The Nevada Test Site is a disposal site for low-level radioactive waste generated by DOE-approved generators. Managed radioactive waste disposal operations began in the early 1960s, and DOE has disposed of low-level, transuranic, mixed, and classified low-level wastes in selected pits, trenches, landfills, and boreholes on the Nevada Test Site. Environmental impacts from the disposal of low-level waste at the Nevada Test Site are discussed in the Nevada Test Site Final EIS (DOE 1996f, pages 2-15 to 2-17). The current source term of low-level and mixed wastes in shallow land disposal on the Nevada Test Site does not constitute a substantial inventory in relation to the radionuclide source term immediately available for groundwater transport from the repository when the first waste packages initially degrade (that is, 2 percent of the total repository radionuclide source term). However, shallow burial continues to be an important waste disposal activity at the Nevada Test Site. Therefore, this section evaluates reasonably foreseeable future activities in this category as a potential cumulative impact.

Waste disposal activities on the Nevada Test Site occur at two specific locations. They are the Area 3 and Area 5 Radioactive Waste Management Sites. The Area 3 Radioactive Waste Management Site is on Yucca Flat and covers an area of approximately 0.2 square kilometer (50 acres). DOE uses conventional landfill techniques to dispose of contaminated debris from the Nevada Test Site Atmospheric Testing Debris Disposal Program and packaged bulk low-level waste from other DOE sites in subsidence craters from underground nuclear tests. The estimated total remaining capacity for low-level waste in the Area 3 site is 1.8 million cubic meters (64 million cubic feet) (DOE 1998l, Section A.5.2).

DOE has used the Area 5 Radioactive Waste Management Site since 1961 to dispose of low-level waste and classified low-level waste from Nevada Test Site operations. In 1978, the Nevada Test Site began accepting low-level waste generated by other DOE sites. The total area of the Area 5 site is 3 square kilometers (740 acres). The developed portion occupies 0.37 square kilometer (92 acres) in the southeast corner and contains 17 landfill cells (pits and trenches), 13 Greater Confinement Disposal boreholes, and a transuranic waste storage pad. DOE proposes to locate the Mixed Waste Disposal Unit, which will be a landfill, on about 0.18 square kilometers (45 acres) of the Area 5 site, immediately north of the developed Radioactive Waste Management Site landfill area. The design has been completed, the unit has been included in the Resource Conservation and Recovery Act permit application, and the environmental assessment is being updated. The estimated total remaining capacity for low-level waste in the Area 5 Radioactive Waste Management Site is 1.2 million cubic meters (42 million cubic feet) (DOE 1998l, Section A.5.3).

DOE projects the total life cycle of low-level waste disposal at the Nevada Test Site to be 217,000 cubic meters (7,700,000 cubic feet) of low-level waste by volume (DOE 1998l, Table 2.9):

- 22,000 cubic meters (78,000 cubic feet) during the period from 1996 through 2000
- 85,000 cubic meters (3,000,000 cubic feet) during the period from 2001 through 2030
- 110,000 cubic meters (3,900,000 cubic feet) during the period from 2031 through 2070

To date, DOE has projected only the volumetric waste disposal, not the total radioactivity associated with future low-level waste that it would dispose of. Radiological performance assessment information is required to provide a more accurate evaluation of disposal criteria (DOE 1998i, Executive Summary).

The Final Waste Management Programmatic EIS (DOE 1997b, Summary) reported volumes of radioactive waste DOE may dispose of at the Nevada Test Site for "current plus 20 years" of waste disposal. The current inventory plus 20 years of additional disposal inventory would total 3,000 cubic meters (106,000 cubic feet) of low-level mixed waste, 1,700 cubic meters (60,000 cubic feet) of low-level waste, and 610 cubic meters (21,500 cubic feet) of transuranic waste (DOE 1997b, Summary, Page 102). The Nevada Test Site Final EIS (DOE 1996f, Table 4-1, page 4-6) estimates the total current inventory already in shallow disposal at the Nevada Test Site to be 500,000 curies at the time of disposal (uncorrected for decay to the present time).

According to the Final Waste Management Programmatic EIS, the only expected groundwater impacts from low-level mixed, low-level radioactive, and transuranic waste disposal at the Nevada Test Site in excess of regulatory limits are for the hazardous chemicals 1,2-dichloroethane, methylene chloride, and benzene, and those only under Regionalized Alternative 3 and the Preferred Alternative in that EIS (DOE 1997b, page 11-61). None of these hazardous chemicals would be in the Yucca Mountain Repository inventory, so there would be no potential cumulative impacts from those chemicals from the Proposed Action or Inventory Module 1 or 2.

In summary, the source term of shallow-land disposal sites for past and reasonably foreseeable future disposal at the Nevada Test Site would be small in comparison to the radionuclide source term available for groundwater transport from the repository. Therefore, cumulative long-term impacts from shallow-land disposal at the Nevada Test Site with the repository, if any, would be very small.

8.3.2.2 Past Actions at Beatty Low-Level Radioactive Waste Disposal Facility

A low-level radioactive waste disposal facility, formerly operated by U.S. Ecology, a subsidiary of American Ecology, is 16 kilometers (10 miles) southeast of Beatty, Nevada, and 180 kilometers (110 miles) northwest of Las Vegas. This site is about 15 kilometers (9.3 miles) west of the proposed Yucca Mountain Repository (see Figure 8-2). The disposal facility, which opened in 1962, covers roughly 0.14 square kilometer (35 acres) of unlined trenches. It remains open for hazardous waste disposal, but acceptance of low-level radioactive waste ended December 31, 1992 (DOE 1997p, Chapter 4, Table 4-17). The Nevada State Health Division formally accepted permanent custody of the low-level radioactive commercial waste disposal in a letter to American Ecology dated December 30, 1997 (AEC 1998, all).

From 1962 through 1992, the inventory shipped to the Beatty low-level radioactive waste facility totaled 137,000 cubic meters (4.8 million cubic feet) in volume (DOE 1997p, Chapter 4, Table 4-17) with radioactivity of about 640,000 curies (DOE 1997p, Chapter 4, Table 4-18). The radioactivity in this sum was measured by year of shipment (that is, it is not corrected for decay since that time).

The Manifest Information Management System (MIMS 1999, all) calculated the total radionuclide inventory the Beatty facility received from 1986 through 1992, which represents 29 percent of the total undecayed inventory at that facility. Even if multiplied by a factor of 3 to 4 to compensate for the period (1962 to 1985) for which the Manifest Information Management System did not provide information, the source term represents a small percentage of the radionuclide source term immediately available for groundwater transport from the repository when the first waste packages initially degrade (that is, 2 percent of the total repository radionuclide source term). Therefore, cumulative long-term impacts from the Beatty Low-Level Radioactive Waste Disposal Facility with the repository would be very small.

8.4 Cumulative Transportation Impacts

This section discusses the results of the cumulative impact analysis of transportation. Paralleling the transportation analyses of the Proposed Action in Chapter 6, potential national transportation cumulative impacts from Inventory Module 1 or 2, and past, present, and reasonably foreseeable future actions, are presented in Section 8.4.1. Potential cumulative impacts with construction and operation of the Nevada transportation implementing rail and heavy-haul truck alternatives are included in Section 8.4.2.

The shipment of Inventory Module 1 or 2 to the repository would use the same transportation routes, but would take more shipments and an additional 14 years compared to the Proposed Action. Table 8-2 lists the estimated number of shipments for Modules 1 and 2. Impacts from Module 1 or 2 would be similar because the shipping rate would be the same for spent nuclear fuel and high-level radioactive waste and only about 3 percent more shipments would be made over the 38-year period under Module 2 to transport Greater-Than-Class-C and Special-Performance-Assessment-Required wastes. Because the difference in impacts between Inventory Modules 1 and 2 would be small, the following discussions present the impacts from both modules as being the same.

8.4.1 NATIONAL TRANSPORTATION

This section describes potential cumulative impacts from shipping Inventory Module 1 or 2 from commercial nuclear generating sites and DOE facilities to the proposed Yucca Mountain Repository (Section 8.4.1.1). Section 8.4.1.2 presents potential cumulative national transportation impacts for the Proposed Action and Module 1 or 2 when combined with past, present, and reasonably foreseeable future shipments of radioactive material.

8.4.1.1 Inventory Module 1 or 2 Impacts

This section describes the potential cumulative impacts of loading operations at generating sites and incident-free radiological impacts, vehicle emission impacts, and accident impacts associated with transportation activities for Inventory Module 1 or 2. Cumulative impact results are provided for the mostly legal-weight truck and mostly rail scenarios which are described in Chapter 6. The section also describes potential cumulative impacts from transportation of other materials, personnel, and repository-generated waste for Modules 1 or 2. Appendix J contains additional detailed analysis results.

Loading operations would be extended for an additional 14 years to load the greater quantities of spent nuclear fuel and high-level radioactive waste under Inventory Module 1 or 2. The impacts of routine loading operations described for the Proposed Action in Chapter 6, Section 6.2.2, would increase for Module 1 or 2 due to the additional inventory. DOE would not expect any releases of radioactive material from loading operations that would cause public impacts from either the Proposed Action or Module 1 or 2. Table 8-56 lists estimated radiological and industrial hazard impacts to involved workers for the routine loading operations under Module 1 or 2. The Proposed Action impacts are listed for comparison.

Because noninvolved workers would not have tasks that involved radioactive exposure, there would be no or very small radiological impacts to noninvolved workers. For the reasons identified in Chapter 6, Section 6.1.2.2, industrial hazard impacts to noninvolved workers would be about 25 percent of the impacts to the individual worker shown in Table 8-56.

The impacts of loading accident scenarios under Inventory Module 1 or 2 would be the same as those described for the Proposed Action in Chapter 6, Section 6.2.4.1. The same type of single accident event and its impacts are applicable to shipments under the Proposed Action or Module 1 or 2. As summarized

Table 8-56. Radiological and industrial hazard impacts to involved workers from loading operations.[a,b]

Impact	Proposed Action[b] Mostly legal-weight truck scenario	Proposed Action[b] Mostly rail scenario	Inventory Module 1 or 2 Mostly legal-weight truck scenario	Inventory Module 1 or 2 Mostly rail scenario
Radiological				
Maximally exposed individual				
Dose (rem)[c]	12	12	12	12
Probability of latent cancer fatalities	0.005	0.005	0.005	0.005
Involved worker population				
Dose (person-rem)	14,000	5,000	28,000	9,000
Number of latent cancer fatalities	6	2	11	4
Industrial hazards				
Total recordable cases[d]	150	65	280	110
Lost workday cases[e]	66	29	140	50
Fatalities[f]	0.14	0.06	0.3	0.1

a. Includes all involved workers at all facilities.
b. Source: Chapter 6, Section 6.2.
c. Assumes 500 millirem per year to radiation workers. The average individual exposure was assumed to be 24 years for both the Proposed Action and Inventory Module 1 or 2 since 24 years is a conservatively long time to assume an individual would be involved in loading operations.
d. Total recordable cases (of injury and illness) based on a 1992-1997 DOE complex loss incidence rate of 0.03 (DOE 1999c, all).
e. Lost workday cases based on a 1992-1997 DOE complex loss incidence rate of 0.31.
f. Fatalities based on a 1988-1997 DOE complex loss incidence rate of 0.000029.

in Chapter 6, Section 6.2.4.1, the analysis results indicate that there would be no or very small potential radiological consequences from loading accident scenarios involving spent nuclear fuel or high-level radioactive waste. These consequences would bound the consequences from similar accidents involving Greater-Than-Class-C or Special-Performance-Assessment-Required waste because of the lower available radionuclide inventory (see Appendix A).

Table 8-57 lists radiological impacts to involved workers and the public and vehicle emission impacts from incident-free transportation for the mostly legal-weight truck and mostly rail scenarios. The analysis

Table 8-57. Radiological and vehicle emission impacts from incident-free national transportation.

Category	Proposed Action[a,b] Mostly legal-weight truck scenario[d]	Proposed Action[a,b] Mostly rail scenario[e]	Inventory Module 1 or 2[c] Mostly legal-weight truck scenario[d]	Inventory Module 1 or 2[c] Mostly rail scenario[e]
Involved worker				
Collective dose (person-rem)	11,000	1,900 - 2,300	20,000	3,000 - 3,800
Estimated number of latent cancer fatalities	4.5	0.77 - 0.93	8.0	1.2 - 1.5
Public				
Collective dose (person-rem)	35,000	3,300 - 5,000	62,000	5,000 - 8,100
Estimated number of latent cancer fatalities	18	1.6 - 2.5	31	2.5 - 4.0
Estimated vehicle emission-related fatalities	0.6	0.3	1.1	0.46 - 0.52

a. Source: Chapter 6, Section 6.2.3.
b. Impacts are totals for shipments over 24 years.
c. Impacts are totals for shipments over 38 years.
d. Includes rail shipments of naval spent nuclear fuel to Nevada, and intermodal transfer station and heavy-haul truck operations for this fuel in Nevada.
e. Includes legal-weight truck shipments from commercial nuclear generator sites that do not have the capacity to handle or load rail casks, and the rail and heavy-haul truck implementing alternatives for Nevada described in Chapter 6.

of impacts for the mostly legal-weight truck scenario assumed that shipments would use commercial motor carriers for highway transportation and general freight commercial services for rail transportation for the naval spent fuel shipments that cannot be transported by legal-weight trucks. The mostly rail analysis accounts for legal-weight truck shipments that would occur for the commercial nuclear generator sites that do not have the capacity to handle or load rail casks. In addition, for the mostly rail analysis, DOE assumed that it would use either a branch rail line or heavy-haul trucks in conjunction with an intermodal transfer station in Nevada to transport the large rail casks to and from the repository. The range provided in the table for the mostly rail scenario addresses the different possible rail and heavy-haul truck implementing alternatives described in Chapter 6. The lower end of the range reflects use of a branch rail line in Nevada and the upper end of the range reflects use of heavy-haul trucks in Nevada. The involved worker impacts in Table 8-57 include estimated radiological exposures of truck and rail transportation crews and security escorts for legal-weight truck and rail shipments; the public doses account for the public along the route, the public sharing the route, and the public during stops. The Inventory Module 1 or 2 impacts would exceed those of the Proposed Action due to the additional number of shipments.

DOE does not expect radiological impacts for maximally exposed individuals to change from the Proposed Action due to the conservative assumptions used in the analysis of the Proposed Action (see Chapter 6, Section 6.2.3). The assumptions for estimating radiological dose include the use of the maximum allowed dose rate and conservative estimates of exposure distance and time. For example, the U.S. Department of Transportation maximum allowable dose rate of 10 millirem per hour at a distance of 2 meters (6.6 feet) [40 CFR 173.44(b)]was used for estimating exposure to individuals. In addition, the conservative assumptions for exposure distance and time for workers (that is, crew members, inspectors, railyard crew member) and the public (that is, resident along route, person in a traffic jam, person at a service station, resident near a rail stop) for the Proposed Action are unlikely to be exceeded for Inventory Module 1 or 2 (see Chapter 6, Section 6.2.3).

Table 8-58 lists the radiological accident risk and traffic fatalities for transportation by mostly legal-weight truck and mostly rail for Inventory Module 1 or 2. The radiological accident risk measures the total impact of transportation accidents over the entire shipping campaign (24 years for the Proposed Action and 38 years for Module 1 or 2). The consequences from a maximum reasonably foreseeable accident scenario would be identical to those discussed for the Proposed Action (see Chapter 6, Sections 6.2.4.2.1 and 6.2.4.2.2) because the parameters and conditions for the hypothetical accident event involving spent nuclear fuel or high-level radioactive waste would be the same for a shipment under the Proposed Action or Module 1 or 2. In addition, the hypothetical accident would be bounding for accident scenarios involving Greater-Than-Class-C and Special-Performance-Assessment-Required wastes.

Table 8-58. Accident risk for mostly legal-weight truck and mostly rail scenarios.

	Proposed Action[a]		Inventory Module 1 or 2	
Category	Mostly legal-weight truck scenario	Mostly rail scenario	Mostly legal-weight truck scenario	Mostly rail scenario
Radiological accident risk				
Collective dose risk (person-rem)	130	42 – 47	210	64 – 72
Estimated number of latent cancer fatalities	0.07	0.021 - 0.024	0.10	0.032 – 0.036
Traffic accident fatalities	3.9	2.7 – 3.6	7.0	4.6 – 6.2

a. Source: Chapter 6, Section 6.2.4.2.

As summarized in Chapter 6, Section 6.1.3, and further described in Appendix J, in addition to the transportation of spent nuclear fuel and high-level radioactive waste to the repository, other material would require transportation to and from the proposed repository. These materials would include construction materials, consumables, disposal containers, office and laboratory supplies, mail, and laboratory samples. Required transportation would also include personnel commuting to the Yucca Mountain site and the shipment of repository-generated wastes offsite for treatment, storage, or disposal. The implementation of Inventory Module 1 or 2 would increase this transportation as a result of the additional required subsurface development and the longer time required for repository development, emplacement, and closure. However, even with the increased transportation of other material, personnel, and repository-generated wastes for Module 1 or 2, DOE would expect these transportation impacts to be small contributors to the total transportation impacts on a local, state, and national level with no large cumulative impacts based on the analysis of the Proposed Action in Section 6.1.3. The annual air quality impacts for Inventory Module 1 or 2 would be the same as those conservatively estimated in Section 6.1.3 and, therefore, no cumulative air quality impacts would be expected in the Las Vegas airshed, which is in nonattainment for carbon monoxide. Table 8-59 summarizes fatalities from transporting other materials, personnel, and repository-generated waste. The estimated fatalities assume truck shipments which would have higher potential impacts than shipments by rail. The Proposed Action impacts are listed in the table for comparison.

Table 8-59. Impacts from transportation of materials, consumables, personnel, and waste.[a,b]

	Proposed Action		Inventory Module 1 or 2	
Category	Kilometers[c] traveled	Fatalities	Kilometers traveled (Module 1/Module 2)	Fatalities (Module l/Module 2)
Materials (including disposal containers)	130,000,000	2.5	225,000,000	4.2
Personnel	450,000,000	6.0	650,000,000	8.6
Repository-generated waste				
Hazardous	110,000	0.002	170,000/200,000	0.03/0.04
Low-level radioactive	460,000	0.008	750,000/860,000	0.01/0.02
Nonhazardous solid	560,000	0.01	660,000	0.01
Dual-purpose canisters	1,600,000	0.03	2,700,000	0.05
Totals	**580,000,000**	**8.6**	**1,100,000,000**	**12.9**

a. Totals might differ from sums due to rounding.
b. Source: Appendix J.
c. To convert kilometers to miles, multiply by 0.62137.

8.4.1.2 Cumulative Impacts from the Proposed Action, Inventory Module 1 or 2, and Other Federal, Non-Federal, and Private Actions

The overall assessment of cumulative national transportation impacts for past, present, and reasonably foreseeable future actions concentrated on the cumulative impacts of offsite transportation, which would yield potential radiation doses to a greater portion of the general population than onsite transportation and would result in fatalities from traffic accidents. The collective dose to workers and to the general population was used to quantify overall cumulative radiological transportation impacts. This measure was chosen because it could be related directly to latent cancer fatalities using a cancer risk coefficient and because of the difficulty in identifying a maximally exposed individual for shipments throughout the United States from 1943 through 2047. Operations at the Hanford Site and the Oak Ridge Reservation began in 1943, and 2047 is when the EIS analysis assumed that radioactive material shipments to the repository for Inventory Module 1 or 2 would end. The source of this cumulative transportation impacts analysis is the Yucca Mountain EIS Environmental Baseline File on transportation (TRW 1999u, Section 7.0), with the exception of impacts from the Proposed Action and Module 1 or 2, which are from Table 8-57.

The cumulative impacts of the transportation of radioactive material would consist of impacts from:

- Historic DOE shipments of radioactive material associated with the Nevada Test Site, the Idaho National Engineering and Environmental Laboratory, the Savannah River Site, the Hanford Site, the Oak Ridge Reservation, and naval spent nuclear fuel and test specimens

- Reasonably foreseeable actions that include the transportation of radioactive material identified in DOE Environmental Policy Act analyses; for example, the Nevada Test Site Environmental Impact Statement (DOE 1996f, all), the Department of Energy Spent Nuclear Fuel Management Environmental Impact Statement (DOE 1995a, all; DOE 1996c, all), and the Final Department of Energy Waste Management Environmental Impact Statement (DOE 1997b, all) (see Table 8-60). [Note: Table 8-60 includes reasonably foreseeable projects that include limited transportation of radioactive material (for example, shipment of submarine reactor components from the Puget Sound Naval Shipyard to the Hanford Site for burial, and shipments of uranium billets and low-specific-activity nitric acid from the Hanford Site to the United Kingdom). In addition, for reasonably foreseeable future actions where a preferred alternative was not identified or a Record of Decision has not been issued, the analysis used the alternative estimated to result in the largest transportation impacts. While this is not an exhaustive list of the projects that could include limited transportation of radioactive material, it indicates that the transportation impacts associated with such projects are low in comparison to major projects or general transportation.]

- General radioactive materials transportation that is not related to a particular action; for example, shipments of radiopharmaceuticals to nuclear medicine laboratories and shipments of commercial low-level radioactive waste to commercial disposal facilities

- Shipments of spent nuclear fuel, high-level radioactive waste, Greater-Than-Class-C waste, and Special-Performance-Assessment-Required waste under the Proposed Action or Inventory Module 1 or 2

Table 8-60 summarizes the worker and general population collective doses from the transport of radioactive material. The estimated total cumulative transportation-related collective worker doses from the mostly legal-weight truck shipments (past, present, and reasonably foreseeable actions) with the Proposed Action would be about 340,000 person-rem (140 latent cancer fatalities), and with Inventory Module 1 or 2 about 370,000 person-rem (150 latent cancer fatalities). The estimated total general population collective doses for the mostly legal-weight truck shipments would be about 340,000 person-rem (170 latent cancer fatalities) with the Proposed Action, and about 390,000 person-rem (200 latent cancer fatalities) with Module 1 or 2. Most of the collective dose for workers and the general population would be due to general transportation of radioactive material. The estimated total number (workers plus population) of latent cancer fatalities with the Proposed Action would be about 310, and about 350 with Module 1 or 2. Over a corresponding period from 1943 to 2033 for the Proposed Action and from 1943 to 2047 for Module 1 or 2, approximately 46 million and 54 million people, respectively, would die from cancer in the United States based on 510,000 annual cancer fatalities (Bureau of the Census 1993, all). The estimated number of transportation-related latent cancer fatalities would be indistinguishable from other cancer fatalities, and the transportation-related latent cancer fatalities would be less than 0.0007 percent of the total number of cancer fatalities.

For transportation accidents involving radioactive material, the dominant risk is due to accidents that are not related to the cargo (traffic or vehicular accidents). Typically, the radiological accident risk (latent cancer fatalities) from transportation accidents is less than 1 percent of the vehicular accident risk (see Table 8-58). In addition, no acute radiological fatalities due to transportation accidents have ever

Table 8-60. Cumulative transportation-related radiological collective doses, latent cancer fatalities, and traffic fatalities.[a]

Category	Collective worker dose (person-rem)	Collective general population dose (person-rem)	Traffic fatalities
Historical DOE shipments (DOE 1996f, all)	330	230	NL[b]
Reasonably foreseeable actions			
Nevada Test Site expanded use (DOE 1996f, all)	--[c]	150[d]	8
Spent nuclear fuel management (DOE 1995a, all; DOE 1996c, all)	360	810	0.77
Waste Management PEIS (DOE 1997b, all)[e]	16,000	20,000	36
Waste Isolation Pilot Plant (DOE 1997o, all)	790	5,900	5
Molybdenum-99 production (DOE 1996j, all)	240	520	0.1
Tritium supply and recycling (DOE 1995e, all)	--	--	0.029
Surplus HEU disposition (DOE 1996k, all)	400	520	1.1
Storage and Disposition of Fissile Materials (DOE 1996e, all)	--	2,400[d]	5.5
Stockpile Stewardship (DOE 1996l, all)	--	38[d]	0.064
Pantex (DOE 1996m, all)	250[f]	490[d]	0.006
West Valley (DOE 1996b, all)	1,400	12,000	3.6
S3G and D1G prototype reactor plant disposal (DOE 1997q, all)	2.9	2.2	0.010
S1C prototype reactor plant disposal (DOE 1996n, all)	6.7	1.9	0.0037
Container system for Naval spent nuclear fuel (USN 1996a, all)	11	15	0.045
Cruiser and submarine reactor plant disposal (USN 1996b, all)	5.8	5.8	0.00095
Submarine reactor compartment disposal (USN 1984, all)	--	0.053	NL
Uranium billets (DOE 1992b, all)	0.50	0.014	0.00056
Nitric acid (DOE 1995h, all)	0.43	3.1	NL
General radioactive material transportation			
1943 to 2033	310,000	260,000	19
1943 to 2047	330,000	290,000	22
Proposed Action			
Mostly legal-weight truck	11,000	35,000	3.9
Mostly rail	1,900 - 2,300	3,300 - 5,000	3.6
Module 1 or 2[g]			
Mostly legal-weight truck	20,000	62,000	7.0
Mostly rail	3,100 - 3,800	5,000 - 8,100	6.2
Total collective dose (total latent cancer fatalities)[h] *and total traffic fatalities*			
Proposed Action			
Mostly legal-weight truck	340,000 (140)	340,000 (170)	83
Mostly rail	330,000 (130)	310,000 (160)	83
Module 1 or 2[g]			
Mostly legal-weight truck	370,000 (150)	390,000 (200)	86
Mostly rail	350,000 (140)	340,000 (170)	85

a. Sources: TRW (1999u, Section 7) except for the Proposed Action and Inventory Module 1 or 2, which are from Table 8-56. All references in this table refer to the original source of information cited in TRW (1999u, Section 7).

b. NL = not listed.

c. -- = reported or included with the general population collective dose.

d. Includes worker and general population collective doses.

e. Includes mixed low-level waste and low-level waste; transuranic waste included in DOE (1997o, Volume 1).

f. Includes all highly enriched uranium shipped to Y-12.

g. The transportation-related radiological collective doses for Inventory Module 1 or 2 include the doses from the Proposed Action (see the definition of Modules 1 and 2 in Section 8.1.2.1).

h. The conversion factors for worker and general population collective dose to latent cancer fatalities are 0.0004 and 0.0005 latent cancer fatality per person-rem, respectively (NCRP 1993a, page 31).

occurred in the United States. Therefore, the number of vehicular accident fatalities was used to quantify the cumulative impacts of transportation accidents.

From 1943 through 2033 an estimated 4 million people would be killed in motor vehicle accidents and 180,000 people would be killed by railroad accidents. From 1943 through 2047, an estimated 4.4 million people would be killed in motor vehicle accidents and 200,000 people would be killed in railroad accidents. Based on the estimated number of traffic fatalities for the reasonably foreseeable actions and for the Proposed Action and Inventory Module 1 or 2 listed in Table 8-60, the transport of radioactive material would contribute about 100 fatalities to these totals.

8.4.2 NEVADA TRANSPORTATION

This section analyzes potential cumulative impacts that Inventory Module 1 or 2 and past, present, and other reasonably foreseeable future Federal, non-Federal, and private actions could have on the construction and operation of a branch rail line or the construction and operation of an intermodal transfer station and associated highway upgrades for heavy-haul trucks in the State of Nevada. The analysis included potential cumulative impacts in the vicinity of the five potential branch rail line corridors, the three potential intermodal transfer station locations, and the five associated potential highway routes for heavy-haul trucks.

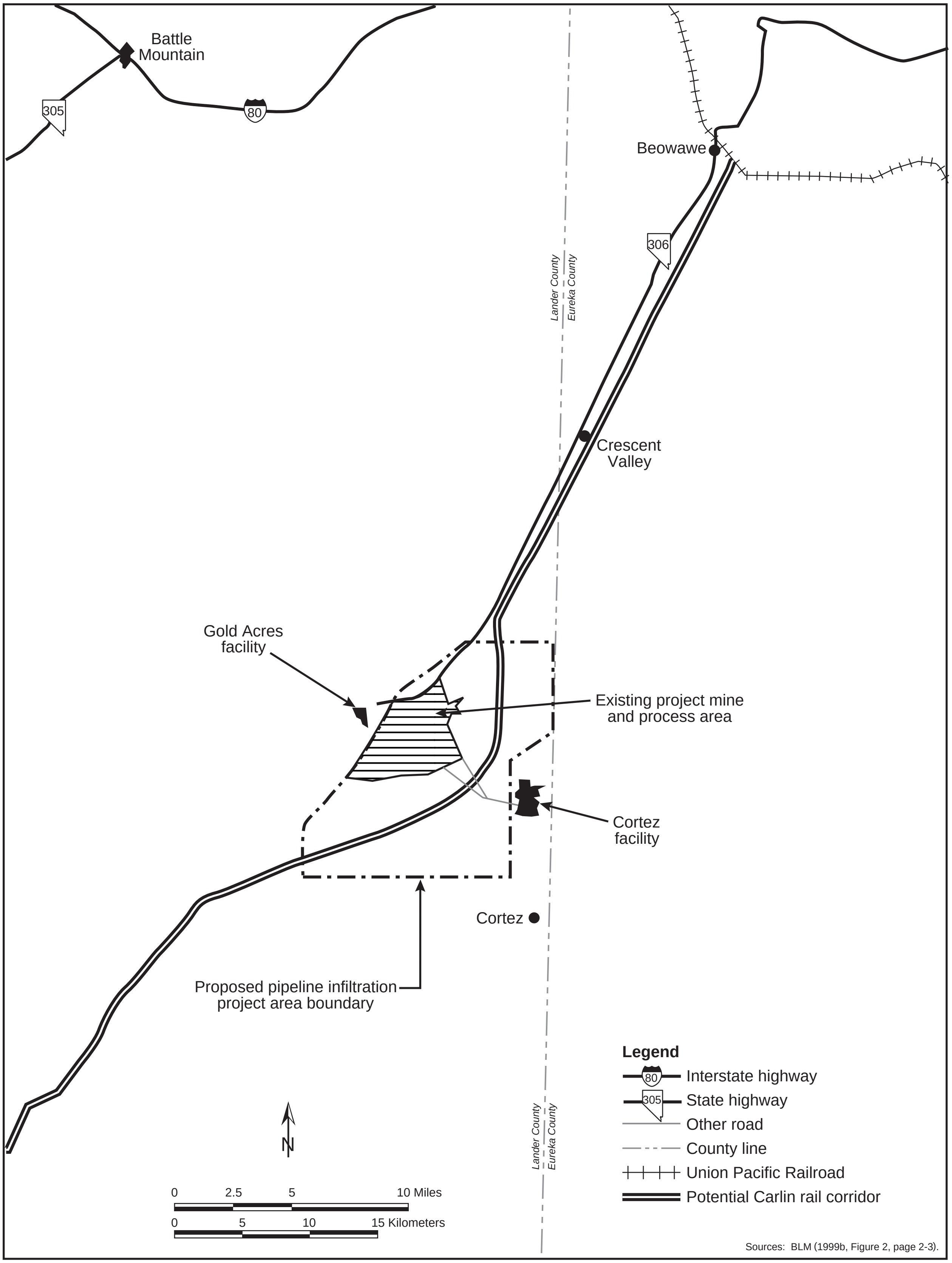
With respect to potential cumulative impacts from Inventory Module 1 or 2, there would be no cumulative construction impacts because the need for a new branch rail line or new intermodal transfer station and associated highway upgrades for heavy-haul trucks would not change; that is, whatever DOE would build for the Proposed Action would also serve Module 1 or 2. In addition, because the planned annual shipment rate of spent nuclear fuel and high-level radioactive waste to the Yucca Mountain Repository would be about the same for Module 1 or 2 and the Proposed Action, the only cumulative operations impacts would result because of the extra 14 years of shipping time required for Module 1 or 2. With this basis, the operation and maintenance of a branch rail line or an intermodal transfer station and associated highway route for heavy-haul trucks were analyzed for potential cumulative impacts from Module 1 or 2.

Land-use and ownership impacts would be unlikely for the Proposed Action (see Chapter 6, Section 6.3), and DOE expects no cumulative impacts from extending shipping operations from approximately 24 to 38 years. Similarly, DOE expects no cumulative impacts from the extended 14 years of operation for Inventory Module 1 or 2 to air quality; hydrology (surface water and groundwater); biological resources and soils; cultural resources; socioeconomics; noise; aesthetics; and utilities, energy, and materials, the impacts of which were assessed on a per shipment, weekly, or annual basis (see Chapter 6, Section 6.3).

Cumulative impacts from Inventory Module 1 or 2 to occupational and public health and safety are included in the occupational and public health and safety impacts of national transportation in Section 8.4.1. The operation of an intermodal transfer station for more years under Module 1 or 2 would affect waste management impacts. The same waste types and annual quantities would be generated as for the Proposed Action, but the total waste quantities would be about 60 percent more than those for the Proposed Action due to the additional years of operation. However, the small waste quantities generated for Module 1 or 2 would have a minimal impact to the receiving treatment and disposal facilities. Because there would be no large cumulative impacts for any of the resource areas from Module 1 or 2, disproportionately high and adverse cumulative impacts to minority or low-income populations or to Native Americans would be unlikely.

Other than Inventory Module 1 or 2, one other Federal action and several private actions could have the potential for cumulative impacts with the construction and operation of a new branch rail line or intermodal transfer station and associated highway route for heavy-haul trucks.

One private action that could lead to cumulative impacts with the Carlin rail corridor implementing alternative is by Cortez Gold Mine, Inc., which has an existing Pipeline Project mining operation and processing facility (BLM 1996, all), a proposed Pipeline Infiltration Project (BLM 1999b, all), and a possible Pipeline Southeast Expansion Project (BLM 1996, page 5-7) in the Crescent Valley area of Nevada through which the Carlin branch rail line would pass (see Section 8.1.2.3 and Figure 8-4). Because the Carlin corridor would pass through the general area of these projects, there could be cumulative land-use and ownership impacts that would require mitigation. Because the Pipeline Southeast Expansion Project is currently under study, the Final EIS will review new information that



Sources: BLM (1999b, Figure 2, page 2-3).

Figure 8-4. Cortez Gold Mine existing pipeline project and proposed pipeline infiltration project.

becomes available on this project for additional cumulative impacts. The analysis for the Carlin rail corridor represents the maximum impact other rail corridor implementing alternatives would have smaller impacts. Cumulative impacts for the mostly legal-weight truck scenario would also have smaller impacts.

Another private action that could result in cumulative impacts would be shared use of a branch rail line that DOE constructed and operated to transport spent nuclear fuel and high-level radioactive waste to the Yucca Mountain Repository by others (for example, mine operators, private freight shippers) because of the increased rail traffic. Because predicting the increase in rail traffic would be difficult, this analysis cannot estimate the cumulative impacts. There could be some added impacts to all the resource areas beyond those evaluated for the Proposed Action in Chapter 6, but there would also be benefits from the improved economic potential for resource development in interior areas of Nevada as well as greater economic development potential for nearby communities. DOE would have to consider these impacts in any decision it made to allow shared use of the branch rail line.

A Federal action and a private action could lead to cumulative impacts with the construction and operation of the Caliente intermodal transfer station. DOE has specified the Caliente site as one of four possible locations for the construction and operation of an intermodal transfer station for the shipment of low-level radioactive waste to the Nevada Test Site (DOE 1998m, pages 2-4 to 2-12). In addition, a commercial venture planned by Apex Bulk Commodities for the Caliente site would construct an intermodal transfer station for the transport of copper concentrate. Figure 8-5 shows a possible layout plan for these intermodal transfer stations at Caliente. Section 8.1 provides more information on the potential DOE and Apex intermodal transfer stations. The following sections describe the potential cumulative impact analysis at the Caliente site from the construction and operation of an intermodal transfer station to support the proposed Yucca Mountain Repository, coupled with an intermodal transfer station for shipment of low-level radioactive waste to the Nevada Test Site and an intermodal transfer station proposed by Apex Bulk Commodities.

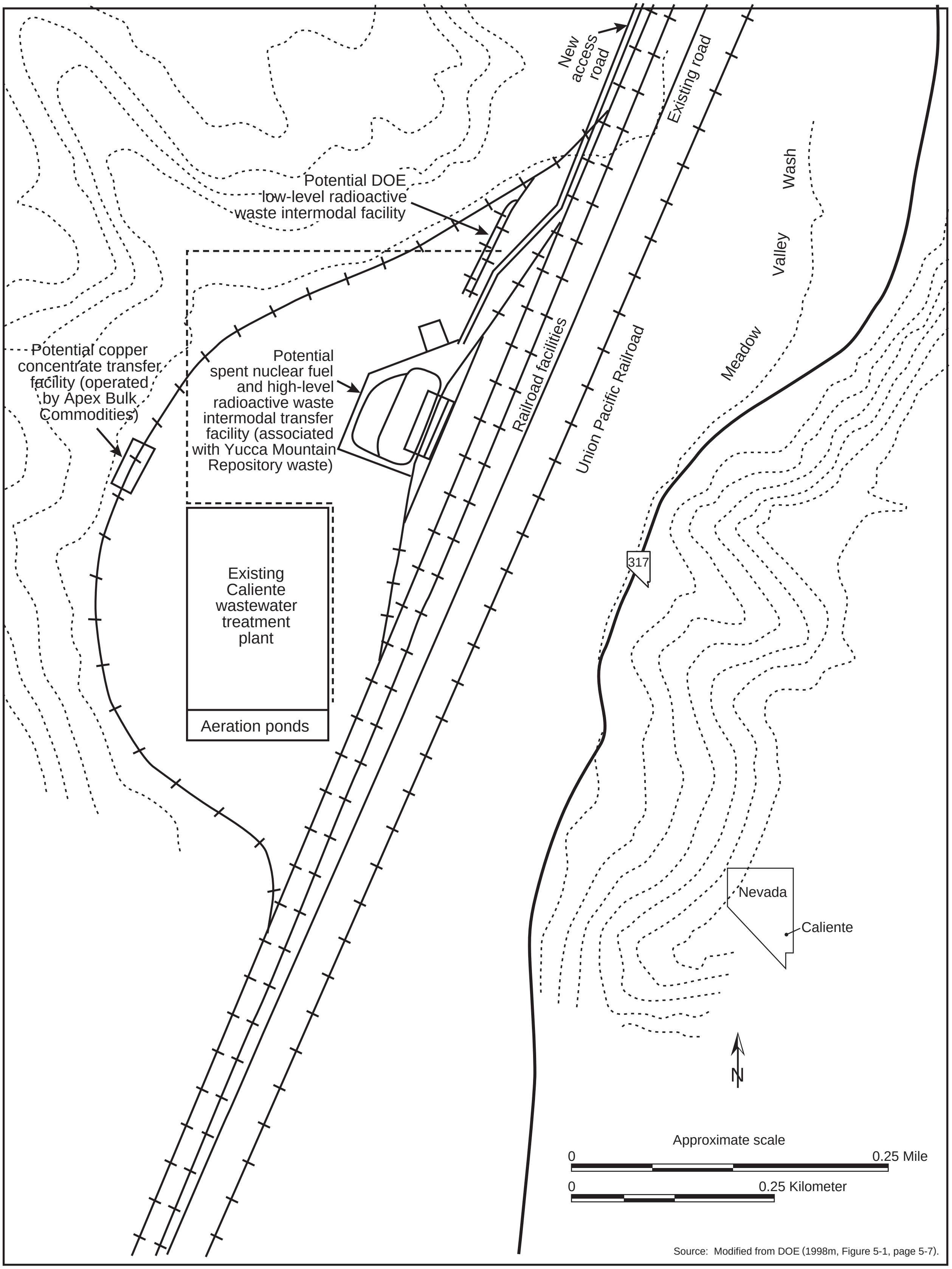
8.4.2.1 Land Use and Ownership

The land required for the DOE low-level radioactive waste and Apex intermodal transfer stations would add to the approximately 0.21 square kilometer (50 acres) of property that would be required for the intermodal transfer station that would support the proposed Yucca Mountain Repository. The rail spur and facility for the low-level radioactive waste intermodal transfer station would disturb approximately 0.02 square kilometer (5 acres) of land. The Apex transfer facility would be in a building about 90 by 30 meters (300 by 100 feet). In addition, Apex would have a truck maintenance facility in a building about 30 by 18 meters (100 by 60 feet) that it could share with the low-level radioactive waste intermodal facility. The incremental impacts resulting from the changes in land use associated with the three intermodal transfer stations would not result in a substantial cumulative impact.

8.4.2.2 Air Quality

Air quality cumulative impacts during construction of the three intermodal transfer stations would not be expected to occur since construction activities would likely occur at different times. Even if construction for all three intermodal transfer stations occurred concurrently, administrative controls would be implemented to prevent an adverse impact from collective emissions and dust-generating activities.

During operations, there would be approximately one or two repository rail shipments and three or four associated heavy-haul trucks a day, an average of about three trains and seven trucks a day for DOE low level radioactive waste shipments, and one truck an hour for the Apex copper concentrate transport. At present, an average of one train an hour and light highway traffic travels through Caliente. The incremental increase in air pollutants from rail and highway traffic resulting from the three actions would



Source: Modified from DOE (1998m, Figure 5-1, page 5-7).

Figure 8-5. Potential locations of intermodal transfer stations at Caliente.

cause slight, temporary increases in pollutants, but would not exceed Federal standards (Chapter 6, Section 6.3.2; DOE 1998m, pages 4-13, 5-5, and 5-8). Criteria pollutants released during routine operations of the intermodal transfer stations would include nitrogen dioxide, sulfur dioxide, carbon monoxide, and particulate matter. DOE expects these emissions would also be well within Federal standards.

8.4.2.3 Hydrology

Surface Water

Mitigation measures used during the construction of the intermodal transfer stations would minimize surface-water impacts. Floodplain impacts probably would occur if DOE selected the Caliente intermodal transfer station (see Appendix L). If that location was selected, DOE would conduct a detailed floodplain/wetland assessment and integrate good construction practices to minimize impacts. Construction probably would involve some permanent drainage alterations. Runoff rates would differ from natural or existing terrain but, given the relatively small size of the area, there would be little effect on overall runoff quantities for the area (Chapter 6, Section 6.3.3.1; DOE 1998m, pages 4-13 and 5-8). DOE expects very small impacts to surface waters during the construction and operation of the stations.

Groundwater

Construction activities for the intermodal transfer stations would disturb and loosen the ground for some time, which could result in higher infiltration rates. However, these activities and their resultant short-term impacts probably would occur at different times for the three stations. The relatively small sizes of the three facilities would minimize changes in groundwater infiltration rates during operations. Potential sources of contamination would include one to three diesel fuel tanks for the standby generators and heavy equipment for all three stations. The small overall water demand could be met by installing wells or by existing water distribution systems. In addition, the operation of the Apex copper concentrate and DOE low-level radioactive waste intermodal transfer station would only overlap with the beginning years of spent nuclear fuel and high-level radioactive waste shipment to the proposed Yucca Mountain Repository.

8.4.2.4 Biological Resources and Soils

The proposed locations of the intermodal transfer stations are in an irrigated pasture area that is partly wetland. However, because the area was modified as pasture and the native habitat has been degraded, cumulative impacts to biological resources would be low. Construction activities could lead to soil erosion. Water would be applied to suppress dust and compact soil. The operation of the stations would have small cumulative impacts on soils. Erosion damage control would be performed as necessary throughout the operational periods.

8.4.2.5 Cultural Resources

Impacts could occur to archaeological, historic, and traditional Native American cultural sites from the construction of the intermodal transfer stations. Cultural resource surveys of this portion of the Meadow Wash Area have identified two archaeological sites in the vicinity of the proposed DOE low-level radioactive waste intermodal site (DOE 1998m, pages 4-13). Neither site falls within the proposed intermodal transfer station areas. DOE would perform special ethnographic studies and archaeological surveys during the engineering design phases and before construction.

8.4.2.6 Socioeconomics

Employment levels for operation of the repository, Apex, and DOE low-level radioactive waste intermodal transfer stations would be 66, 25, and 14 employees, respectively (Chapter 6 and Section 8.1.2.2). Employment associated with the repository and low-level radioactive waste intermodal transfer stations includes operations personnel and truck drivers. Concurrent operations for all three stations would occur over a portion of the entire 24- or 38-year shipping period for the Proposed Action or Inventory Module 1 or 2, respectively. Employment levels would increase gradually to the maximum values listed above and then decrease gradually toward the end of emplacement activities for repository-related workers. Impacts to employment, population, personal income, Gross Regional Product, and state and local government expenditures during station operations would be small for Lincoln County (Chapter 6, Section 6.3.2.2; DOE 1998m, pages 4-14 and 5-9).

The truck traffic in the Caliente area would be increased from the three intermodal transfer stations. The small increase would have a very small impact on U.S. Highway 93, which would be used when entering and leaving the intermodal transfer station access road. U.S. 93 is currently characterized as having light traffic. The period of concurrent truck traffic from the three intermodal transfer stations would also occur only over a portion of the 24- or 38-year shipping duration for the Proposed Action or Inventory Module 1 or 2, respectively.

8.4.2.7 Occupational and Public Health and Safety

The incremental impacts resulting from an increase in radiological risk associated with the intermodal transfer stations for the repository and low-level radioactive waste shipments at Caliente would not result in a substantial cumulative impact. The estimated total collective worker dose from the entire DOE low-level radioactive waste intermodal shipping campaign, including transportation impacts, would be about 4.21 person-rem (DOE 1998m, page 4-10). This dose, added to the total repository intermodal transfer station and rail and heavy-haul truck shipments worker dose of about 530 to 550 person-rem for the Caliente intermodal transfer station for Inventory Module 1 or 2 (Appendix J, Table J-57) would be an increase of less than 3 percent. The population dose associated with low-level radioactive waste shipments by truck from the intermodal transfer station would be 7.55 person-rem for the entire shipping campaign (DOE 1998m, Table C-11, page C-23). This dose, added to the dose from shipments in Nevada that use heavy-haul trucks of 1,400 person-rem over 38 years, would increase the population dose and associated health effects by less than 1 percent.

8.4.2.8 Noise

There would be an increase in noise levels at the Caliente Site from the three intermodal transfer stations and the associated train switching operations and truck traffic. Noise levels would increase during daytime and night hours for rail activities and during daytime hours for truck shipment activities associated with the repository heavy-haul trucks and the DOE low-level radioactive waste trucks. Apex truck shipments would occur once an hour, 24 hours a day. Noise associated with railcar shipments would occur as the railcars were uncoupled from trains and transferred in and out of the stations, which could occur during the day or night. Elevated noise levels would occur during loading and unloading operations and briefly as trucks passed on the highway. Trucks would not travel through Caliente for shipments to either Yucca Mountain or the Nevada Test Site. Overall, the elevation of noise levels associated with rail and truck activity near a level that would cause concern would be unlikely. In addition, due to the location of the intermodal transfer stations in an uninhabited canyon area, noise impacts from rail and truck loading and unloading would be low. Cumulative effects would also be limited because operations at the DOE low-level radioactive waste and Apex intermodal transfer stations would overlap only a portion of the shipping campaign associated with the proposed repository.

8.4.2.9 Aesthetics

The alteration of the landscape immediately surrounding the Class II lands [within about 8 kilometers (5 miles) of the Kershaw-Ryan State Park] could exceed the Class II objective. Class II designation by the Bureau of Land Management could require retention of the existing character of the landscape. However, the area proposed for the intermodal operations has been classified as Class III, which would require partial retention of the existing character of the landscape. The intermodal facilities would not greatly alter the landscape more than the current passing trains and sewage treatment operations. Public exposure would be limited due to obstruction by natural vegetation. Therefore, visual impacts would be very small (DOE 1998m, pages 4-12 and 5-8).

8.4.2.10 Utilities, Energy, and Materials

Electric power lines with adequate capacity are available near the site. Electric power, water supply, and sewage disposal facilities are currently provided to the sewage treatment facility near the proposed location of the intermodal transfer stations (DOE 1998m, page 4-12). Therefore, cumulative impacts to utilities would be small. The quantities of concrete, asphalt, and steel needed to build the intermodal facilities (associated mostly with the repository intermodal transfer station) would be unlikely to affect the regional supply system.

8.4.2.11 Management of Intermodal Transfer Station-Generated Waste and Hazardous Materials

The expected quantities of sanitary waste, small amounts of hazardous waste, and low-level radioactive waste associated with radiological surveys would be unlikely to have large impacts to landfill, treatment, and disposal facilities available for use by this site. Therefore, cumulative impacts for waste management would be small. Only limited quantities of hazardous materials would be needed for station operations, and DOE does not expect these needs to affect the regional supply system (DOE 1998m, pages 4-12, 4-13, and 5-8).

8.4.2.12 Environmental Justice

Because there would be no large cumulative impacts to human health and safety from the construction or operation of the intermodal transfer stations, there would be no disproportionately high and adverse impacts to minority and low-income populations. The absence of large cumulative environmental impacts for the general population means that there would be no disproportionately high and adverse environmental impacts for the minority or low-income communities. An evaluation of subsistence lifestyles and cultural values confirms these general conclusions. The foregoing conclusions and evaluations and the commitment by DOE to ensure minimal impacts to cultural resources show that construction and operation of the intermodal transfer stations would not be expected to cause or contribute to disproportionately high and adverse impacts to Native Americans (DOE 1998m; pages 4-14 and 5-9).

8.5 Cumulative Manufacturing Impacts

This section describes potential cumulative environmental impacts from the manufacturing of the disposal containers and shipping casks required to emplace Inventory Module 1 or 2 in the proposed Yucca Mountain Repository. No adverse cumulative impacts from other Federal, non-Federal, or private actions have been identified because no actions have been identified that, when combined with the Proposed Action or Inventory Module 1 or 2, would exceed the capacity of existing manufacturing facilities.

The overall approach and analytical methods and the baseline data used for the evaluation of cumulative manufacturing impacts for Inventory Module 1 or 2 were the same as those discussed in Section 4.1.14 for the Proposed Action. The evaluation focused on ways in which the manufacturing of the disposal containers and shipping casks could affect environmental resources at a representative manufacturing site and potential impacts to material sources and supplies.

Table 8-61 lists the total number of disposal containers and shipping casks required for the Proposed Action and Inventory Modules 1 and 2. As listed, the total number would increase by approximately 70 to 80 percent for Modules 1 and 2 in comparison to the Proposed Action. The highest total number of disposal containers and shipping casks would be for the Module 2 disposable canister packaging scenario, and this was the number used in the cumulative impact analysis. The number of disposal containers and shipping casks would not vary with the thermal load scenarios.

Table 8-61. Number of disposal containers and shipping casks required for the Proposed Action and Inventory Modules 1 and 2.

	Proposed Action			Module 1			Module 2		
Components	UC[a]	DISP[b]	DPC[c]	UC	DISP	DPC	UC	DISP	DPC
Disposal containers[d]	10,000	11,000	10,000	17,000	20,000	17,000	18,000	20,000	18,000
Shipping casks[e,f]									
Legal-weight truck	119	11	11	241	17	17	241	17	17
Railcar	0	98	98	0	175	175	0	195	175

a. UC = uncanistered packaging scenario.
b. DISP = disposable canister packaging scenario.
c. DPC = dual-purpose canister packaging scenario.
d. Source: TRW (1999c, all).
e. Shipping casks include transportation overpacks.
f. Sources: Chapter 4, Section 4.2; House (1999, all).

Based on the total number of disposal containers and shipping casks that would be required over a 38-year period for Inventory Module 1 or 2, the annual manufacturing rate would increase about 33 percent over that for the Proposed Action. Thus, the annual Module 1 or 2 impacts for air quality, socioeconomics, material use, and waste generation would be less than 20 percent higher than those discussed in Section 4.2 for the Proposed Action, and these impacts would continue for 38 years rather than the 24 years for the Proposed Action. The total number of worker injuries and illness or fatalities would increase in proportion to the increase in disposal containers and shipping casks manufactured. The potential number of injuries and illnesses over the 38-year period for Module 1 or 2 would be about 500 and the estimated number of fatalities would be 0.24 (that is, no expected fatalities). As for the Proposed Action, there would be few or no impacts on other resources because existing manufacturing facilities would meet the projected manufacturing needs and new construction would not be necessary and environmental justice impacts (that is, disproportionately high and adverse impacts to minority or low-income populations) would be unlikely.

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9

Management Actions to Mitigate the Potential for Environmental Impacts

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9. MANAGEMENT ACTIONS TO MITIGATE POTENTIAL ADVERSE ENVIRONMENTAL IMPACTS

This chapter describes management actions that the U.S. Department of Energy (DOE) would consider using to reduce or mitigate adverse impacts to the environment that could occur if the Department implemented the Proposed Action to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. In keeping with previous chapters in this environmental impact statement (EIS), this chapter contains separate discussions for the mitigation of repository impacts and the mitigation of impacts from transportation activities. Under the regulations of the National Environmental Policy Act (40 CFR Section 1508.20), mitigation includes activities that (1) avoid the impact altogether by not taking a certain action or parts of an action; (2) minimize impacts by limiting the degree or magnitude of the action and its implementation; (3) repair, rehabilitate, or restore the affected environment; (4) reduce or eliminate impacts over time by preservation or maintenance operations during the life of the action; or (5) compensate for the impact by replacing or substituting resources or environments.

Apart from the considerations required under the National Environmental Policy Act, Section 116(c) of the Nuclear Waste Policy Act, as amended (NWPA) states that "the Secretary shall provide financial and technical assistance to (an affected unit of local government or the State of Nevada)… to mitigate the impact on such (an affected unit of local government or the State of Nevada) of the development of (a) repository and the characterization of (the Yucca Mountain) site." Such assistance can be given to mitigate likely "economic, social, public health and safety, and environmental impacts." Within that broad framework, neither Section 116 nor any other provision of the NWPA limits the impacts that are subject to assistance under Section 116 to the environmental impacts considered in this EIS.

Under the NWPA, the Section 116 impact assistance review process and the Yucca Mountain Repository EIS process are distinct from one another, and the implementation of one is not dependent on the implementation of the other. Thus, the provision of assistance under Section 116 would not necessarily be limited either by the impacts identified in this EIS or by its findings on such impacts. Any decision to provide assistance under Section 116 will be based on an evaluation of a report submitted by an affected unit of local government or the State of Nevada pursuant to Section 116 to document likely economic, social, public health and safety, and environmental impacts.

9.1 Types of Management Actions

The design, construction, operation and monitoring, and closure planning for the proposed repository incorporate physical features, procedures, and safeguards to reduce environmental consequences. Some of these features, procedures, and safeguards are the result of DOE determinations based on site characterization activities and the ongoing evaluation of planning and design for the proposed repository. To complement the measures already incorporated, DOE is considering a range of additional mitigation measures aimed at reducing effects of the proposed repository project. The repository and transportation mitigation analyses in this chapter discuss impact reduction measures that DOE has committed to implement as well as other mitigations DOE is evaluating for inclusion.

9.1.1 DOE-DETERMINED IMPACT REDUCTION FEATURES, PROCEDURES, AND SAFEGUARDS

DOE has studied the Yucca Mountain site, vicinity, and regions of influence for more than a decade and has accumulated considerable knowledge. The Department has identified many improvements in its project design and plan to reduce potential impacts. The Proposed Action includes commitments to reduce impacts that DOE has made as a result of its site characterization studies and the ongoing evaluation of repository planning and design. This chapter identifies these commitments in appropriate areas.

9.1.2 MITIGATION MEASURES UNDER CONSIDERATION FOR INCLUSION IN PROJECT PLAN AND DESIGN

Although DOE has conducted extensive site characterization studies, it continues to evaluate whether to commit to additional mitigation measures in the event the U.S. Nuclear Regulatory Commission grants a license for the repository project. DOE is considering these additional measures to reduce the potential effects of the repository project. This chapter identifies measures under consideration in appropriate subject areas.

9.1.3 ONGOING STUDIES THAT COULD INFLUENCE MITIGATION MEASURES IN THE PROJECT PLAN AND DESIGN

Accelerator Transmutation of Waste technology has been under consideration for many years as a process for the treatment of nuclear waste. This technology would involve the use of a chemical separation process, a linear accelerator, and a subcritical nuclear assembly. The chemical process would separate transuranic and certain long-lived radioisotopes from the spent nuclear fuel. The linear accelerator and subcritical nuclear assembly would change the transuranic and long-lived radioisotopes into short-lived radioisotopes and stable (nonradioactive) elements.

The National Research Council studied Accelerator Transmutation of Waste and other technologies for use in the treatment of spent nuclear fuel (National Research Council 1996, all). The study concluded that:

- The use of separation and transmutation to treat spent nuclear fuel is technically feasible.
- Treatment would cost many tens of billions of dollars and require many decades to implement.
- While other technologies would be based on considerable experience, Accelerator Transmutation of Waste technology would require extensive development before DOE could realistically assess its technical feasibility.
- No separation and transmutation technology offers sufficient promise to abandon current spent nuclear fuel management programs or delay the opening of the first nuclear waste repository.
- Even with a successful separation and transmutation program, a monitored geologic repository would still be necessary because the process would be unlikely to provide perfect transmutation, in which case there would be residual materials requiring long-term isolation from human populations and concentrations of human activity.
- Separation and transmutation technology might delay or eliminate the need for a second repository, but there are legislative and less expensive technical ways to increase the capacity of the first repository by an equivalent amount.

In the Fiscal Year 1999 Energy and Water Appropriation Act, Congress directed DOE to conduct an Accelerator Transmutation of Waste study and to prepare a plan for the development of this technology in Fiscal Year 1999. The plan is to address the following:

- The technical issues to be resolved
- A proposed time schedule and program to resolve the technical issues
- The estimated cost of the program
- Consideration of and proposals for collaborative efforts with other countries and programs developing this technology
- The institutional challenges of an Accelerator Transmutation of Waste program
- The impact this technology could have on the civilian spent nuclear fuel program
- Areas of development that could provide benefits to other ongoing programs
- The estimated capital and operational life-cycle costs to treat civilian spent nuclear fuel

The elimination or reduction of certain radionuclides in the disposal inventory could add flexibility to the design of the repository and reduce uncertainties about its performance. DOE will incorporate information from the ongoing study and from any future studies in its decisions during the preparation of the Final EIS and a Mitigation Action Plan for this EIS, if one becomes necessary.

9.2 Yucca Mountain Repository

This section discusses mitigation measures DOE has determined it would implement, or has identified for consideration, to reduce potential impacts from the construction, operation and monitoring, and eventual closure of the proposed repository.

9.2.1 AIR QUALITY

Construction and operation activities such as vehicle movement, clearing, grading, rock pile maintenance, and excavating could generate substantial quantities of fugitive dust. Standard mitigation measures could reduce dust emissions from fugitive dust-generating activities at the Yucca Mountain site. Other dust-generating sources such as operation of the concrete batch plant and backfill preparation facilities would be comparatively small contributors. DOE expects concentrations of other criteria pollutants to be less than 1 percent of regulatory limits (see Chapter 4, Section 4.1.2). Activities that would generate other criteria pollutants include the operation of internal combustion engines in construction equipment, boiler operation, and similar devices, along with limited emissions of radionuclides.

Air Quality Measures Under the Proposed Action

- Reduce fugitive dust emissions using standard dust control measures routinely applied during construction projects including, for example, routine watering of unpaved surfaces; wet suppression for material storage, handling, and transfer operations; and wind fences to control windblown dust. The efficiency of these controls tends to vary depending on site characteristics, but it ranges from a 60- to 80-percent reduction in fugitive dust emissions (Cowherd, Muleski, and Kinsey 1988, page 5-22).

- Reduce maximum fugitive dust concentrations with working controls such as scheduling construction operations to minimize concurrent generation by activities that were near each other (for example, conducting adjacent clearing and grading activities at different times).

9.2.2 HYDROLOGY

This section describes potential mitigation measures for surface water and groundwater.

9.2.2.1 Surface Water

Potential impacts to surface water from the construction, operation and monitoring, and eventual closure of the proposed repository would fall into the following categories: (1) introduction of contaminants, (2) alteration of drainage either by changing infiltration and runoff rates or channel courses, and (3) flood hazards. Changes in infiltration and runoff rates could alter flow rates in channels, cause ponding, and increase erosion. DOE expects such impacts to be minimal (see Chapter 4, Section 4.1.3). Nevertheless, the mitigation of impacts could produce such benefits as erosion control and pollution prevention.

Flash floods could spread contamination from accidental spills. Design and operational controls could mitigate the potential for contamination of surface water from accidental releases of radiological or hazardous constituents. DOE's intent would be to respond rapidly with appropriate cleanup actions.

Surface-Water Measures Under the Proposed Action

- Minimize disturbance of surface areas and vegetation, thereby minimizing changes in surface-water flow and soil porosity that would change infiltration and runoff rates.

- Mitigate flood hazards by designing facilities to withstand or accommodate a 100-year flood, and by designing facilities that would manage radiological materials to withstand the calculated probable maximum flood.

- Minimize physical changes to drainage channels by building bridges or culverts where roadways would intersect areas of intermittent water flow. Use erosion and runoff control features such as proper placement of pipe, grading, and use of rip-rap at these intersections to enhance the effectiveness of the bridges or culverts.

- Maintain natural contours to the maximum extent feasible, stabilize slopes, and avoid unnecessary offroad vehicle travel to minimize erosion.

- In and near floodplains, follow reclamation guidelines (DOE 1995g, all) for site clearance, topsoil salvage, erosion and runoff control, recontouring, revegetation, siting of roads, construction practices, and site maintenance.

- Implement best management practices, including training employees in the handling, storage, distribution, and use of hazardous materials, to provide practical prevention and control of potential contamination sources.

- Conduct fueling operations and store hazardous materials and other chemicals in bermed areas away from floodplains to decrease the probability of an inadvertent spill reaching the floodplains.

- Provide rapid response cleanup and remediation capability, techniques, procedures, and training for potential spills.

Surface-Water Measures Under Consideration

- Use physical controls such as secondary containment for fuel storage tanks to reduce the potential for releases to mingle with stormwater runoff.

- Use control measures such as the installation of hay bales and fabric fences to trap sediments moved by runoff.

9.2.2.2 Groundwater

Impacts to groundwater from the proposed repository could include introduction of contaminants and alteration of infiltration and runoff rates that could change the rate of recharge to the aquifer. Design and operational actions to reduce such impacts for the active life of the repository and the alteration of infiltration and runoff rates would be identical to those described above for surface-water impacts.

The purpose of proposing a monitored geologic repository is to provide a natural setting that, with engineered repository and waste package barriers, would provide long-term confinement and isolation of spent nuclear fuel and high-level radioactive waste. Two aspects of groundwater analysis—(1) the ability of the repository and the engineered barriers to keep waste packages isolated from groundwater over time, and (2) the extent to which groundwater could become contaminated with radionuclides from breached waste packages and transport radionuclides to places where human exposure could occur—are central elements in determining the potential for a proposed repository to succeed. The selection of a potential site with favorable characteristics is a fundamental impact reduction measure.

DOE’s detailed study of the Yucca Mountain site has resulted in the inclusion of many engineered barrier elements to complement the site’s natural characteristics to keep unsaturated zone groundwater from reaching and transporting radionuclides and, thereby, to reduce the long-term potential for impacts. The following summarizes the engineered barrier elements that would contribute to a reduction of the long-term potential for impacts from radionuclides isolated in a Yucca Mountain Repository.

Groundwater Measures Under the Proposed Action

- The Yucca Mountain site has several characteristics (as described in Chapter 3) that indicate a high potential for reducing possible long-term impacts from the disposal of spent nuclear fuel and high-level radioactive waste, including:

    - The Yucca Mountain vicinity is isolated from concentrations of human population and human activity and is likely to remain so.

    - The climate is arid and conducive to evapotranspiration, resulting in a relatively small volume of water that has the capability to move as groundwater within the unsaturated zone of the mountain.

    - The groundwater table is substantially below the level at which DOE would locate a repository, providing additional separation from materials emplaced in waste packages.

    - The sparsely populated hydrogeologic basin into which groundwater from Yucca Mountain flows is closed, providing a barrier to a general spread of radionuclides in the event waste packages were breached and radionuclides reached groundwater.

- Use performance confirmation measures to detect any departure from expected capability of the repository in confining and isolating waste.

- Recycle water collected in subsurface areas for use in dust suppression and other activities, to minimize water consumption.

- Implement measures to minimize the potential for water used during operations to interfere with waste isolation in the repository.

- Minimize surface disturbance, thereby minimizing changes in surface-water flow and soil porosity that could change infiltration and runoff rates.

- Use resistant waste packages and other engineered barriers to prevent water intrusion.

- Monitor to detect and define unanticipated spills, releases, or similar events.

- Evaluate thermal load scenarios to minimize the potential for different heat levels to have a direct effect on corrosion rates and the integrity of containers, as well as on the hydrology, geochemistry, and stability of the drifts. Thermal load could indirectly affect general groundwater flow and the transport of radionuclides.

- Use stainless-steel-lined concrete basins that include leak detection systems, pool cleanup equipment, and transfer equipment capable of moving waste in the event of a leak, and that are designed to seismic standards to minimize the potential for leaks in fuel transfer and holding pools located inside surface facilities.

Groundwater Measures Under Consideration

- Use drip shields to deflect water migrating downward through the unsaturated zone to waste storage areas.

9.2.3 BIOLOGICAL RESOURCES AND SOILS

Potential impacts to biological resources and soils from repository construction, operation and monitoring, and closure could result from land clearing, vehicle movement, materials placement, trenching and excavation, and accidents. This section discusses the potential mitigation of impacts that could affect the desert tortoise and biological resources and soils in general.

9.2.3.1 Desert Tortoise

The desert tortoise is the only Federally protected species that resides on the site of the proposed repository (see Chapter 3, biology sections). Activities that could cause impacts to desert tortoises include site clearing, vehicle traffic, pond management, and taking of habitat. DOE has been conducting site characterization activities in accordance with Fish and Wildlife Service biological opinions on the potential for impacts to desert tortoises (Buchanan 1997, pages 1 and 2). During these activities, five desert tortoises are known to have been killed by site characterization activities, all by vehicle traffic. A recent report (TRW 1998h, page 9) indicates that 27 of 28 tortoise relocations were successful and that two nest relocations were also successful. The one unsuccessful relocation involved a tortoise that returned to the area of disturbance and became one of the five killed by traffic.

The final biological opinion on site characterization (Buchanan 1997, pages 19 to 25) identified the following actions as requirements that DOE would need to implement to minimize impacts on desert tortoises:

- Alignment and final siting of facilities, construction roadways, cleared areas, laydown areas, and similar elements of construction activity can avoid sensitive areas, lessen the likelihood of entrapment of tortoises, and minimize the fragmentation of known desert tortoise habitat.

- Measures to control erosion, dust, and particulate matter would lessen consequences of repository construction, operation and monitoring, and closure for desert tortoises. Similarly, approaches to minimize soil compaction and crushing of vegetation would lessen consequences for desert tortoises.

- Clearance surveys for desert tortoises before vegetation removal or soil disturbances of more than about 2 hectares (5 acres).

- Removal of tortoises or tortoise eggs found in areas to be disturbed, and tortoises in immediate danger along roads or near ongoing activities to safe nearby locations, with project activity ceasing until removal occurred.

- Prohibitions against driving vehicles off existing roads in nonemergency situations unless authorized. All workers at Yucca Mountain would participate in a required tortoise education program.

- A litter-control program that would include the use of covered, raven-proof trash receptacles, disposal of edible trash in trash receptacles following the end of each workday, and disposal of trash in a designated sanitary landfill.

- Revegetation of project areas no longer required.

- Construction and maintenance of tortoise-proof fencing to lessen the potential for endangerment to desert tortoises from project-related activities.

- Placement of escape ramps in trenches and inspection of trenches before filling.

If the proposed project proceeds, the Fish and Wildlife Service would establish conditions for repository construction, operation and monitoring, and eventual closure that DOE would have to observe to protect the desert tortoise. DOE and the Fish and Wildlife Service have not completed the consultation process on potential impacts to the desert tortoise, so the Fish and Wildlife Service has not yet established those conditions. DOE would implement terms and conditions set out in any future biological opinions on the desert tortoise. As discussed in Chapter 4, the proposed repository location is at the extreme northern edge of the range of the desert tortoise, and the population of tortoises at that location is small in relation to other portions of its range. No part of the repository location has been declared critical habitat for the desert tortoise.

The following text discusses potential measures DOE has identified for the protection of the desert tortoise based on determinations the Fish and Wildlife Service made for site characterization.

Desert Tortoise Measures Under the Proposed Action

DOE will adopt all reasonable and prudent impact reduction measures to protect the desert tortoise that are stated in any future biological opinions on the Proposed Action.

Desert Tortoise Measures Under Consideration

- Align and locate facilities, roadways, and cleared areas and place appropriate signs to lessen the likelihood of trapping tortoises and to minimize habitat fragmentation.

- Minimize soil compaction and vegetation crushing.

- Ensure through purification or fencing that evaporation pond water is safe for tortoises.

- Conduct surveys for desert tortoises before any habitat disturbance of more than 4,000 square meters (1 acre). The reasons for the limitation on size of land surveyed are that the desert tortoise density across the site is low and surveys of smaller areas are biologically and economically inefficient.

- Move desert tortoises or desert tortoise eggs from areas to be disturbed, from roadways, and from proximity to ongoing activities to safe nearby locations; stop project activity until completion of these actions.

- Require authorization for nonemergency offroad vehicle travel.

- Ensure that all workers on the Yucca Mountain Project participate in a tortoise education program.

- Establish a litter-control program that would include the use of covered, raven-proof trash receptacles, disposal of edible trash in trash receptacles at the end of each workday, and disposal of trash in a designated sanitary landfill located away from desert tortoise habitat in order to avoid attracting potential predators.

- Revegetate project areas no longer required for the Proposed Action.

- Post road signs to remind drivers of the presence of desert tortoises and other animals, and enforce speed limits.

- Construct and maintain tortoise-proof fencing around actively used construction and operation sites to lessen the potential for danger from project-related activities.

- Provide escape ramps from trenches; inspect trenches before filling them.

9.2.3.2 General Biological Resources and Soils

Impacts to biological resources at the Yucca Mountain site could include habitat fragmentation, loss of individual members of different species, and encroachment of noxious weeds.

Potential soil impacts or concerns related to the proposed repository can be categorized as (1) increased soil erosion rates, (2) slow recovery rate of disturbed soils in the Yucca Mountain environment, and (3) introduction of contaminants. Erosion could result in the loss of the thin topsoil from the disturbed areas, which could affect long-term recovery, be a threat to structures in the region, and result in increased depositions downhill.

General Biological Resources and Soils Measures Under the Proposed Action

- Use the measures described in Section 9.2.1 to control erosion, dust, and particulate matter and therefore to lessen the consequences for biological resources and soils from repository construction, operation and monitoring, and closure.

- Use dust suppression measures on disturbed areas to minimize erosion and aid recovery by reducing wind erosion and supporting compaction.

- Conduct preconstruction surveys in floodplains to ensure that work would not affect important biological resources and to determine the reclamation potential of sites.

- Consider measures to relocate sensitive species in floodplains.

- If construction could threaten important biological resources in floodplains, and modification or relocation of the roads and rail line would not be reasonable, develop additional mitigation.

General Biological Resources and Soils Measures Under Consideration

- Align and locate facilities, roadways, cleared areas, laydown areas, and similar construction activities to minimize fragmentation of habitat potentially affected by the proposed project.

- Mitigate potential soil erosion by minimizing areas of surface disturbance and using engineering practices to stabilize disturbed areas. These practices could include such measures as stormwater runoff control through the use of holding ponds, baffles, and other devices and the compacting of disturbed ground, relocated soil, or excavated material in places outside desert tortoise habitat.

- Mitigate the introduction of contaminants to soils, using methods similar to those described for surface-water impacts (see Section 9.2.2.1).

- To aid recovery, strip and stockpile topsoil from disturbed areas (excavated rock pile, etc.). When the disturbed areas are no longer needed, spread the topsoil over the areas and reseed the soil to improve the success of vegetation reestablishment and prevent encroachment of noxious weeds.

- Provide escape ramps from ponds and basins.

9.2.4 CULTURAL RESOURCES

Land clearing, excavation, and construction activities have the potential to disturb or cause the relocation of cultural artifacts. The operation of industrial facilities can degrade the value of traditional sites or uses. In addition, human activity in project areas causes concern that members of the workforce could affect cultural resource sites, especially those at buried locations or with artifacts.

Actions that DOE would take to mitigate adverse impacts to cultural resources at Yucca Mountain include those required by law or regulation and those that DOE determined the project would include to reduce such impacts. In some cases, precise mitigation measures cannot be identified due to the limited nature of the data (for example, construction activities could reveal previously unidentified sites). To address these cases, programmatic mitigation measures that comply with historic preservation laws and regulations are in place to ensure that DOE would implement appropriate measures following the identification and evaluation of important cultural resources.

The *Programmatic Agreement Between the United States Department of Energy and the Advisory Council on Historic Preservation for the Nuclear Waste Deep Geologic Repository Program, Yucca Mountain, Nevada* (DOE 1988b, all) contains the requirements and general procedures for the mitigation of adverse effects at important archaeological and historic sites in the Yucca Mountain region. The *Research Design and Data Recovery Plan for the Yucca Mountain Project – Permanent Copy* (DOE 1990, all) outlines more detailed approaches and procedures for implementing the mitigation of impacts to archaeological sites. Along with other topics, that document provides specific guidelines for determining the rationale, methods, analytical requirements, and logistics for archaeological mitigation measures at Yucca Mountain. In addition, the Department would consult affected Native American tribes and organizations to ensure that repository activities avoided or minimized adverse impacts to resources or places that are important to Native Americans.

Cultural Resources Measures Under the Proposed Action

- Ensure that onsite employees complete cultural resource sensitivity and protection training to reduce the potential for intentional or accidental harm to sites or artifacts. The training could include descriptions of the importance of different cultural resource types, procedures to follow if resources were encountered in the field, and employment-related and legal penalties for not following the requirements.

- Continue to use the Yucca Mountain Project Native American Interaction Program, which has been in existence since 1985, to promote a government-to-government relationship with Native American tribes and concentrate on the continued protection of important cultural resources. A considerable part of this effort could continue to be directed at protecting these resources and mitigating adverse effects to the fullest extent possible. Historically, as part of this program, members of Native American tribes have made recommendations to DOE about potential adverse effects, mitigation procedures that involve required consultation with tribal governments, and direct involvement of Native Americans in proposed project activities that could affect cultural resources or values (AIWS 1998, pages 1-1, 2-3, and B-1 *et seq.*). Examples of suggested mitigations include incorporating the assistance of Native American people, continued protection of archaeological sites, funding Native American studies on impacts to natural resources and impacts from transportation (AIWS 1999, pages 4-8 to 4-12).

- Conduct preconstruction surveys to ensure that work would not affect important archaeological resources and to determine the reclamation potential of sites.

- If construction could threaten important archaeological resources, and modification or relocation of roads or rail lines would not be reasonable, develop additional mitigation measures.

9.2.5 OCCUPATIONAL AND PUBLIC HEALTH AND SAFETY

There would be a potential for repository workers to receive doses from exposure to radiation during the operation and monitoring and closure phases of repository activities (Chapter 4, Sections 4.1.7 and 4.1.8).

Erionite and cristobalite are hazardous materials that occur naturally in the Yucca Mountain subsurface. Erionite occurs in strata at varying depths below the planned level of the repository. DOE is mapping these strata as part of a general approach that emphasizes avoidance of erionite. If erionite was encountered during drilling, DOE would shut down the affected portion of its operation until it could put proper controls in place.

Cristobalite, which occurs generally in the subsurface rock structure, could be released during excavation operations or in fugitive dust from the excavated rock pile. There would be a potential for cristobalite to be an inhalation hazard to workers. Implementing specific health and safety plans to prevent worker exposure would minimize risks. Chapter 4, Section 4.1.7, discusses erionite and cristobalite.

After closure, there would be potential for human intrusion that could result in release of radioactive materials.

Occupational and Public Health and Safety Measures Under the Proposed Action

- Avoid erionite-bearing strata where practicable during repository construction.
- If drilling encounters erionite, close operations in potentially affected areas until proper controls are in place.
- Use high-efficiency particulate air filters or similar controls if drilling occurs in an area where there is potential for encountering erionite.
- Design repository construction procedures to reduce the risk of worker inhalation of cristobalite.
- Specify features of ventilation systems and other underground equipment to ensure the elimination of opportunities for occupational exposure to health and safety hazards.
- Use ventilation, planned transfer of cristobalite from work areas, and scrubbing of in-place dust to minimize exposure. Use monitoring devices and respirators as appropriate.
- Use ventilation to keep radon levels low in subsurface areas. Use higher ventilation rates and shorter air travel paths to reduce worker exposure to radon.
- Unload, handle, and package spent nuclear fuel and high-level radioactive waste remotely in hot cells or under water.
- Design task procedures to reduce the potential for accidents.
- Implement health and safety procedures to minimize risks to construction and operations workers.

9.2.6 UTILITIES, ENERGY, AND MATERIALS

A monitored repository at Yucca Mountain would require a range of utility services, energy to power a variety of activities, and a number of diverse materials. DOE intends to promote efficiency in the use of utilities, energy, and materials.

Utility, Energy, and Materials Measures Under the Proposed Action

- Implement procedures and equipment that would minimize the use of utility services, energy, and materials.

Utility, Energy, and Materials Measures Under Consideration

- Construct and operate a 3-megawatt solar electric generating facility to reduce demand on the regional power system.

9.2.7 MANAGEMENT OF REPOSITORY-GENERATED WASTE AND HAZARDOUS MATERIALS

As part of the repository design, DOE would institute a waste minimization program similar to the waste minimization and pollution prevention awareness plan successfully implemented during site characterization activities to minimize quantities of generated waste and to prevent pollution (DOE 1997h, all). In addition, DOE would consider innovations to augment the existing program. The Department could keep the size of the Restricted (for radiological control) Area as small as possible, and it could implement programs to ensure that construction and operation activities used, as practicable, smaller quantities of products such as solvents and cleaners. The design of the proposed repository would incorporate pollution prevention measures and would provide cradle-to-grave waste management, as DOE provided during site characterization.

Waste and Hazardous Materials Measures Under the Proposed Action

- Recycle wastewater to reduce the amount of water needed for repository facilities and the amount of wastewater that could require disposal (DOE 1997l, page 14).
- Use practical, state-of-the-art decontamination techniques such as recycling the aqueous low-level radioactive waste stream in the Waste Treatment Building. Use techniques such as pelletized solid carbon dioxide blasting that would reduce waste generation in comparison with other techniques (DOE 1997l, pages 9-13 and 9-14).
- Institute preventive maintenance and inventory management programs to minimize waste from breakdowns and overstocking (TRW 1999a, page 55).
- Whenever practicable, recycle nonradioactive materials such as paper, plastic, glass, nonferrous metals, steel, fluorescent bulbs, shipping containers, oils, and lubricants rather than dispose of them (TRW 1999a, pages 62 and 70). Encourage the reuse of materials and the use of recycled materials.

Waste and Hazardous Materials Measures Under Consideration

- Avoid use of hazardous materials where feasible.

9.2.8 LONG-TERM REPOSITORY PERFORMANCE

DOE proposes a repository at Yucca Mountain to provide for permanent disposal of spent nuclear fuel and high-level radioactive waste. DOE's proposal includes a natural geologic setting that, with engineered repository and waste package barriers, would provide long-term isolation of contaminants. In its design process, DOE is considering many features and approaches to contain and isolate the contaminants it proposes to place in the repository.

DOE's detailed study of the Yucca Mountain site and vicinity has resulted in the evaluation of three categories of potential measures: barriers to limit the release and transport of radionuclides, measures to control heat and moisture in the confined environment of the repository, and measures to improve operational efficiency or safety. Each of these measures has the potential to complement the site's natural characteristics. These measures are conceptual in nature, (that is, they have not been developed or analyzed in detail). The following summarizes elements under consideration that could contribute to a reduction of the long-term potential for impacts from radionuclides isolated in a Yucca Mountain Repository. Appendix E discusses these measures in more detail. Appendix E, Section E.3, discusses enhanced design alternatives, which are various combinations and refinements of the measures described in this section.

Long-Term Performance Measures Under the Proposed Action

DOE has designed an engineered barrier system that would complement the geologic and hydrologic properties of Yucca Mountain to isolate radionuclides in spent nuclear fuel and high-level radioactive waste from accessible portions of the environment. DOE would make use of these engineered features to:

- Locate emplacement areas approximately 300 meters (980 feet) below the surface and approximately 300 meters above the water table.
- Use two-layer waste packages designed to remain intact for thousands of years (at a minimum), with layers that would fail only from different mechanisms and at different rates.

- Encapsulate spent nuclear fuel (normally in zirconium-alloy cladding) and immobilize high-level radioactive waste (normally in borosilicate glass or ceramic matrices) in the waste packages.

- Use steel and concrete supports to hold waste packages off the floors of emplacement drifts.

- Use heat generated from the decay of radioactive material to heat the surrounding rock for 3,000 to 4,000 years to drive water and gas away from the emplaced waste packages.

Long-Term Performance Measures Under Consideration

1. *Barriers to Limit Release and Transport of Radionuclides.* The most direct method to provide the long-term isolation of contaminants is to use structures and techniques that have the potential to inhibit directly the release of contaminants from waste packages or to reduce the likelihood of the transport of released contaminants from the repository. DOE is considering a range of barrier measures that could enhance resistance to corrosion, delay or reduce water transport, retard radionuclide movement and release rates, and reduce the potential for damage to canisters. The Department will continue to evaluate the potential benefits and consequences of these measures together with their compatibility with overall repository system design. The following list contains 10 barrier measures:

- Ceramic coatings on the exterior of the waste package – Could increase waste package life and repository waste isolation performance by reducing corrosion of the waste package surface and delaying the release of radionuclides.

- Drip shields – Would provide a partial barrier to divert infiltrating water away from waste packages in an emplacement drift.

- Backfill in the waste emplacement drifts – Would provide protection to waste packages and drip shields from rockfall and could provide protection against corrosion of the waste packages.

- Waste package corrosion resistant barrier (metal or ceramic) – Would replace the corrosion-allowance barrier in the reference design with a second corrosion-resistant barrier, promoting longer waste package lifetimes and potentially leading to improved long-term waste isolation performance for the repository.

- Richards barrier – Would involve placing a coarse-grained, sand-sized material and then a fine-grained, sand-sized material over emplaced waste packages at closure, potentially delaying the transport of water to the waste packages, retarding waste package corrosion, and improving long-term repository performance.

- Diffusive barrier under waste packages – Loose, dry, granular material placed in the space between each waste package and the bottom of the emplacement drift to form a restrictive barrier to seepage, potentially slowing fluid and radionuclide movement to the natural environment.

- Getter under waste package – Placing a fine-grained material [either phosphate rock (apatite) or iron oxide (hematite, geothite, etc.] with an affinity for sorption of radionuclides in the recess below waste packages prior to waste emplacement could improve long-term waste isolation through retardation of radionuclide movement from the repository drifts.

- Canistered assemblies and waste-specific disposal containers – Placing spent fuel assemblies in canisters at the Waste Handling Building before inserting them into waste packages could provide an additional barrier and further limit mobilization of radionuclides if the waste package was breached.

- Additives and fillers – Placing materials (for example, oxides of iron and aluminum) into waste packages (in addition to those normally required for the basket material) to fill the basket and waste form void spaces could improve both the long-term repository performance (by retarding of release of radionuclides to the groundwater) and the long-term criticality control.

- Ground support options – Placing an engineered system into repository drifts to ensure drift stability before closure could both enhance safety during emplacement and potential retrieval and improve long-term repository performance by reducing or delaying damage to canisters from rockfall (damaged areas are locations for enhanced corrosion even if the canister is not breached by the rockfall).

2. *Measures to Control Heat and Moisture in the Repository Environment.* Long-term influence over heat and moisture in the repository environment could increase the ability of the waste packages to isolate waste. DOE is evaluating measures that have the potential to control temperature and humidity levels in the repository to reduce corrosion rates, increase structural and support system stability, and increase the capability to retain released radionuclides in the repository. The Department will continue to examine the potential for enhancements in repository performance offered by these measures, other consequences of implementing them, and their compatibility with overall repository system design. DOE is considering the 11 items listed below:

- Tailored waste package spatial distribution – Tailoring spatial distribution of the waste packages within the repository block according to waste package heat production, or the tendency of radionuclides in different packages to travel, resulting in a more uniform temperature across the repository. This would improve the performance of waste packages by delaying and reducing contact of water and/or increasing sorption of released radionuclides by zeolites in the unsaturated zone, thereby potentially improving repository waste isolation performance.

- Low thermal load alternative evaluation (similar to the 25-MTHM-per-acre thermal load option evaluated in this EIS) – Increasing repository ventilation rates, increasing the spacing between waste packages or drifts, or reducing the size of waste packages and maintaining reference design spacing could reduce uncertainties regarding elevated temperature of the host rock and could potentially reduce waste package material corrosion rates.

- Continuous post-closure ventilation design – Continuous ventilation of the emplacement drifts during the postclosure period could increase removal of moisture from air around the waste packages for a period of time (though moisture would eventually reestablish itself), and it could improve performance by retarding waste package corrosion.

- Preemplacement aging and blending of spent nuclear fuel and high-level radioactive waste could provide thermal performance benefits for the proposed repository. Aging would reduce the total thermal energy that the repository must accommodate, and blending would reduce the variability in the distribution of the thermal energy in the repository drifts. Potential benefits are improved rock stability and retardation of waste package degradation.

- Continuous preclosure ventilation – Continuous ventilation in the emplacement drifts before repository closure would reduce rock wall and air temperatures and remove moisture to reduce corrosion rates and increase the stability of the ground support system.

- Drift diameter – A smaller diameter drift would be more stable (less rockfall potential), could reduce seepage into the drifts, and could reduce the need for ground support systems, while a larger diameter drift would allow for other modes of emplacement, such as horizontal or vertical borehole emplacement.

- Waste package spacing and drift spacing – Emplacing waste packages nearly end-to-end [that is, with a 0.1-meter (0.3-foot)-gap] with no consideration of individual waste package characteristics would provide a more intense and uniform heat source along the length of emplacement, requiring an increase in emplacement drift spacing and, potentially, continuous ventilation of emplacement drifts, but also would keep emplacement drifts hot and dry for a longer period, decrease the amount of water that could contact waste packages, and reduce the number of emplacement drifts needed for waste emplacement.

- Near-field rock treatment during construction – Filling cracks in a portion of the rock above each emplacement drift with grout to reduce or retard water seepage into the drifts after closure of the repository.

- Surface modification (alluvium) – Covering the surface of Yucca Mountain above the repository footprint with alluvium (soil) could decrease the net infiltration of precipitation water into the repository.

- Surface modification (drainage) – Removing the thin alluvium layer over the footprint of the repository would promote rapid runoff of surface water, potentially reducing infiltration from the top and improving long-term isolation of the waste.

- Higher thermal loading – Higher thermal loading than the 85 MTHM per acre analyzed in this EIS would keep the drift temperature above the boiling point for a longer period, thereby minimizing the amount of moisture around the waste packages for a longer postclosure period, but it potentially would have adverse effects on the surrounding rock.

3. *Repository Designs to Support Operational Considerations.* Including elements in the design that would enhance the repository's operational capabilities could improve access to waste packages after their emplacement, increase access for conducting performance confirmation, inspection, and maintenance activities, ease any effort to augment the repository system with later-developed materials or processes, and facilitate retrieval of waste packages if retrieval became necessary. DOE is considering measures that could provide additional shielding for personnel, increase usable space in drifts, increase opportunities for monitoring, and reduce the potential for moisture to contact waste packages. The Department will continue to assess the potential for design modifications to assist operational activities within the context of overall repository system design. DOE is considering six potential design modification measures:

- Enhanced access design – Additional shielding around the waste package would allow for personnel accessibility during waste package loading, transfer to the drift, emplacement, and performance confirmation, permitting personnel to carry out performance confirmation activities, offering increased access for maintenance and ease of operations, and potentially eliminating some remote handling equipment.

- Modified waste emplacement mode design – Emplacing unshielded waste packages in configurations where the repository's natural or engineered barriers provide shielding (for example, in boreholes drilled into the floor or wall of emplacement drifts, in alcoves off the emplacement drifts, in trenches at the bottom of the emplacement drift, or in short cross drifts excavated between pairs of excavated drifts) would enhance human access, improve performance confirmation efficiency, and facilitate inspections and ground support.

- Rod consolidation – Rod consolidation would involve bringing fuel rods into close contact with one another, allowing the capacity of waste packages to be increased and/or the size of waste packages to be reduced, potentially reducing the size or number of waste packages and, if consolidation were accomplished at the reactor sites, possibly reducing waste transportation shipments.

- Timing of repository closure – Extending the period before final closure, together with a maintenance program to accommodate an extended long-term repository service life and ground support components designed and maintained for a service life of up to 300 years, would allow for reduction of waste package heat output after closure, extended monitoring before closure, and an extended retrieval period for the waste.

- Waste package self shielding – Adding a shielding material on the outside of waste packages would reduce the radiation in the drifts to levels such that personnel access would be possible.

- Repository horizon – A two-level repository would increase repository capacity without moving out of the characterized area. It would increase thermal load to reduce the amount of water that could come in contact with waste packages; add flexibility in emplacing waste packages on the lower level, which could be shielded from moisture infiltration by the upper level; and potentially facilitate retrieval due to the ability to operate two independent retrieval operations at the same time.

9.3 Transportation

This section discusses mitigation measures DOE is required to implement, has determined to implement, or has identified for consideration, to reduce potential impacts from the national transportation of spent nuclear fuel and high-level radioactive waste. These measures address impacts from the possible construction of a branch rail line or an intermodal transfer station in Nevada; construction of other transportation routes; upgrading of existing Nevada highways to accommodate heavy-haul vehicles; transportation of spent nuclear fuel and high-level radioactive waste from existing storage sites to the proposed repository; and fabrication of casks and canisters.

9.3.1 LAND USE

Mitigation measures could address three types of potential land-use impacts resulting from the construction and operation of a rail line or an intermodal transfer station: (1) impacts to publicly used lands such as grazing allotments, (2) direct and indirect land loss, and (3) displacement of capital improvements. Mitigation would not necessarily be associated with the potential selection of a route for heavy-haul trucks, which would follow existing rights-of-way and would require little additional land disturbance.

Land Use Measures Under the Proposed Action

- Ensure that construction activities were consistent with best management practices, by:
    - Ensuring that the location selection and final route alignment for a branch rail line or location selection for an intermodal transfer station consider (1) the minimum impacts to private lands, capital improvements, floodplains or wetlands, areas containing cultural resources, or other environmentally sensitive areas, and (2) indirect loss of land (the division of property or limitation of access) such as the use of grazing allotments.
    - Minimizing the size and number of easements.
    - During the rail construction phase, locating construction camps and staging areas along the rail line in consultation with parties controlling the surrounding lands.
    - Reclaiming disturbed areas outside the permanent right-of-way as soon as practicable after completion of construction.

9.3.2 AIR QUALITY

If DOE selected the Valley Modified rail corridor, mitigation measures could be needed to reduce fugitive dust emissions from rail line construction and carbon monoxide emissions from operations in the Las Vegas nonattainment area. As described in Chapter 6, Section 6.3.2.2.5, fugitive dust emissions during the construction phase could be above the General Conformity Rule *de minimis* levels for particulates. Vehicles used to transport workers and trains used to transport materials would generate criteria pollutants. States could place requirements for control of emissions of volatile organic compounds and nitrous oxide on facilities that manufacture containers and casks.

Air Quality Measures Under Consideration

- Use buses to transport workers, reducing nitrogen oxide and hydrocarbon emissions.
- Reduce fugitive dust emissions using standard dust control measures routinely applied during construction projects including, for example, routine watering of unpaved surfaces; wet suppression for material storage, handling, and transfer operations; and wind fences to control windblown dust. The efficiency of these controls tends to vary depending on site characteristics, but it ranges from a 60- to 80-percent reduction in fugitive dust emissions (Cowherd, Muleski, and Kinsey 1988, page 5-22).
- Reduce maximum fugitive dust concentrations with working controls such as scheduling construction operations to minimize concurrent generation by activities that were near each other (for example, conducting adjacent clearing and grading activities at different times).

9.3.3 HYDROLOGY

This section describes potential mitigation actions for both surface water and groundwater.

9.3.3.1 Surface Water

Three categories of potential impacts to surface water from the construction and operation of a Nevada transportation route are (1) the introduction of contaminants, (2) the alteration of drainage patterns or runoff rates, and (3) flood hazards. The spread of contamination by surface water could result in adverse impacts to plants and animals or to human health in the immediate area. It could also result in the recharge of contaminated water to groundwater. DOE's intent is to respond rapidly to such spills with appropriate cleanup actions.

Surface-Water Measures Under the Proposed Action

- Minimize disturbance of surface areas and vegetation, thereby minimizing changes in surface-water flow and soil porosity that would change infiltration and runoff rates.
- Mitigate flood hazards by designing facilities to withstand or accommodate a 100-year flood.
- Minimize the potential for contamination spread or other physical impacts to surface water by avoiding spills in unconfined areas and areas subject to flash floods, where practicable, and by locating the alignment of a branch rail line or heavy-haul road to avoid floodplains and surface waters, including wetlands, springs, and riparian areas, when possible, and to minimize any potential impacts to these features.
- Maintain natural contours to the maximum extent feasible, stabilize slopes, and avoid unnecessary offroad vehicle travel to minimize erosion.
- Minimize physical changes to drainage channels by building bridges or culverts where roadways would intersect areas of intermittent water flow. Use erosion control features such as proper placement of pipe, revegetation, and use of erosion control at these intersections where practicable to enhance the effectiveness of the bridges or culverts.
- Use physical controls such as secondary containment for fuel storage tanks to reduce the potential for releases to mingle with stormwater runoff.
- In and near floodplains, follow reclamation guidelines (DOE 1995g, all) for site clearance, topsoil salvage, erosion and runoff control, recontouring, revegetation, siting of roads, construction practices, and site maintenance.
- Implement best management practices including training employees in the handling, storage, distribution, and use of hazardous materials to provide practical prevention and control of potential contamination sources.
- Conduct fueling operations and store hazardous materials and other chemicals in bermed areas away from floodplains to decrease the probability of an inadvertent spill reaching the floodplains.
- Provide rapid response cleanup and remediation capability, techniques, procedures, and training for potential spills.

Surface-Water Measures Under Consideration

- Designate bermed or contained sites outside areas subject to flash flooding for fueling and chemical handling to minimize the potential for contamination spreading if spills occurred.

9.3.3.2 Groundwater

Potential transportation-related impacts to groundwater would be most likely to occur from construction activities associated with a potential Nevada transportation route and could include introduction of contaminants and alteration of infiltration and runoff rates that could change the rate of recharge to the aquifer. Design and operational actions to reduce impacts would be identical to those described above for surface-water impacts.

Groundwater Measures Under the Proposed Action

- Implement best management practices, such as training employees in the handling, storage, distribution, and use of hazardous materials, to provide practical prevention and control of potential contamination sources.

- Minimize surface disturbance, thereby minimizing changes in surface-water flow and soil porosity that could change infiltration and runoff rates.

Groundwater *Measures Under Consideration*

- Place construction wells only in undesignated basins. (A Designated Groundwater Basin is one in which the quantity of appropriated water approaches or exceeds the perennial yield as *determined* by the Nevada State Engineer.)

- Employ water-use minimization and recycling techniques to reduce water consumption.

9.3.4 BIOLOGICAL RESOURCES AND SOILS

9.3.4.1 Desert Tortoise

The desert tortoise is the only Federally protected species that resides at or along the potential rail corridors, intermodal transfer station locations, and routes for legal-weight and heavy-haul trucks in Nevada (see Chapter 6, Sections 6.3.1, 6.3.2.1, and 6.3.3.1). Activities that could cause impacts to desert tortoises include site clearing, vehicle traffic, pond management, and taking of habitat.

DOE has been conducting site characterization activities in accordance with Fish and Wildlife Service biological opinions on the potential for impacts to desert tortoises (Buchanan 1997, pages 1 and 2). During these activities, five desert tortoises are known to have been killed by site characterization activities, all by vehicle traffic. A recent report (TRW 1998h, page 9) indicates that 27 of 28 individual tortoise relocations were successful and that two nest relocations were also successful. The one unsuccessful relocation involved a tortoise that returned to the area of disturbance and became one of the five killed by traffic.

The final biological opinion on site characterization (Buchanan 1997, pages 19 to 25) identified the following actions as requirements that DOE would need to implement to minimize impacts on desert tortoises:

- Alignment and final siting of facilities, construction roadways, cleared areas, laydown areas, and similar elements of construction activity could avoid sensitive areas, lessen the likelihood of entrapment of tortoises, and minimize the fragmentation of known desert tortoise habitat.

- Measures to control erosion, dust, and particulate matter would lessen consequences of repository construction, operation and monitoring, and closure for desert tortoises. Similarly, approaches to minimize soil compaction and crushing of vegetation would lessen consequences for desert tortoises.

- Clearance surveys for desert tortoises before vegetation removal or soil disturbances of more than about 2 hectares (5 acres).

- Removal of tortoises or tortoise eggs found in areas to be disturbed, and tortoises in immediate danger along roads or near ongoing activities to safe nearby locations, with project activity ceasing until removal occurred.

- Prohibitions against driving vehicles off existing roads in nonemergency situations unless authorized. All workers at Yucca Mountain would participate in a required tortoise education program.

- A litter-control program that would include the use of covered, raven-proof trash receptacles, disposal of edible trash in trash receptacles following the end of each workday, and disposal of trash in a designated sanitary landfill.

- Revegetation of project areas no longer required.

- Construction and maintenance of tortoise-proof fencing to lessen the potential for endangerment to desert tortoises from project-related activities.

- Placement of escape ramps in trenches and inspection of trenches before filling.

If the proposed project proceeded, the Fish and Wildlife Service would establish conditions for repository-related transportation activities that DOE would have to observe to protect the desert tortoise. DOE would implement terms and conditions set out in any future biological opinions on the desert tortoise. As discussed in Chapter 6, areas that would be affected by transportation activities are at the extreme northern edge of the range of the desert tortoise, and the population of tortoises in these areas is low in relation to other portions of its range. No part of the repository location has been declared critical habitat for the desert tortoise.

The following text discusses potential measures DOE has identified for the protection of the desert tortoise based on determinations the Fish and Wildlife Service made for site characterization.

Desert Tortoise Measures Under the Proposed Action

If a consultation process results from a determination that construction or operation of a transportation corridor associated with the proposed repository could affect threatened or endangered species or their habitat, DOE will adopt all reasonable and prudent measures to protect the desert tortoise or other species that are stated in future biological opinions on transportation corridors.

Desert Tortoise Measures Under Consideration

- Align and locate facilities, roadways, and cleared areas and place appropriate signs to lessen the likelihood of trapping tortoises and to minimize habitat fragmentation.

- Minimize soil compaction and vegetation crushing.

- Move desert tortoises or desert tortoise eggs from areas to be disturbed, from roadways, and from proximity to ongoing activities to safe nearby locations; stop project activity until completion of these actions.

- Require authorization for nonemergency offroad vehicle travel.

- Ensure that all workers on the Yucca Mountain Project participate in a tortoise education program.

- Establish a litter-control program that would include the use of covered, raven-proof trash receptacles, disposal of edible trash in trash receptacles at the end of each workday, and disposal of trash in a designated sanitary landfill located away from desert tortoise habitat in order to avoid attracting potential predators.

- Revegetate project areas no longer required for the Proposed Action.

- Post road signs to remind drivers of the presence of desert tortoises and other animals, and enforce speed limits.

- Construct and maintain tortoise-proof fencing around actively used construction and operation sites to lessen the potential for danger from project-related activities.

- Provide escape ramps from trenches; inspect trenches before filling them.

9.3.4.2 General Biological Resources and Soils

Certain herds of migratory animals could be substantially affected if they were prevented from moving back and forth between ranges at different times of the year. Some of the transportation routes under consideration cross game management areas and wild horse and wild burro management areas. Some routes cross areas traversed by herds of antelope, mule deer, elk, and mountain sheep. Fencing would not be likely to affect the movement of mule deer and elk. Fencing could impede the movements of antelope, mountain sheep, wild horses, and wild burros, effectively dividing management areas for these species.

General Biological Resources and Soils Measures Under the Proposed Action

- Use the measures described in Section 9.2.1 to control erosion, dust, and particulate matter and therefore to lessen the consequences for biological resources and soils from transportation activities.

- Use dust suppression measures on disturbed areas to minimize erosion and aid recovery by reducing wind erosion and supporting compaction.

- Conduct preconstruction surveys in floodplains to ensure that work would not affect important biological resources and to determine the reclamation potential of sites.

- Consider measures to relocate sensitive species in floodplains.

- If construction could threaten important biological resources in floodplains, and modification or relocation of the roads and rail line would not be reasonable, develop additional mitigation.

General Biological Resources and Soils Measures Under Consideration

- Mitigate the introduction of contaminants to soils, using methods similar to those described for surface-water impacts (see Section 9.3.3.1).

- Conduct surveys of areas along the transportation corridor selected for construction to locate areas that are potential habitats for sensitive or State-protected species before the beginning of construction activities. Avoid springs, wetlands, waters of the United States, and riparian areas, if possible.

- Reduce habitat fragmentation and barriers to animal movement by considering the needs and movement patterns of mobile species (for example, wild horses) in the design and construction of rail lines, routes, and fencing. Seek input from wildlife agencies and organizations.

- If the construction and operation of a transportation route in Nevada could not avoid springs and wetlands, minimize the amount of disturbance (to the maximum extent possible) by carefully timing construction activities; minimizing corridor widths; locating laydown, excavated rock pile, and fueling areas away from sensitive areas where practicable; and conducting any wetlands replacement activities in accordance with plans approved by the U.S. Army Corps of Engineers.

- Align and locate facilities, roadways, cleared areas, laydown areas, and similar construction activities to minimize fragmentation of habitat potentially affected by the proposed project.

- Mitigate potential soil erosion by minimizing areas of surface disturbance and using engineering practices to stabilize disturbed areas. These practices could include such measures as stormwater runoff control through the use of holding ponds, baffles, and other devices and the compacting of disturbed ground, relocated soil, or excavated material in places outside desert tortoise habitat.

- To aid recovery, strip and stockpile topsoil from disturbed areas (excavated rock pile, etc.). When the disturbed areas are no longer needed, spread the topsoil over the areas and reseed the soil to improve the success of vegetation reestablishment and prevent encroachment of noxious weeds.

9.3.5 CULTURAL RESOURCES

Land clearing, excavation, and construction activities have the potential to disturb or cause the relocation of cultural artifacts. The operation of industrial facilities can degrade the value of traditional sites or uses. In addition, human activity in project areas causes concern that members of the workforce could affect cultural resource sites, especially those at buried locations or with artifacts.

Actions that DOE would take to mitigate adverse impacts to cultural resources along transportation routes include those required by law or regulation and those built into the project to reduce such impacts. In some cases, DOE cannot identify precise mitigation measures due to the limited nature of the data (for example, construction activities could reveal previously unidentified sites). To address these cases, DOE has programmatic mitigation measures that comply with historic preservation laws and regulations in place to ensure that it would implement appropriate actions after the identification and evaluation of important cultural resources.

Cultural Resources Measures Under the Proposed Action

- Ensure that onsite employees complete cultural resource sensitivity and protection training to reduce the potential for intentional or accidental harm to sites or artifacts. The training could include descriptions of the importance of different cultural resource types, procedures to follow if resources were encountered in the field, and employment-related and legal penalties for not following the requirements.

- Continue to use the Yucca Mountain Project Native American Interaction Program, which has been in existence since 1985, to promote a government-to-government relationship with Native American tribes and concentrate on the continued protection of important cultural resources. A considerable part of this effort could continue to be directed at protecting these resources and mitigating adverse effects to the fullest extent possible. Historically, as part of this program, members of Native American tribes have made recommendations to DOE about potential adverse effects, mitigation procedures that involve required consultation with tribal governments, and direct involvement of Native Americans in proposed project activities that could affect cultural resources or values (AIWS 1998, page 2-19). AIWS (1998, page 4-1) suggested mitigations such as setting aside important cultural and ceremonial areas, and assisting in revegetation and reclamation activities.

- Conduct preconstruction surveys to ensure that work would not affect important archaeological resources and to determine the reclamation potential of sites.

- If construction could threaten important archaeological resources, and modification or relocation of the roads and rail line would not be reasonable, develop additional mitigation measures.

9.3.6 OCCUPATIONAL AND PUBLIC HEALTH AND SAFETY

Over time, traffic accidents involving vehicles associated with the proposed repository would occur. The analysis indicated that fatalities and injuries from traffic accidents (nonradiological events) probably would constitute the largest impact to public health associated with the project. (See the Occupational and Public Safety and Health sections in Chapters 4 and 6.)

During the transportation of spent nuclear fuel and high-level radioactive waste, drivers and escort personnel would be routinely exposed to radiation and would receive radiological doses from this exposure. Workers and members of the public could receive doses from exposures resulting from an accident that released radionuclides.

Occupational and Public Health and Safety Measures Under Consideration

- Establish contract requirements to minimize worker exposure to ionizing radiation.
- Improve design of affected roadways to reduce accidents.
- Promote alternative transportation such as buses for workers to reduce automobile accidents.
- Implement a radiation protection plan for drivers and escort personnel.
- Implement accident reduction measures such as the Commercial Vehicle Safety Alliance procedures.

9.3.7 NOISE

Noise impacts could occur along a transportation corridor, depending on the scenario. Native Americans have expressed concern about noise associated with the transportation corridors and the movement of spent nuclear fuel and high-level radioactive waste to the proposed repository (AIWS 1998, page 2-16). Impacts could result from the construction and operation of the facilities associated with transportation. There is concern that transportation activities could disrupt ceremonies that address Native American concerns for ecological health and the solitude needed for healing or prayer. Other communities could be subject to adverse noise levels, depending on the selected route and the potential to reduce such consequences. DOE expects the potential for adverse impacts from noise to be low.

Noise Control Measures Under Consideration

- Avoid areas with sensitive receptors.

- Avoid Native American ceremonial sites.

- Consider noise intensity, time and distance, and noise canceling or interference factors when planning construction activities and facilities.

- If the transportation corridor passes through areas close to sensitive human receptors (schools, institutions, etc.), plan for noise abatement walls to reduce noise levels at specific locations.

- Install equipment that meets decibel limitations (see Chapter 6).

- Schedule vehicle travel through communities during daylight hours.

- Ensure that the receipt and transfer of material from railcars to heavy-haul trucks at an intermodal transfer station occurred during daylight hours.

9.3.8 MANAGEMENT OF WASTE AND HAZARDOUS MATERIALS

The manufacture of casks and containers could produce liquid and solid waste streams that would require disposal.

Waste and Hazardous Materials Measures Under the Proposed Action

- Design construction to include use of materials, such as depleted uranium, that could otherwise require disposal as wastes.
- Recycle lubricating and cutting oils.
- Recycle solid waste components where practicable.
- Employ ion exchange and filtration or similar methods to treat water used for ultrasonic weld testing for reuse in the manufacturing process.

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10

Unavoidable Adverse Impacts; Short-Term Uses and Long-Term Productivity; and Irreversible or Irretrievable Commitment of Resources

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10. UNAVOIDABLE ADVERSE IMPACTS; SHORT-TERM USES AND LONG-TERM PRODUCTIVITY; AND IRREVERSIBLE OR IRRETRIEVABLE COMMITMENT OF RESOURCES

This chapter discusses adverse impacts that would remain after the application of mitigation measures (see Chapter 9). It analyzes the relationship between short-term uses of the human environment and the maintenance and enhancement of long-term productivity, and it identifies irreversible or irretrievable commitments of resources. The chapter presents information drawn from the analysis of the Proposed Action. It summarizes and consolidates information from the impact and mitigation analyses in Chapters 4, 5, 6, and 9, and provides references to earlier chapters for readers who require more detailed information.

The chapter discusses only resource areas for which preceding analyses have identified unavoidable impacts. Nevertheless, the discussions in Sections 10.1, 10.2, and 10.3 reflect an examination of the resource areas analyzed in this EIS.

The construction, operation and monitoring, and eventual closure of the proposed Yucca Mountain Repository and the associated transportation of spent nuclear fuel and high-level radioactive waste would have the potential to produce some environmental impacts that the U.S. Department of Energy (DOE) could not mitigate. Similarly, some aspects of the Proposed Action could affect the long-term productivity of the environment or would require the permanent use of some resources.

10.1 Unavoidable Adverse Impacts

This section summarizes potential impacts associated with the proposed repository and transportation actions that would be unavoidable and adverse and that would remain after DOE implemented mitigation measures. Chapter 9 discusses mitigation measures. This chapter mentions some but not all mitigation measures. Some aspects and activities discussed in Section 10.1 are analyzed from different perspectives in Sections 10.2 and 10.3.

10.1.1 YUCCA MOUNTAIN REPOSITORY

This section summarizes unavoidable adverse impacts associated with the construction, operation and monitoring, closure, and long-term performance of the proposed repository.

10.1.1.1 Land Use

To develop the proposed Yucca Mountain Repository, DOE would need to obtain permanent control of land surrounding the Yucca Mountain site. DOE could obtain permanent control over the land only if Congress completed a land withdrawal action. A Congressional withdrawal would include lands already withdrawn for the Nevada Test Site and Nellis Air Force Range as well as lands under the control of the Bureau of Land Management and not currently withdrawn.

In general, the permanent withdrawal of land for the repository would prevent human use of the withdrawn lands for other purposes. Nevada Test Site activities would continue on a noninterference basis unless the Congressional land withdrawal specifically precluded them. Because the Yucca Mountain site has a low present resource value, is remote, and is partly withdrawn, the resultant impact would be small.

The disposal of spent nuclear fuel and high-level radioactive waste could permanently affect the availability of the surface and subsurface of the Yucca Mountain site. The Chapter 4 land-use discussion includes the availability of the land and the consequences of withdrawal.

10.1.1.2 Air Quality

Construction, operation and monitoring, and closure of a repository at Yucca Mountain would produce very small impacts to regional air quality. Radiological impacts could occur from the release of radionuclides. The principal radionuclides released from the subsurface would be naturally occurring radon-222 and its decay products in ventilation exhaust air. There are no applicable regulatory limits for radon releases from Yucca Mountain facilities. Other impacts would come from criteria pollutants and materials such as cristobalite and erionite. Exposures of maximally exposed individuals to radionuclides and criteria pollutants would be a small fraction of applicable regulatory limits.

10.1.1.3 Hydrology

Construction activities would temporarily restrict and minimally alter natural surface-water drainage channels. Facilities and roadways would be designed to withstand at least a 100-year flood. Therefore, after construction was complete, only flow from infrequent more intense floods would affect those facilities and roadways. Ground-disturbing activities and the surface facilities that DOE would build would alter surface-water infiltration and runoff rates in localized areas. Given the relatively small size of the affected land in comparison to the total drainage area, drainage channels and washes would experience little difference in impacts as a result of the disturbances. DOE estimates that overall consequences from the construction of roadways and facilities would be minimal. Appendix L contains a floodplain/wetlands assessment that examines the effects of branch rail line and highway route construction, operation, and maintenance on floodplains in the vicinity of Yucca Mountain.

There would be withdrawals of groundwater during construction, operations and monitoring, and closure, but they would not exceed estimates of perennial yield. Chapter 4, Section 4.1.3, provides details on the effects of repository construction, operation and monitoring, and closure on hydrology.

In the reference design, waste packages would be placed about 300 meters (1,000 feet) below the mountain surface and about 300 meters above the water table (see Section 5.2). Even if future climates were much wetter than they are today, the mountain would not be likely to erode and leave the waste exposed, and the water table would not be likely to rise high enough to reach the waste.

In the current semiarid climate, about 18 centimeters (7 inches) of water a year from rain and snow fall on Yucca Mountain. Nearly all of that precipitation, about 95 percent, runs off or evaporates. Only about 0.65 centimeter (0.31 inch) of water per year moves down (or percolates) through the nearly 300 meters (1,000 feet) of rock to reach the proposed level of the repository (see Chapter 3, Section 3.1.4).

After waste packages were placed in the repository, the heat generated from radioactive decay would raise the temperature in the drifts above the boiling point of water. The heat should dry the surrounding rock and drive any water away for hundreds to thousands of years. However, as the waste decayed and the repository cooled, some water would begin to seep through fractures in the rock into the drifts and pass through the repository.

Analysts estimate that, after the repository cooled enough, about 5 percent of the packages could experience dripping water under the current climate. If the climate changed to a wetter long-term average, about 30 percent of the packages could experience dripping water. Based on preliminary results of corrosion experiments and the opinions of experts, computer simulations indicated that most waste packages would last more than 10,000 years, even if water was dripping on them. The longevity of manmade materials in the repository environment over such long periods is subject to considerable uncertainty, however, and some waste packages could fail earlier. Analysts estimated that dripping water could cause the first penetrations—tiny pinholes—to appear in some waste packages after about 4,000 years. More substantial penetrations could begin to occur about 10,000 years later. Analysts also assumed that at least one waste package would fail within 1,000 years due to a manufacturing defect (see Chapter 5, Section 5.4.1).

After water entered a waste package, it would have to penetrate the metal cladding of the spent nuclear fuel to reach the waste. For about 99 percent of the commercial spent nuclear fuel, the cladding is highly corrosion-resistant metal designed to withstand the extreme temperature and radiation environment in the core of an operating nuclear reactor. Current models indicate that it would take thousands of years to corrode cladding sufficiently to allow water to reach the waste and begin to dissolve the radionuclides.

During the thousands of years required for water to reach the waste, the radioactivity of most of the radionuclides would decay to virtually zero. For the remaining radionuclides to get out of the waste package, they would have to dissolve in the water. Few of the remaining radionuclides could dissolve at a meaningful rate. Thus, only long-lived water-soluble radionuclides could get out of the waste package. Long-lived water-soluble radionuclides that migrated from the waste packages would have to move down through about 300 meters (1,000 feet) of rock to the water table and then travel about 20 kilometers (12 miles) to reach a point where they could be taken up in a well and consumed or used to irrigate crops (see Chapter 5, Sections 5.3 and 5.4).

As the long-lived water-soluble radionuclides began to move down through the rock, some would stick (or adsorb) to the minerals in the rock and be delayed in reaching the water table. After reaching the water table, radionuclides would disperse to some extent in the larger volume of groundwater beneath Yucca Mountain, and the concentrations would be diluted. Eventually, groundwater with varying concentrations of different radionuclides would reach locations in the hydrologic (groundwater) region of influence where the water could be consumed.

Of the approximately 200 different radioactive isotopes present in spent nuclear fuel and high-level radioactive waste, nine are present in sufficient quantities and are sufficiently long-lived, soluble, mobile, and hazardous to contribute meaningfully to calculated radiation exposures.

10.1.1.4 Biological Resources and Soils

Unavoidable adverse impacts to biological resources would include the loss of small pieces of habitat totaling less than 2 square kilometers (500 acres). The pieces that would be disturbed are habitat for terrestrial plant and animal species that are widespread throughout the region and typical of the Mojave and Great Basin Deserts. The death or displacement of individuals of some animal species as a result of site clearing and vehicle traffic would be unavoidable; however, changes in the regional population of any species would be minimal and largely undetectable.

No endangered species are found on the site. The only threatened species on the site is the desert tortoise (see Chapter 4, Section 4.1.4). Approximately 2 square kilometers (500 acres) of desert tortoise habitat would be lost. This habitat is at the northern end of the range of the desert tortoise and is not designated critical habitat for the tortoise. The quantity of habitat that could be lost would be minimal in comparison to the range of the desert tortoise. Individual tortoises could be killed inadvertently during site clearing and by vehicle traffic. Preconstruction surveys, relocation of affected individuals, and general adherence to conditions developed in the course of endangered species consultations would minimize, but not prevent, such deaths. Chapter 4, Section 4.1.4, discusses in detail the potential for loss of habitat or the deaths of individual members of this species. Chapter 9 (Sections 9.2.3 and 9.3.4) discusses mitigation measures to reduce potential impacts to the desert tortoise, including measures to locate facilities and roadways to avoid sensitive areas and measures to protect tortoises from construction impacts.

10.1.1.5 Cultural Resources

In the view of Native Americans, the implementation of the proposed repository and its facilities would further degrade the environmental setting. Even after closure and reclamation, the presence of the repository would, from the perspective of Native Americans, represent an irreversible impact to traditional lands.

Some unavoidable adverse impacts could occur to archaeological sites and other cultural resources, although no such sites or culturally important artifacts have been found at the site of the proposed repository. There could be a loss of archaeological information due to illicit artifact collection. In addition, excavation activities could cause a loss of archaeological information. Chapter 3, Section 3.1.6, discusses the program DOE has in place to address and mitigate cultural resource impacts and issues. DOE anticipates this program would continue through repository closure.

NATIVE AMERICAN VIEW

A Native American view of facility and transportation route development, especially in remote areas such as Yucca Mountain and its surroundings, as expressed in the *American Indian Perspectives on the Yucca Mountain Site Characterization Project and the Repository Environmental Impact Statement* (AIWS 1998, pages 2-20 and 3-1), is that development of such facilities and routes inherently degrades the entire environment. This view is based on the concept that the earth, its waters, the air, and the sky are a whole and have a sacred integrity in their natural form. Chapter 4, Section 4.1.13, of this EIS presents an environmental justice discussion of this Native American perspective.

10.1.1.6 Occupational and Public Health and Safety

There would be a potential for injuries to or fatalities of workers from facility construction, including accidents and inhalation of cristobalite. Cristobalite is a naturally occurring hazardous material in the rock of Yucca Mountain. Engineering controls and training and safety programs would reduce but not eliminate the potential for injuries or fatalities to workers.

Short-term impacts during the operation and monitoring phase would present a potential for injuries or fatalities to workers from industrial accidents and exposure to radioactive materials. Engineering controls and training and safety programs would reduce but not eliminate the potential. There would also be a potential for injuries and fatalities during closure. The occupational and public health and safety discussion in Chapter 4 (Sections 4.1.7 and 4.1.8) provides details on the potential for worker injuries and fatalities. The potential for injury or death to members of the public from exposure to radioactive materials or industrial activity would be extremely small.

While there would be a potential for radioactive contamination of groundwater during the 10,000-year analysis period from materials stored at the proposed repository, there would be only a small potential for such contamination to produce long-term adverse health impacts in the surrounding region during this period. Potential long-term impacts to human health from the repository in the far future would be dominated by impacts from radioactive materials dissolved or suspended in water pathways. The dose to the maximally exposed individual would depend on the distance from the repository and the uses made of the land and waters.

At the closest distance evaluated [5 kilometers (3 miles)], the highest 95th-percentile annual dose to the maximally exposed individual for the 10,000-year analysis period could be 1.3 millirem per year. The highest chance of a latent cancer fatality to this hypothetical individual would be 4.4 in 100,000 (see Chapter 5, Section 5.4.1). A latent cancer fatality is a cancer fatality that could occur after and as a result of exposure to radionuclides from the repository and that would be in addition to cancer fatalities occurring from all other causes.

Expected doses and consequences to the population from exposure to radionuclides transported by groundwater from the repository were forecast for the 10,000-year analysis period. The 95th-percentile population dose over the 10,000-year period could be 0.032 person-rem over an assumed 70-year lifetime. The estimated 95th-percentile chance that a single latent cancer fatality could occur in the population during any 70-year lifetime would be 1.6 in 100,000. Over the 10,000-year analysis period, the estimated chance that a latent cancer fatality could occur would be 5.3 in 10,000 (see Chapter 5, Section 5.4.1). These consequences would be small.

DOE estimates that most waste packages would remain intact longer than 10,000 years. Current model simulations forecast that some packages would last more than 1 million years. The highest 95th-percentile peak annual dose rate to a hypothetical maximally exposed individual could be 9,100 millirem per year approximately 320,000 years in the future. The highest mean peak annual dose rate to a maximally exposed individual could be 1,400 millirem per year approximately 792,000 years in the future (see Chapter 5, Section 5.4).

There would also be a potential that chromium releases could produce estimated peak concentrations during the first 10,000 years of 0.037 milligram per liter at 5 kilometers (3 miles) (95th-percentile probability). This value is about one-third of the threshold for contamination in drinking water.

10.1.2 NEVADA TRANSPORTATION ACTIONS

This section summarizes unavoidable adverse impacts associated with the transportation of spent nuclear fuel and high-level radioactive waste and with the construction and operation of transportation facilities and routes in Nevada. Chapter 6 (Sections 6.1.2 and 6.3) provides more detailed discussions.

10.1.2.1 Land Use

Constructing and operating a new branch rail line would result in unavoidable changes to present land uses and control of the lands affected directly. The range of potentially affected uses includes grazing, wildlife habitat and management areas, utility corridors, lands leased for oil and gas development, and military lands. Present uses of adjoining lands would be affected only minimally. Each of the five alternative rail alignments encompasses a range of different land uses and surface features. If the choice was to construct a new branch rail line, the selection of a specific corridor would determine the land actually taken and the extent of impacts to land uses along that corridor. Land disturbed for a specific corridor implementing alternative could vary from 5 to 19 square kilometers (1.9 to 7.3 square miles). Most land along the corridors under consideration is government-owned.

Routes for heavy-haul or legal-weight trucks would follow existing highways and would require little additional land disturbance. Building and operating an intermodal transfer station would result in unavoidable changes of land use and ownership. The land for an intermodal transfer station could be public or private. Actual land uses lost would depend on the site selected. DOE expects that the total land disturbance for any implementing alternative for the construction of an intermodal transfer station and construction along existing highways would be 0.2 square kilometer (about 50 acres). For heavy-haul truck routes originating at Caliente, an additional 0.04 square kilometer (10 acres) could be required for a mid-route stop. For the Caliente heavy-haul truck route only. A further 0.04 square kilometer could be required for the construction of a highway segment near Beatty, Nevada.

In some instances transportation facilities could remain in place to serve other purposes after DOE had ended use. Similarly, affected land could revert to other uses after the end of transportation activities and the removal of facilities.

10.1.2.2 Hydrology

The construction of a branch rail line or the upgrading of roads to accommodate heavy-haul transportation in Nevada would involve the unavoidable adverse impact of altering natural surface-water drainage patterns. Any of the Nevada transportation corridors would cross a number of natural drainage channels. Upgrade activities for a route to be used by heavy-haul trucks would involve the extension of existing drainage control structures as necessary to support the road upgrades. In this case, there would be minor changes to drainage channels already altered to some extent by the original road construction. The construction of a branch rail line would require alterations to many natural drainage areas along the line. Bridges and culverts would be used as necessary to cross streams, creeks, or, most predominantly, washes of any size. These structures would be built to accommodate a 100-year flow in the channels; the resulting drainage alteration would be confined to relatively small areas. Construction could alter small drainage channels or washes more because the railway design could call for the collection of some channels to a single culvert. At the end of the period during which DOE would transport spent nuclear fuel and high-level radioactive waste to the repository, the Department could remove facilities built for transportation and land recovery could begin, or it could use the facilities for other purposes. Appendix L contains a floodplain/wetlands assessment that presents a comparison of what is known about the floodplains, springs, and riparian areas along the five alternative rail routes and at the three alternative intermodal transfer station sites with their five associated heavy-haul routes.

10.1.2.3 Biological Resources and Soils

Unavoidable adverse impacts to biological resources from transportation in Nevada could occur as a result of habitat loss and the deaths of small numbers of individual members of the species along transportation routes. Habitat loss would be associated with the construction of either a new rail line or an intermodal transfer station and upgrades to existing highways. This loss would occur in widely distributed land cover types, and would include the loss of a small amount of desert tortoise habitat and the deaths of a small number of tortoises. The deaths of individual members of a species as a result of construction activities or from vehicle traffic would be unlikely to produce detectable changes in the regional population of a species.

Transportation route construction or upgrades would subject disturbed soils to increased erosion for at least some of the construction phase. The recovery of these disturbed areas to predisturbance conditions would occur with the passage of time. Transportation facilities such as a branch rail line could be used for nonrepository-related purposes, potentially extending their useful life beyond the period needed for the Proposed Action. The removal of transportation facilities after the end of their useful life would assist habitat recovery.

10.1.2.4 Cultural Resources

Some unavoidable impacts could occur to archaeological sites and other resources as a result of the construction of a rail line or the upgrade of a highway to heavy-haul capability. The potential for impacts to specific resources cannot be identified before final surveys and actual construction. An agreement now in effect between DOE and the Advisory Council on Historic Preservation for repository site characterization could serve as a model for an agreement to protect archaeological sites and other resources along transportation corridors. In addition, a number of statutes provide protective frameworks (see Chapter 11). Nevertheless, there would be a potential for grading and other construction activities to degrade, cause the removal of, or alter the setting of archaeological sites or other cultural resources. Although mitigated to some extent by worker education programs, there could be some loss of archaeological information due to the illicit collection of artifacts. In addition, excavation activities could cause loss of archaeological information.

10.1.2.5 Occupational and Public Health and Safety

Certain adverse impacts to workers and the public from the construction and operation of the rail and heavy-haul implementing alternatives would be unavoidable. Table 10-1 presents potential impacts to worker health during construction and the potential for traffic fatalities among the implementing alternatives during operations.

Table 10-1. Unavoidable adverse impacts from rail and heavy-haul truck implementing alternatives.[a]

Implementing alternative	Construction (worker injuries and illnesses)	Operation (traffic fatalities)
Rail		
Caliente	110	0.83
Carlin	100	0.85
Caliente-Chalk Mountain	80	0.81
Jean	68	0.61
Valley Modified	32	0.60
Heavy-haul truck		
Caliente	32	2.7
Caliente-Chalk Mountain	19	2.2
Caliente-Las Vegas	22	2.5
Apex/Dry Lake	13	1.5
Sloan/Jean	14	1.6

a. Source: Chapter 6, Sections 6.3.2.1 and 6.3.3.1.

The transportation of spent nuclear fuel and high-level radioactive waste would have the potential to affect workers and the public through exposure to radiation and vehicle emissions and through traffic accidents. This EIS evaluates two transportation scenarios—one in which DOE would transport the materials mostly by truck and the other in which it would transport the materials mostly by rail. DOE estimates that the transportation of spent nuclear fuel and high-level radioactive waste in the mostly truck scenario could cause approximately 23 latent cancer fatalities among workers and the public as a result of exposure to radiation and emissions over the course of 24 years. Over the same period, DOE estimates that transportation mostly by rail could cause approximately 4 latent cancer fatalities among workers and the public. In addition, DOE estimates that transportation mostly by truck or mostly by rail could result in approximately 3.9 or 3.7 traffic fatalities, respectively (see Chapter 6, Section 6.2.4.2).

10.2 Relationship Between Short-Term Uses and Long-Term Productivity

The Proposed Action could require short-term uses of the environment that would affect long-term environmental productivity. This section describes possible consequences to long-term productivity from those short-term environmental uses.

The EIS analysis identified two distinct periods for the evaluation of the use of the environment by the Proposed Action:

- A 120- to more than 300-year period for surface activities consisting of construction, operation and monitoring, and closure of the proposed repository. DOE activities during this period would include construction of facilities, receipt and emplacement of spent nuclear fuel and high-level radioactive waste, recovery of recyclable materials, decontamination, closure of surface and subsurface facilities, reclamation of land, and long-term monitoring. Sections 10.1.1.1 through 10.1.1.6 describe the unavoidable impacts that could occur during this period. This period would be the only time during which DOE would actively use the affected lands and the only time during which activities would involve the surface of the land used for the repository.

- The balance of a 10,000-year period would be for the evaluation of consequences from the disposal of spent nuclear fuel and high-level radioactive waste.

In general, transportation and disposal activities associated with the proposed repository would benefit long-term productivity by removing spent nuclear fuel and high-level radioactive waste from 72 commercial and 5 DOE sites around the country. In addition, removing these materials from existing sites would also free people and resources committed—now and in the future—to monitoring and safeguarding these materials for other potentially more productive activities. Removal could create conditions that would enable the initiation of other productive uses at the commercial and DOE sites. Finally, disposing of spent nuclear fuel and high-level radioactive waste in the proposed repository would provide a long-term global benefit by isolating the materials from concentrations of human population and human activity, thereby reducing the potential for sabotage.

10.2.1 YUCCA MOUNTAIN REPOSITORY

This section summarizes the relationship between short-term uses of land and resources and long-term land and resource productivity for the construction, operation and monitoring, closure, and long-term performance of the proposed repository. The terms "short-term" and "long-term" commonly used in National Environmental Policy Act analyses do not have a consistent duration in this section. For the analysis of impacts associated with repository activities, *short-term* refers to the time from the start of construction to the end of relevant surface and subsurface human activity, which DOE anticipates to be a 120- to 300-year period. *Long-term* refers to the time between the end of relevant surface and subsurface human activity and the time when environmental resources have recovered from the potential for impacts and are again productive, or a maximum of 10,000 years. For transportation, *short-term* refers to the time of construction or actual transportation, as appropriate. *Long-term* refers to the time from the end of the short-term period to the time of environmental recovery. *Productivity* refers to the ability of an element of the environment to generate crops, provide habitat, or otherwise serve as a medium for the creation of value.

10.2.1.1 Land Use

From the start of construction through the 10,000-year period, the construction, operation and monitoring, and closure of the proposed repository would deny other users the use of the Yucca Mountain vicinity for other purposes. Chapter 4, Section 4.1.1, discusses the long-term uses of land. Conversely, a repository at Yucca Mountain would enable consideration of other uses for the sites where spent nuclear fuel and high-level radioactive waste are being stored and the land buffering those sites. Many present storage sites are in locations that would permit a wider range of alternative uses than does Yucca Mountain.

10.2.1.2 Hydrology

The proposed repository would be in a terminal basin that is hydrologically isolated and separated from other bodies of surface and subsurface water; that is, once water enters the basin it can leave only by evapotranspiration. As noted in Section 10.1.1.3, there would be a potential for materials disposed of at the proposed Yucca Mountain Repository to reach groundwater at some time between several thousand years and several hundred thousand years. If such contamination reached groundwater in the accessible environment, and if the groundwater contamination exceeded applicable regulatory requirements, there could be an attendant loss of productivity for the affected groundwater and for surface waters in the basin that the groundwater supplied. Conversely, the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain would free a wide range of major and minor water bodies throughout the United States from the potential threat of radioactive contamination from the materials at the present storage sites.

10.2.1.3 Biological Resources and Soils

Short-term uses that could cause impacts to biological resources and soils would be associated with the construction, operation and monitoring, and closure of the repository; those activities could lead to long-term productivity loss in disturbed areas. This loss would be limited to less than 2 square kilometers (500 acres) of widely distributed habitats adjacent to existing disturbed areas. Biological resources would be affected directly by land disturbances. The overall impact to populations of species would be limited because the area disturbed and the number of individual animals lost would be small in relation to the regional availability.

Long-term productivity loss for soils would be limited to areas affected by land disturbances. These areas would be revegetated after the completion of closure activities. Revegetation would be accomplished through the reclamation of disturbed sites using surface soils stockpiled during construction, reseeding, and similar activities that would enhance recovery. Chapter 4, Section 4.1.4, contains more detail on productivity losses and reclamation. The disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain would remove these materials from proximity to biota near the present storage sites across the United States.

10.2.1.4 Occupational and Public Health and Safety

A repository at Yucca Mountain would be likely to have a positive effect on the nationwide general occupational and public health because of the cessation of doses to workers at the present storage sites and because the spent nuclear fuel and high-level radioactive waste would be substantially more isolated from concentrations of people and from pathways to concentrations of people.

10.2.2 TRANSPORTATION ACTIONS

The construction of a rail line or an intermodal transfer station and improvements to existing highways, all short-term uses, could lead to a long-term loss of productivity in disturbed areas along the routes. In the context of transportation, *long-term* refers to the period of environmental recovery after the end of the construction period or the active use of a transportation route for repository purposes. A route could be used for repository purposes from 10 to approximately 30 years.

The land cover types along any route are widely distributed in the region. A loss of vegetation from a disturbed area along a route would have little effect on the regional productivity of plants and animals.

Productivity loss for soils would be limited to areas affected by land clearing and construction. These areas would not be available for revegetation and habitat for some time. Disturbed areas would recover, however, and eventually would return to predisturbance conditions, although the process of recovery would be slow in the arid environment. Chapter 6 contains more data on transportation.

The construction of a rail line, if the line were also used for nonrepository uses, could result in productivity benefits for Nevada by increasing transportation opportunities, lowering transportation costs, reducing accidents, and lowering nitrogen oxides, carbon monoxide, and other gaseous criteria pollutant emissions by diverting transportation from highway to rail.

The major long-term consequence of transporting spent nuclear fuel and high-level radioactive waste to the repository would be the permanent consolidation of these materials in an isolated location away from concentrations of people and without exposure pathways to concentrations of people.

10.3 Irreversible or Irretrievable Commitment of Resources

The Proposed Action would involve the irreversible or irretrievable commitment of land, energy, and materials. The commitment of a resource is irreversible if its primary or secondary impacts limit future options for the resource. An irretrievable commitment refers to the use or consumption of resources that are neither renewable nor recoverable for later use by future generations. Construction, operation and monitoring, and eventual closure of a repository at Yucca Mountain would result in a permanent commitment of land, groundwater, surface, subsurface, mineral, biological, soil, and air resources; materials such as steel and concrete; and consume energy in forms such as gasoline, diesel fuel, and electricity. Water use would support construction, operation and monitoring, and closure actions, and options for using groundwater could become limited if there was contamination from radionuclides. There would be an irreversible and irretrievable commitment of associated natural resource services such as uses of land and habitat productivity.

10.3.1 YUCCA MOUNTAIN REPOSITORY

The construction, operation and monitoring, closure, and long-term performance of the Yucca Mountain Repository would result in the permanent commitment of the surface and subsurface of Yucca Mountain and the permanent withdrawal of lands from public use. Because of the remote location of Yucca Mountain, the lack of present uses of the land, the terminal and isolated nature of the water basin, and the limited amounts of materials and energy required for the repository in comparison to the supply capability of the regional and national economies, the irreversible and irretrievable commitments of resources for repository-related activities would be small.

Mitigation approaches that would involve the excavation of archaeological sites to prevent degradation by construction activities would destroy the contexts of those sites and reduce the finite number of such resources in the region. DOE expects that its activities at the proposed repository would affect no more than a minimal number of such sites. The Department would use state-of-the-art mitigation techniques on the Yucca Mountain Project.

Electric power, fossil fuels, and construction materials would be irreversibly committed to the project. Most of the steel used for the surface facilities would be recyclable and, therefore, not an irreversible or irretrievable commitment. Some copper and steel in the ramps and access mains to subsurface facilities would be recyclable, while some in the emplacement drifts would be irreversibly and irretrievably lost. Some steel, such as rebar, would be difficult to recycle. The quantity of resources consumed would be small in comparison to their national consumption or their availability to consumers in southern Nevada.

These quantities are described in Chapter 4. To the extent that there is value in spent nuclear fuel or high-level radioactive waste, that value would be committed to the repository.

Aggregate would be crushed as required and mixed in concrete for the cast-in-place and precast concrete structures and liners that would be used in the repository. The amount of sand and aggregate could range from 500,000 to 1.5 million metric tons (550,000 to 1.7 million tons). If Yucca Mountain tuff was used, the amount crushed and used as sand and aggregate would be about 10 percent of the total excavated from the drifts (see Chapter 4, Section 4.1.11).

10.3.2 TRANSPORTATION ACTIONS

The construction of a rail line or an intermodal transfer station would result in an irretrievable but not irreversible commitment of resources. Many resources could be retrieved at a later date through such actions as removing roadbeds, revegetating land, and recycling materials. Land uses would change along the selected transportation corridor during repository construction, operation and monitoring, and closure, thereby limiting or eliminating other land uses for that period. At the end of that period, however, land along the corridor could revert to public or private ownership.

Mitigation approaches involving the recovery of archaeological resources before construction activities degraded the sites would reduce the finite number of such resources in the Yucca Mountain region and destroy the context of sites. DOE would use state-of-the-art mitigation techniques during the construction of a rail corridor or an intermodal transfer station or the modification of roadways to accommodate heavy-haul trucks. Heavy-haul construction would be likely to generate only minimal impacts to cultural resources because construction would largely involve modifications to existing roads.

DOE would use about 500 to 700 million liters (132 to 185 million gallons) of fossil fuel from the nationwide supply system to transport spent nuclear fuel and high-level radioactive waste to the repository. The analysis in Chapter 6 (Sections 6.1.2.10, 6.3, 6.3.2.1, 6.3.2.2, 6.3.3.1, and 6.3.3.2), evaluates fuel use for the different transportation scenarios. The amount used would be a very small fraction of a percent of the Nation’s supply over the period of fuel use.

The manufacture of casks and containers would require commitment of aluminum, chromium, copper, depleted uranium, lead, molybdenum, nickel, and steel. The required amounts of these materials, expressed as percentages of U.S. production, would be low with the exception of nickel, which would require approximately 8.2 percent of annual U.S. production.

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11

Statutory and Other Applicable Regulations

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11. STATUTORY AND OTHER APPLICABLE REQUIREMENTS

The U.S. Department of Energy (DOE) has conducted site characterization activities in accordance with requirements of applicable laws and regulations and a range of permits and approvals that regulate the various aspects of the activities. The Department has successfully met environmental protection standards for its site characterization activities by developing a comprehensive approach to environmental compliance that ensures adherence to Federal and state requirements. It has implemented specific environmental compliance programs for pollution prevention, protection of cultural resources, and protection of threatened or endangered species. In its future actions involving Yucca Mountain, DOE will continue to comply with applicable Federal and state environmental requirements and with the conditions of the permits and approvals that might be required to conduct its activities.

This chapter identifies major requirements that could be applicable to the Proposed Action, which is to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. Section 11.1 lists statutory and regulatory provisions that set requirements potentially applicable to siting a monitored geologic repository. Section 11.2 summarizes statutes and regulations that set environmental protection requirements that could apply to a repository at Yucca Mountain. Section 11.3 contains a list of DOE Orders that could apply to activities related to the proposed repository. Section 11.4 contains a list of potentially applicable requirements compiled by the DOE Office of Civilian Radioactive Waste Management.

Table 11-1 lists potential new permits, licenses, and approvals that DOE could need for construction, operation, and closure of the Yucca Mountain Repository.

11.1 Statutes and Regulations Establishing or Affecting Authority To Propose, License, and Develop a Monitored Geologic Repository

Nuclear Waste Policy Act of 1982, as amended (42 USC 10101-10270)

The Nuclear Waste Policy Act, as amended in 1987 (called the NWPA), directs DOE to characterize and evaluate the suitability of only Yucca Mountain in southern Nevada as a potential site for a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste. After considering the suitability of the site and other information, the Secretary may then recommend approval of the site to the President. Further, the NWPA directs that this Site Recommendation would constitute a major Federal action and that an EIS must accompany a recommendation that the President approve the site for a repository. In accordance with the NWPA, the Secretary of Energy must submit an application for construction authorization to the U.S. Nuclear Regulatory Commission within 90 days of the effective date of a Presidential designation of Yucca Mountain as a site for a repository.

The NWPA directs the U.S. Environmental Protection Agency to promulgate generally applicable standards for protection of the environment from offsite releases from radioactive material in repositories. In addition, it requires the Nuclear Regulatory Commission to consider and approve or disapprove an application (if DOE submits one) for authorization to construct a repository for these materials based on Commission standards, which are to be consistent with the Environmental Protection Agency standards. In 1983, the Nuclear Regulatory Commission promulgated licensing requirements (10 CFR Part 60) that contain criteria governing the issuance of a construction authorization and license for a geologic repository (see Table 11-1, item 1). These requirements would allow DOE to develop a repository for the receipt and disposal of spent nuclear fuel and high-level radioactive waste and would establish conditions under which DOE could receive and possess source, special nuclear, and byproduct

Table 11-1. Permits, licenses, and approvals needed for a monitored geologic repository.

Activity	Regulatory action	Statute or regulation	Agency(ies)
1. Repository construction, operation, and closure	Construction authorization, license to operate and monitor, and license for closure	10 CFR[a] Part 60	Nuclear Regulatory Commission
2. Repository construction, operation, and closure	Authorization to Withdraw Land From Public Use	43 CFR Part 2300	Congress, Bureau of Land Management
3. Air emissions	Approvals for New Sources of Toxic Air Pollutants	40 CFR Parts 61 and 63	Environmental Protection Agency
		NAC 445B.287 *et seq.*[b]	Nevada Division of Environmental Protection
4. Air emissions	Air Quality Operating Permit	NAC 445B.287 *et seq.*	Nevada Division of Environmental Protection
5. Air emissions	National Emission Standards for Hazardous Air Pollutants Subpart H (Radionuclides)	40 CFR Part 61	Environmental Protection Agency
		10 CFR Part 20	Nuclear Regulatory Commission
	National Primary and Secondary Ambient Air Quality Standards	40 CFR Part 50	Environmental Protection Agency
6. Certification of facilities	Certification of Air and Water Pollution Control Facilities	40 CFR Part 20	Environmental Protection Agency
7. Drinking water	Water System Operating Permit	NAC Section 445A	Nevada Health Division
8. Effluents	Stormwater Discharge	40 CFR Part 122	Environmental Protection Agency
		NAC 445.070 *et seq.*	Nevada Division of Water Planning
9. Effluents	National Pollutant Discharge Elimination System	40 CFR Part 122	Environmental Protection Agency
	State Water Pollution Control Permit	NAC Section 445A	Nevada Division of Water Planning, Nevada Division of Environmental Protection
10. Excavation; facility construction	Cultural Resource Review Clearance, Section 106 Agreement	36 CFR Part 800	Advisory Council on Historic Preservation, State Historic Preservation Officer
11. Excavation; facility construction	Permit to Proceed (Objects of Antiquity)	36 CFR Part 296	Department of the Interior
		43 CFR Parts 3 and 7	
12. Excavation; facility construction	Permit for Excavation or Removal of Archaeological Resources	16 USC 470 *et seq.*	Department of the Interior, affected Native American Tribes
13. Facility construction	Free-Use Permit	43 CFR Part 3600	Bureau of Land Management, Forest Service
14. Facility construction	Permit for the discharge of dredged or fill materials to Waters of the United States	Clean Water Act, Section 404	U.S. Army Corps of Engineers
15. Facility construction	Right-of-way reservation	43 CFR 2800	Bureau of Land Management
16. Facility construction and operation	Endangered Species Consultation	50 CFR 402.6	Fish and Wildlife Service
17. Materials storage	Hazardous Materials Storage Permit	NAC Sections 459 and 477	Nevada State Fire Marshal

[a] CFR = Code of Federal Regulations.

[b] NAC = Nevada Administrative Code.

material at a geologic repository. The requirements in 10 CFR Part 60 do not apply to any nonrepository activities licensed under other parts of Title 10 of the Code of Federal Regulations.

Congress originally passed the Nuclear Waste Policy Act in 1982. The original legislation directed the Secretary of Energy to recommend potential sites to the President for possible characterization as geologic repositories, and it directed the President to select sites for characterization. The original Nuclear Waste Policy Act also required the Secretary of Energy to issue general guidelines for use in recommending potential geologic repository sites for detailed site characterization. DOE issued those guidelines in 1984 (10 CFR Part 960) and applied them when it nominated five sites as suitable for characterization and recommended characterization of three of the sites.

DOE also decided to include in the general guidelines a process for evaluating the data obtained from site characterization activities to be used in determining whether a site should be recommended for the development of a geologic repository. In 1996, DOE proposed amendments to the general guidelines to establish a site-specific standard for evaluating the suitability of the Yucca Mountain site for possible recommendation for development as a repository. DOE has not issued final amendments. In the Site Recommendation, if any, DOE will consider the guidelines applicable at that time.

Section 116(c) of the NWPA establishes a procedure by which DOE can consider and, if appropriate, address a broad array of considerations. The State of Nevada or an affected unit of local government can describe impacts that are likely to result from site characterization in a report and submit it to the Secretary of Energy. Section 116 of the NWPA allows DOE to consider these impacts as a basis for DOE providing technical or financial assistance. In contrast to the National Environmental Policy Act process, a Section 116(c) determination of impact assistance is not tied to an extensive body of past precedent or regulatory interpretations. DOE has broad discretion under Section 116(c) to consider impacts that the State of Nevada or an affected unit of local government might identify.

Energy Policy Act of 1992 (42 USC 10101 *et seq.*)

The Nuclear Waste Policy Act of 1982 directed the Environmental Protection Agency to establish standards to protect the general environment from offsite releases of radioactive materials from repositories, and directed the Nuclear Regulatory Commission to issue technical requirements and criteria for such repositories. In 1992, Congress passed the Energy Policy Act, modifying the rulemaking authorities of the Environmental Protection Agency and the Nuclear Regulatory Commission with respect to a potential repository at Yucca Mountain. Section 801(a) of the Energy Policy Act of 1992 directed the Environmental Protection Agency (1) to retain the National Academy of Sciences to make findings and recommendations on reasonable public health and safety standards for Yucca Mountain, and (2) to establish Yucca Mountain-specific standards based on and consistent with these findings and recommendations. The standards are to set health-based limits for any radioactive releases from a repository at Yucca Mountain. The DOE repository design must meet Nuclear Regulatory Commission requirements for demonstrating compliance with the Environmental Protection Agency standards.

The National Academy of Sciences issued its findings and recommendations in a 1995 report (National Research Council 1995, all). When the Environmental Protection Agency establishes its final standards, it will place them in the Code of Federal Regulations, probably at 40 CFR Part 197.

Section 801(b) of the Energy Policy Act directs the Nuclear Regulatory Commission to revise its general technical requirements and criteria for geologic repositories (10 CFR Part 60) to be consistent with the site-specific Yucca Mountain standard established by the Environmental Protection Agency. In February 1999, the Nuclear Regulatory Commission issued draft site-specific technical requirements and criteria (proposed 10 CFR Part 63). When finalized, the Commission would use these requirements and criteria in their final forms to approve or disapprove an application to construct a repository at Yucca Mountain, to receive and possess spent nuclear fuel at such a repository, and to close and decommission such a repository.

National Environmental Policy Act of 1969, as amended (42 USC 4321 *et seq.*)

The National Environmental Policy Act requires agencies of the Federal Government to prepare environmental impact statements (EISs) on potential impacts of proposed major Federal actions that may significantly affect the quality of the human environment.

DOE has prepared this EIS in accordance with the requirements of the National Environmental Policy Act as implemented by Council on Environmental Quality regulations (40 CFR Parts 1500 through 1508) and DOE National Environmental Policy Act regulations (10 CFR Part 1021), and in conformance with the NWPA.

Atomic Energy Act of 1954, as amended (42 USC 2011 *et seq.*)

The Atomic Energy Act, as amended, provides fundamental jurisdictional authority to DOE and the Nuclear Regulatory Commission over governmental and commercial use of nuclear materials. The Atomic Energy Act ensures proper management, production, possession, and use of radioactive materials. It provides DOE the authority to develop generally applicable standards for protecting the environment from radioactive materials. In accordance with the Atomic Energy Act, DOE has established a system of requirements that it has issued as DOE Orders.

The Atomic Energy Act gives the Nuclear Regulatory Commission specific authority to regulate the possession, transfer, storage, and disposal of nuclear materials, as well as aspects of transportation packaging design requirements for radioactive materials, including testing for packaging certification. Commission regulations applicable to the transportation of radioactive materials (10 CFR Parts 71 and 73) require that shipping casks meet specified performance criteria under both normal transport and hypothetical accident conditions.

Federal Land Policy and Management Act of 1976 (43 USC 1701 *et seq.*)

The Federal Land Policy and Management Act governs the use of Federal lands administered by the Bureau of Land Management, which is an agency of the U.S. Department of the Interior. Access to and use of public lands administered by the Bureau are primarily governed by the regulations regarding the establishment of rights-of-way (43 CFR Part 2800) and withdrawals of public domain land from public use (43 CFR Part 2300) (see Table 11-1, item 2), as described below in this section.

Some implementing alternative branch rail lines, routes for heavy-haul trucks, and intermodal transfer station locations that could be involved in transportation of spent nuclear fuel and high-level radioactive waste to Yucca Mountain would cross or occupy land administered by the Bureau of Land Management and would require right-of-way reservations (see Table 11-1, item 14). DOE has obtained right-of-way reservations from the Bureau of Land Management and a concurrence from the U.S. Air Force for access to the Yucca Mountain vicinity for characterization activities.

To develop a monitored geologic repository at Yucca Mountain, DOE would need to obtain control of Bureau of Land Management, Air Force, and DOE lands in western Nevada. Land withdrawal is the method by which the Federal Government gives exclusive control of land it owns to a particular agency for a particular purpose. Nuclear Regulatory Commission licensing conditions for a repository include a requirement that DOE either own or have permanent control of lands for which it is seeking a repository license, and that lands used for a repository be free and clear of all encumbrances, if significant, such as (1) rights arising under the general mining laws, (2) easements or rights-of-way, and (3) all other rights arising under lease, rights of entry, deed, patent, mortgage, appropriation, prescription, or otherwise.

The Federal Land Policy and Management Act, by which the Government accomplishes most Federal land withdrawals, contains a detailed procedure for application, review, and study by the Bureau of Land

Management, and decisions by the Secretary of the Interior on withdrawal and on the terms and conditions of withdrawal. Withdrawals accomplished through the Federal Land Policy and Management Act remain valid for no more than 20 years and, therefore, do not appear to meet the permanency of control required by the Nuclear Regulatory Commission.

Only Congress has the power to withdraw Federal lands permanently for the exclusive purposes of specific agencies. Through legislative action, Congress can authorize and direct a permanent withdrawal of lands such as those proposed for the Yucca Mountain Repository. In addition, Congress would determine any conditions associated with the land withdrawal.

Executive Order 11514, *National Environmental Policy Act, Protection and Enhancement of Environmental Quality*

Executive Order 11514 directs Federal agencies to monitor and control their activities continually to protect and enhance the quality of the environment. The Order also requires the development of procedures both to ensure the fullest practicable provision of timely public information and understanding of Federal plans and programs with potential environmental impacts, and to obtain the views of interested parties. DOE has promulgated regulations (10 CFR Part 1021, *National Environmental Policy Act Implementing Procedures*) and has issued a DOE Order (451.1A, *National Environmental Policy Act Compliance Program*) to ensure compliance with this Executive Order.

11.2 Statutes, Regulations, and Orders Regarding Environmental Protection Requirements

11.2.1 AIR QUALITY

Clean Air Act, as amended (42 USC 7401 *et seq.*)

The Clean Air Act is intended to "protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of its population." Section 118 of the Act requires Federal agencies such as DOE, with jurisdiction over any property or facility that might result in the discharge of air pollutants, to comply with "all Federal, state, interstate, and local requirements" related to the control and abatement of air pollution.

The Clean Air Act requires the Environmental Protection Agency to establish National Ambient Air Quality Standards to protect public health, with an adequate margin of safety, from any known or anticipated adverse effects of a regulated pollutant (42 USC 7409). It also requires the establishment of national standards of performance for new or modified stationary sources of atmospheric pollutants (42 USC 7411) and the evaluation of specific emission increases to prevent a significant deterioration in air quality (42 USC 7470). In addition, the Clean Air Act regulates emissions of hazardous air pollutants, including radionuclides, through the National Emission Standards for Hazardous Air Pollutants Program (40 CFR Parts 61 and 63). Air emission standards are established at 40 CFR Parts 50 through 99.

Nevada Revised Statutes: Air Emission Controls, Chapter 445B

These statutes and regulations in the Nevada Administrative Code implement State and Federal Clean Air Act provisions, identify the requirements for permits for each air pollution source (unless it is specifically exempted), and identify ongoing monitoring requirements. In accordance with the Clean Air Act, DOE could have to obtain an Operating Permit from the Nevada Division of Environmental Protection for the control of gaseous, liquid, and particulate emissions associated with the construction and operation of a repository at Yucca Mountain (see Table 11-1, item 4). To ensure that its site characterization activities comply with applicable Clean Air Act and State provisions, DOE has obtained an operating permit for surface disturbances and point source emissions.

11.2.2 WATER QUALITY

Safe Drinking Water Act, as amended [42 USC 300(f) *et seq.*]

The primary objective of the Safe Drinking Water Act is to protect the quality of public water supplies. This law grants the Environmental Protection Agency the authority to protect the quality of public drinking water supplies by establishing national primary drinking water regulations. In accordance with the Safe Drinking Water Act, the Environmental Protection Agency has delegated authority for enforcement of drinking water standards to the states. Regulations (40 CFR Parts 123, 141, 145, 147, and 149) specify maximum contaminant levels, including those for radioactivity, in public water systems, which are generally defined as systems that serve at least 15 service connections or regularly serve at least 25 year-round residents.

The Safe Drinking Water Act also authorizes the Environmental Protection Agency to regulate the underground injection of waste and other contaminants into wells. The Agency has codified its regulations at 40 CFR Part 144. The Proposed Action would not constitute underground injection.

In 1978, the Environmental Protection Agency approved the Nevada program for enforcing drinking water standards. The Nevada Health Division is responsible for enforcement of these standards. The proposed repository would include a drinking water system that obtained water from a source off the repository site, and DOE would operate the system in accordance with Nevada Health Division permitting requirements, if applicable (see Table 11-1, item 6).

Clean Water Act of 1977 (33 USC 1251 *et seq.*)

The purpose of the Clean Water Act, which amended the Federal Water Pollution Control Act, is to "restore and maintain the chemical, physical, and biological integrity of the Nation's water." The State of Nevada has been delegated the authority to implement and enforce most programs in the State under the Clean Water Act; exceptions include those addressed by Section 404, which is administered by the U.S. Army Corps of Engineers, as described below in this section.

The Clean Water Act prohibits the "discharge of toxic pollutants in toxic amounts" to navigable waters of the United States. Section 313 of the Act generally requires all departments and agencies of the Federal Government engaged in any activity that might result in a discharge or runoff of pollutants to surface waters to comply with Federal, state, interstate, and local requirements. Under the Clean Water Act, states generally set water quality standards, and the Environmental Protection Agency and states regulate and issue permits for point-source discharges as part of the National Pollutant Discharge Elimination System permitting program. The Environmental Protection Agency regulations for this program are codified at 40 CFR Part 122, and Nevada rules for this program are codified at Nevada Administrative Code Chapter 445A. If the construction or operation of a Yucca Mountain Project facility or associated transportation route in Nevada would result in point-source discharges, DOE could need to obtain a National Pollutant Discharge Elimination System permit from the State of Nevada Division of Environmental Protection (see Table 11-1, item 8).

Sections 401 and 405 of the Water Quality Act of 1987 added Section 402(p) to the Clean Water Act. Section 402(p) requires the Environmental Protection Agency to establish regulations for the Agency or individual states to issue permits for stormwater discharges associated with industrial activity, including construction activities that could disturb 5 or more acres (40 CFR Part 122). Nevada rules for this program are codified at Nevada Administrative Code Chapter 445A. The Agency has promulgated regulations implementing a separate stormwater permit application process.

Section 404 of the Clean Water Act gives the U.S. Army Corps of Engineers permitting authority over activities that discharge dredge or fill material into waters of the United States. DOE could need to obtain a permit from the Corps for activities associated with a repository at Yucca Mountain if those activities would discharge dredge or fill into any such waters. If the construction or modification of rail lines or highways to the repository included dredge or fill activities or other actions that would discharge dredge or fill into waters of the United States, those activities would also require Section 404 permits. DOE has obtained a Section 404 permit for site characterization-related construction activities it might conduct in Coyote Wash or its tributaries or in Fortymile Wash.

Nevada Revised Statutes: Water Controls, Chapter 445A

These statutes classify the waters of the State, establish standards for the quality of all waters in the State, and specify permitting and notification provisions for stormwater discharges and for other discharges to waters of the State in accordance with provisions of the Federal Clean Water Act. These statutes and regulations in the Nevada Administrative Code also (1) set drinking water standards, specifications for certification, and conditions for issuance of variances and exemptions, (2) set standards and requirements for the construction of wells and other water supply systems, (3) establish the different classes of wells and aquifer exemptions, and (4) establish requirements for well operation and monitoring, plugging, and abandonment activities. Regardless of whether these provisions are applicable, DOE has obtained an Underground Injection Control Permit and a Public Water System Permit for site characterization activities at Yucca Mountain. The Underground Injection Control Permit covers tracers, pump tests, and similar activities. The Public Water System Permit establishes the terms for the provision of potable water.

The Department would install and operate the drinking water system planned for the proposed repository in accordance with Nevada Health Division standards, if applicable, and could obtain a Water System Operating Permit from the Nevada Health Division (see Table 11-1, item 6). DOE could need to obtain a General Permit for Storm Water Discharge from the Nevada Division of Water Resources to construct and operate a repository at Yucca Mountain (see Table 11-1, item 7). Any point-source discharges to waters of the State that occurred in the course of Yucca Mountain Project activities could require a National Pollutant Discharge Elimination System permit issued under these provisions. Regardless of whether these provisions are applicable, DOE has obtained a general discharge permit from the State for effluent discharges to the ground surface during site characterization.

Nevada Revised Statutes: Underground Water and Wells, Chapter 534

These statutes and regulations in the Nevada Administrative Code establish the ownership of underground waters in the State and their appropriation for beneficial use. The regulations also establish licensing requirements for well drillers; requirements for drilling, construction, and plugging of wells; and protection of aquifers from pollution and waste. Regardless of whether these provisions are applicable, DOE has obtained a permit for the use of underground water from several wells during site characterization, and it could apply for additional or expanded authority under these provisions, if needed and applicable.

Executive Order 11988, *Floodplain Management*

This Order directs Federal agencies to establish procedures to ensure that any Federal action undertaken in a floodplain considers the potential effects of flood hazards and floodplain management and avoids floodplain impacts to the extent practicable. For its site characterization activities, DOE conducted a floodplain assessment (see Appendix L) in accordance with this Order (DOE 1992b, all) and DOE implementing regulations (10 CFR Part 1022).

Compliance With Floodplain/Wetlands Environmental Review Requirements (10 CFR Part 1022)

Federal regulations (10 CFR Part 1022) establish policy and procedures for implementing Executive Order 11988, *Floodplain Management*, and for discharging DOE responsibilities regarding the consideration of floodplain/wetlands factors in DOE planning and decisionmaking. These regulations also establish DOE procedures for identifying proposed actions located in floodplains, providing opportunity for early public review of such proposed actions, preparing floodplain assessments, and issuing statements of findings for actions in a floodplain. The rules apply to all DOE proposed floodplain actions.

If DOE determines that an action it proposes would take place wholly or partly in a floodplain, it is required to prepare a notice of floodplain involvement and a floodplain assessment containing a project description, a discussion of floodplain effects, alternatives, and mitigations. For a proposed floodplain action for which a National Environmental Policy Act document such as an environmental impact statement or an environmental assessment is required, DOE is to include the floodplain assessment in the document. For floodplain actions for which DOE does not have to prepare such a document, the Department is to issue a separate document as the floodplain assessment. After the conclusion of public comment, DOE is to reevaluate the practicability of alternatives and of mitigation measures, considering all substantive comments.

If it finds that no practicable alternative to locating in the floodplain is available, DOE must design or modify its action to minimize potential harm to and within the floodplain. For actions in a floodplain, DOE must publish a statement of findings of three pages or less containing a brief description of the proposed action, a location map, an explanation indicating the reason for locating the action in the floodplain, a list of alternatives considered, a statement indicating whether the action conforms to applicable State or local floodplain protection standards, and a brief description of steps DOE will take to minimize potential harm to or within the floodplain. For floodplain actions that require the preparation of an EIS, the Final EIS can incorporate the statement of findings. Before implementing a proposed floodplain action, DOE must endeavor to allow at least 15 days of public review of the statement of findings.

Appendix L contains a floodplain/wetlands assessment that examines the effects of proposed repository construction and operation and potential construction of a rail line or intermodal transfer station. The assessment includes discussion of:

1. Floodplains near Yucca Mountain (Fortymile Wash, Busted Butte Wash, Drillhole Wash, and Midway Valley Wash); there are no delineated wetlands at Yucca Mountain.

2. What is known about floodplains and areas that might have wetlands (for example, springs and riparian areas) along potential rail corridors in Nevada and at intermodal transfer station locations associated with heavy-haul routes. If DOE selects rail as the mode of spent nuclear fuel and high-level radioactive waste transport in Nevada to Yucca Mountain, one of five rail corridors would be selected. If DOE selected heavy-haul as the mode of transport for spent nuclear fuel and high-level radioactive waste to Yucca Mountain, it would select one of five heavy-haul routes and one of three intermodal transfer stations, and would prepare a more detailed floodplain/wetlands assessment of the selected rail corridor or heavy-haul route.

11.2.3 HAZARDOUS MATERIALS PACKAGING AND TRANSPORTATION

Hazardous Materials Transportation Act (49 USC 1801)

The Hazardous Materials Transportation Act gives the U.S. Department of Transportation authority to regulate the transport of hazardous materials, including radioactive materials such as those that would be transported to the proposed Yucca Mountain Repository from 72 commercial and 5 DOE sites. Department of Transportation regulations (49 CFR Parts 171 through 180) would require the identification of hazardous materials during transportation to a repository at Yucca Mountain, set forth rules for the selection of routes that carriers must use when transporting such materials, and provide guidance to states in designating preferred routes.

Emergency Planning and Community Right-to-Know Act of 1986 (42 USC 1001 *et seq.*)

Under Subtitle A of the Emergency Planning and Community Right-to-Know Act (also known as "SARA Title III"), Federal facilities, including a repository at Yucca Mountain, must provide information on hazardous and toxic chemicals to state emergency response commissions, local emergency planning committees, and the Environmental Protection Agency. The goal of providing this information is to ensure that emergency plans are sufficient to respond to unplanned releases of hazardous substances. The required information includes inventories of specific chemicals used or stored and descriptions of releases that occur from sites. This law, implemented at 40 CFR Parts 302 through 372, requires agencies to provide material safety data sheet reports, emergency and hazardous chemical inventory reports, and toxic chemical release reports to appropriate local, state, and Federal agencies. DOE has been complying with the provisions of the Emergency Planning and Community Right-to-Know Act and with regulations for maintaining and using inventories of chemicals for site characterization activities. If the proposed repository received a license, DOE would continue to comply with such provisions, as applicable, in storing and using chemicals for project activities.

Nevada Revised Statutes: Hazardous Materials, Chapter 459

A Nevada Hazardous Materials Storage Permit could be required to store hazardous materials in quantities greater than those specified in the Uniform Fire Code. To receive such a permit, if sought, DOE would submit an application to the Nevada State Fire Marshal (Nevada Revised Statutes, Chapter 477) that describes its plans for the storage of hazardous materials in excess of specified quantities (see Table 11-1, item 16). If permit renewal was sought each year, DOE would have to submit an annual report to the State Fire Marshal that complied with the reporting requirements of the Federal Emergency Planning and Community-Right-to-Know Act, Sections 302, 311, and 312. Regardless of whether these provisions are applicable, DOE has obtained a permit from the State Fire Marshal for the storage of flammable materials during site characterization activities.

Nuclear Regulatory Commission Radioactive Materials Packaging and Transportation Regulations (10 CFR Parts 71 and 73)

Under 10 CFR Part 71, the Nuclear Regulatory Commission regulates the packaging and transport of spent nuclear fuel for its licensees, which include commercial shippers of radioactive material and the DOE Office of Civilian Radioactive Waste Management. In addition, under an agreement with the U.S. Department of Transportation, the Commission sets the standards for packages containing Type B quantities of radioactive materials, including high-level radioactive waste and spent nuclear fuel. Type B packages are designed and built to retain their radioactive contents in both normal and accident conditions.

The demonstration of compliance with these requirements applies a combination of simple calculational methods, computer modeling techniques, and physical testing to the design features of the package. An applicant presents the results of the analyses and tests to the Nuclear Regulatory Commission in a Safety

Analysis Report for Packaging, which the Commission, after review, approves by issuing a Certificate of Compliance. This certificate would be required for the use of a package (cask) to ship spent nuclear fuel or high-level radioactive waste to the repository.

The regulations at 10 CFR Part 73 govern safeguards and physical security during the transit of shipments of spent nuclear fuel. These regulations specify requirements for vehicles, carrier personnel, communications, notification of state governors, escorts, and route planning for such shipments.

Department of Transportation Hazardous Materials Packaging and Transportation Regulations 49 CFR Subchapter C – Hazardous Materials Regulations, Parts 171 Through 180)

The Department of Transportation regulates the shipments of hazardous materials, including spent nuclear fuel and high-level radioactive waste, in interstate and intrastate commerce by land, air, and navigable water. As outlined in a 1979 Memorandum of Understanding with the Nuclear Regulatory Commission (44 *FR* 38690, July 2, 1979), the Department of Transportation specifically regulates carriers of spent nuclear fuel and the conditions of transport, such as routing, handling and storage, and vehicle and driver requirements. It also regulates the labeling, classification, and marking of transportation packages for radioactive materials.

Department of Transportation regulations include requirements for carriers, drivers, vehicles, routing, packaging, labeling, marking, placarding of vehicles, shipping papers, training, and emergency response. The requirements specify the maximum dose rate associated with radioactive material shipments and the maximum allowable levels of radioactive surface contamination on packages and vehicles.

The public highway routing regulations of the Department of Transportation are prescribed in 49 CFR Part 397. The objectives of the regulations are to reduce the impacts of transporting highway route-controlled quantities of radioactive materials to establish consistent and uniform requirements for route selection, and to identify the role of state and local governments in the routing. The requirements at 49 CFR 173.403(l) contain a complete definition of a highway route-controlled quantity of radioactive material. A highway route-controlled quantity of radioactive material (49 CFR 173.403) is a quantity in a single package (shipping cask) that exceeds the smallest of:

- 3,000 times the A_1 values of the radionuclides as specified in 10 CFR 173.435 for special form Class 7 (radioactive) material
- 3,000 times the A_2 values of the radionuclides as specified in 10 CFR 173.433 for normal form Class 7 (radioactive) material
- 27,000 curies

Shipping casks transported by legal-weight trucks typically would contain about 300,000 curies of radionuclides, and rail casks typically would contain larger quantities. These regulations attempt to reduce potential hazards by requiring the use of routes that avoid populous areas and minimize travel times. At present, the Department of Transportation does not regulate the routing of rail shipments of radioactive materials. Department of Transportation regulations also include requirements to protect the health and safety of transportation workers.

11.2.4 CONTROL OF POLLUTION

Pollution Prevention Act of 1990 (42 USC 13101 *et seq.*)

The Pollution Prevention Act of 1990 establishes a national policy for waste management and pollution control that focuses first on source reduction, then on environmentally safe recycling, treatment, and disposal. DOE requires each of its sites to establish specific goals to reduce the generation of waste. If the Department built and operated a repository at the Yucca Mountain site, it would implement an appropriate pollution prevention plan. DOE has implemented a pollution prevention plan for site characterization activities. DOE would update this plan to include construction, operation and monitoring, and closure activities if the repository received a license.

Comprehensive Environmental Response, Compensation, and Liability Act, as amended (42 USC 9601 *et seq.*)

The Comprehensive Environmental Response, Compensation, and Liability Act, as amended by the Superfund Amendments and Reauthorization Act, authorizes the Environmental Protection Agency to require responsible site owners, operators, arrangers, and transporters to clean up releases of hazardous substances, including certain radioactive substances. Under this Act, the Environmental Protection Agency would have the authority to regulate hazardous substances, including certain radioactive materials, at the Yucca Mountain Repository in the event of a release or a "substantial threat of a release" of those materials from the repository. Releases greater than reportable quantities would be reported to the National Response Center.

Standards for Protection Against Radiation (10 CFR Part 20)

The purpose of 10 CFR Part 20 is to provide standards and procedures for protection against radiation. Provisions of 10 CFR Part 20 address radiation protection programs, occupational dose limits, public dose limits, survey and monitoring procedures, exposure control in restricted areas, respiratory protection and controls, precautionary procedures, and related topics.

Resource Conservation and Recovery Act, as amended (42 USC 6901 *et seq.*)

The treatment, storage, and disposal of hazardous and nonhazardous waste is regulated in accordance with the provisions of the Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act and the Hazardous and Solid Waste Amendments of 1984, and applicable state laws.

Environmental Protection Agency regulations implementing the hazardous waste portions of the Resource Conservation and Recovery Act define hazardous wastes and specify requirements for their transportation, handling, treatment, storage, and disposal (40 CFR Parts 260 through 272). In addition, under current Civilian Radioactive Waste system requirements, DOE could not accept hazardous waste for disposal at Yucca Mountain. Before shipping to Yucca Mountain, DOE would treat materials that contained hazardous components to eliminate the hazardous waste characteristics. Before shipping materials containing hazardous components listed under Subpart D of Part 261 or applicable state requirements, DOE would process any necessary delisting petitions with the appropriate regulatory authorities. If the activities at Yucca Mountain generated hazardous or mixed waste, the Department would not treat or dispose of such waste on the site, and would not store such waste on the site for more than 90 days. DOE does not expect to need a Resource Conservation and Recovery Act permit for its activities at the proposed repository.

Noise Control Act of 1972, as amended (42 USC 4901 *et seq.*)

Section 4 of the Noise Control Act directs Federal agencies to carry out programs in their jurisdictions "to the fullest extent within their authority" and in a manner that furthers a national policy of promoting an environment free from noise that jeopardizes health and welfare. This law provides requirements related to noise that would be generated by construction, operation, or closure activities associated with the Proposed Action at Yucca Mountain.

Nevada Revised Statutes: Sanitation, Chapter 444

These statutes and regulations in the Nevada Administrative Code establish the standards, permits, and requirements for septic tanks and other sewage disposal systems for single-family dwellings, communities, and commercial buildings. The construction and operation of a sanitary sewage collection system at Yucca Mountain could require the State of Nevada to approve DOE designs and to issue a permit. In connection with site characterization activities, DOE operates a septic system that the State has permitted under these provisions.

These statutes and regulations also set forth the definitions, methods of disposal, special requirements for solid waste collection and transportation standards, and classification of landfills. Onsite disposal of solid waste from a repository at Yucca Mountain could require that DOE obtain an appropriate permit for these activities.

In compliance with the Resource Conservation and Recovery Act, the Environmental Protection Agency has authorized the State of Nevada to regulate the management and disposal of solid, hazardous, and mixed wastes in the State. The Nevada Division of Environmental Protection or an equivalent solid waste management authority would regulate the onsite disposal of nonhazardous solid wastes generated by activities associated with the proposed repository. DOE would manage such waste in accordance with applicable laws and regulations.

Nevada Administrative Code Chapter 444 contains regulations that provide for fees, variances, and permits, and has adopted Environmental Protection Agency regulations (40 CFR Parts 2, 124, and 260 through 270) as part of the code. The regulations could affect any hazardous or mixed waste generated, treated, or stored onsite by activities associated with a proposed repository at Yucca Mountain. DOE would ship any generated hazardous or mixed wastes off the site within 90 days for treatment, storage, and disposal.

Executive Order 12088, *Federal Compliance with Pollution Control Standards*

Executive Order 12088, as amended by Executive Order 12580, *Federal Compliance with Pollution Control Standards*, generally directs Federal agencies to comply with applicable administrative and procedural pollution control standards established by, but not limited to, the Clean Air Act, the Noise Control Act, the Clean Water Act, the Safe Drinking Water Act, the Toxic Substances Control Act, and the Resource Conservation and Recovery Act. Compliance with these orders, as applicable, would be required for a range of DOE activities associated with a proposed repository at Yucca Mountain.

Executive Order 12856, *Right to Know Laws and Pollution Prevention Requirements*

This Order directs Federal agencies to reduce and report toxic chemicals entering any waste stream; improve emergency planning, response, and accident notification; and encourage the use of clean technologies and testing of innovative prevention technologies. In addition, the Order states that Federal agencies are persons for purposes of the Emergency Planning and Community Right-to-Know Act (SARA Title III), which requires agencies to meet the requirements of the Act. Compliance with these orders, as applicable, would be required for a range of DOE activities associated with a proposed repository at Yucca Mountain.

11.2.5 CULTURAL RESOURCES

National Historic Preservation Act, as amended (16 USC 470 *et seq.*)

The National Historic Preservation Act provides for the placement of sites with significant national historic value on the *National Register of Historic Places*. It requires no permits or certifications. DOE would evaluate activities associated with a repository at Yucca Mountain to determine if they would affect historic resources. If required after this evaluation, the Department would consult with the Advisory Council on Historic Preservation and the Nevada State Historic Preservation Officer. Such consultations generally result in the development of an agreement that includes stipulations to be followed to minimize or mitigate potential adverse impacts to a historic resource (see Table 11-1, item 9).

DOE has entered into a programmatic agreement with the Advisory Council on Historic Preservation for implementation of the National Historic Preservation Act for site characterization activities. This agreement requires DOE to consult and interact with Native Americans during site characterization. In compliance with the agreement provisions, Native American representatives from the Southern Paiute, Western Shoshone, and Owens Valley Paiute and Shoshone Tribes have reviewed Yucca Mountain activities on the site twice each year. These reviews have been followed by discussions between Native American representatives and DOE personnel, submittal of comments by the Native American representatives, and responses to the comments by DOE. If the proposed site was authorized, the implementing agreement would be modified as appropriate and additional consultations would occur under Section 106 of the National Historic Preservation Act (16 USC 106).

Archaeological Resources Protection Act, as amended (16 USC 470aa *et seq.*)

The Archaeological Resources Protection Act requires a permit for excavation or removal of archaeological resources from publicly held or Native American lands (see Table 11-1, item 11). Excavations must further archaeological knowledge in the public interest, and the resources removed are to remain the property of the United States. If a resource is found on land owned by a Native American tribe, the tribe must give its consent before a permit is issued, and the permit must contain terms or conditions requested by the tribe. Requirements of the Archaeological Resources Protection Act would apply to any Yucca Mountain Project excavation activities that resulted in identification of archaeological resources.

American Indian Religious Freedom Act of 1978 (42 USC 1996)

The American Indian Religious Freedom Act reaffirms Native American religious freedom under the First Amendment and establishes policy to protect and preserve the inherent and constitutional right of Native Americans to believe, express, and exercise their traditional religions. This law ensures the protection of sacred locations and access of Native Americans to those sacred locations and traditional resources that are integral to the practice of their religions. Further, it establishes requirements that would apply to Native American sacred locations, traditional resources, or traditional religious practices potentially affected by the construction and operation of a repository at Yucca Mountain.

Native American Graves Protection and Repatriation Act of 1990 (25 USC 3001)

The Native American Graves Protection and Repatriation Act directs the Secretary of the Interior to guide the repatriation of Federal archaeological collections and collections that are culturally affiliated with Native American tribes and held by museums that receive Federal funding. Major actions to be taken under this law include (1) the establishment of a review committee with monitoring and policymaking responsibilities, (2) the development of regulations for repatriation, including procedures for identifying lineal descent or cultural affiliation needed for claims, (3) the oversight of museum programs designed to meet the inventory requirements and deadlines of this law, and (4) the development of procedures to handle unexpected discoveries of graves or grave goods during activities on Federal or tribal land. The provisions of the Act would be invoked if any excavations associated with a repository at Yucca Mountain led to unexpected discoveries of Native American graves or grave artifacts. DOE and the Southern Paiute, Western Shoshone, and Owens Valley Paiute and Shoshone Tribes have entered an agreement to address the potential applicability of the Native American Graves Protection and Repatriation Act to artifacts collected during site characterization activities at Yucca Mountain.

Antiquities Act (16 USC 431 *et seq.*)

The Antiquities Act protects historic and prehistoric ruins, monuments, and objects of antiquity (including paleontological resources) on lands owned or controlled by the Federal Government. If historic or prehistoric ruins or objects were found during the construction or operation of facilities associated with a repository at Yucca Mountain, DOE would have to determine if adverse effects to these ruins or objects would occur. If adverse effects would occur, the Secretary of the Interior would have to grant permission to proceed with the activity (36 CFR Part 296 and 43 CFR Parts 3 and 7) (see Table 11-1, item 10).

Executive Order 11593, *National Historic Preservation*

This Order directs Federal agencies, including DOE, to locate, inventory, and nominate properties under their jurisdiction or control to the *National Register of Historic Places*. This process requires DOE to provide the Advisory Council on Historic Preservation the opportunity to comment on the possible impacts of proposed activities.

Executive Order 13007, *Indian Sacred Sites*

This Order directs Federal agencies, to the extent permitted by law and not inconsistent with agency missions, to avoid adverse effects to sacred sites and to provide access to those sites to Native Americans for religious practices. The Order directs agencies to plan projects to provide protection of and access to sacred sites to the extent compatible with the project.

Executive Order 13094, *Consultation and Coordination with Indian Trial Governments*

This Order directs Federal agencies to establish regular and meaningful consultation and collaboration with tribal governments in the development of regulatory practices on Federal matters that significantly or uniquely affect their communities; reduce the imposition of unfunded mandates on tribal governments; and streamline the application process for and increase the availability of waivers to tribal governments.

11.2.6 ENVIRONMENTAL JUSTICE

Executive Order 12898, *Environmental Justice*

This Order directs Federal agencies, to the extent practicable, to make the achievement of environmental justice part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority and low-income populations in the United States and its territories and possessions. The order provides that the Federal agency responsibilities it establishes are to apply equally to Native American programs.

11.2.7 ECOLOGY AND HABITAT

Endangered Species Act, as amended (16 USC 1531 *et seq.*)

The Endangered Species Act provides a program for the conservation of threatened and endangered species and the ecosystems on which those species rely. If a proposed action could affect threatened or endangered species or their habitat, the Federal agency must assess the potential impacts and develop measures to minimize those impacts. The agency then must consult with the Fish and Wildlife Service (part of the U.S. Department of the Interior) and the National Marine Fisheries Service (part of the Department of Commerce), as required under Section 7 of the Act. The outcome of this consultation would be a biological opinion by the Fish and Wildlife Service or the National Marine Fisheries Service that stated whether the proposed action would jeopardize the continued existence of the species under consideration. If there is a non-jeopardy opinion, but if some individuals might be killed incidentally as a result of the proposed action, the Services can determine that such losses are not prohibited as long as measures outlined by the Services are followed. Regulations implementing the Endangered Species Act are codified at 50 CFR Parts 15 and 402.

There are no known endangered species on the Yucca Mountain site. The desert tortoise is the only threatened species found on the site. The Fish and Wildlife Service has issued a biological opinion stating that site characterization activities at Yucca Mountain would not jeopardize the continued existence of the desert tortoise (Buchanan 1997, page 16).

DOE will prepare a biological assessment on the effects of the proposed repository on threatened or endangered species before making a determination whether to recommend approval of the Yucca Mountain Site. In addition, DOE will fulfill the requirements of the Endangered Species Act, as appropriate, with regard to transportation impacts before making the recommendation determination.

Fish and Wildlife Coordination Act, as amended (16 USC 661, 48 Stat. 401)

The Fish and Wildlife Coordination Act promotes more effectual planning and cooperation between Federal, state, public, and private agencies for the conservation and rehabilitation of the Nation’s fish and wildlife and authorizes the Department of the Interior to provide assistance.

Migratory Bird Treaty Act, as amended (16 USC 703 *et seq.*)

The purpose of the Migratory Bird Treaty Act is to protect birds that have common migration patterns between the United States and Canada, Mexico, Japan, and Russia. It regulates the take and harvest of migratory birds. The Fish and Wildlife Service will review this EIS to determine whether the activities analyzed would comply with the requirements of the Migratory Bird Treaty Act. Studies indicate that no requirements of this Act are applicable to the Yucca Mountain Project.

Bald and Golden Eagle Protection Act, as amended (16 USC 668-668d)

The Bald and Golden Eagle Protection Act makes it unlawful to take, pursue, molest, or disturb bald (American) and golden eagles, their nests, or their eggs anywhere in the United States (Section 668, 668c). The Department of the Interior regulates activities that might adversely affect bald and golden eagles. The Fish and Wildlife Service will review this EIS to determine whether the activities analyzed in this EIS would comply with the Bald and Golden Eagle Protection Act. DOE has established a program to ensure compliance with this law during site characterization activities.

National Wildlife Refuge System Administration Act of 1966 (42 USC 668dd)

The National Wildlife Refuge System Administration Act provides guidelines for the administration and management of lands in the system, including “wildlife refuges, areas for the protection and conservation of fish and wildlife that are threatened with extinction, wildlife ranges, game ranges, wildlife management areas, or waterfowl production areas.” If use of lands for transportation corridors and facilities such as a rail line or intermodal transfer station associated with a repository at Yucca Mountain could affect lands in the system, DOE would consult with the Fish and Wildlife Service. Regulations implementing the Act are codified at 50 CFR Parts 25 and 27 through 29. The Fish and Wildlife Service will review this EIS to determine if the Proposed Action would comply with the Act. It is DOE policy to place transportation corridors and facilities to avoid existing wildlife refuges.

Nevada Revised Statutes: Protection and Preservation of Timbered Lands, Trees, and Flora, Chapter 527

These provisions broadly protect the indigenous flora of the State of Nevada. If the State determines that a species or subspecies of native flora is threatened with extinction, that species or subspecies is to be placed on the State list of fully protected species. In general, no member of the species or subspecies may be taken or destroyed unless an authorized State official issues a special permit. Activities associated with a repository at Yucca Mountain arguably could affect such species and could require special permits.

Nevada Revised Statutes: Hunting, Fishing, and Trapping; Miscellaneous Protective Measures, Chapter 503; Nevada Administrative Code, Chapter 503: Sections 010-104, General Provisions

These provisions specify procedures for the classification and protection of wildlife. If the State determines that an animal species is threatened with extinction, the species is to be placed on the State list of fully protected species. In general, no member of the species may be taken or destroyed unless the Nevada Division of Wildlife issues a special permit. Activities associated with a repository at Yucca Mountain arguably could affect such species and could require special permits. Regardless of whether these provisions are applicable, DOE has obtained a permit for site characterization activities from the State of Nevada.

Executive Order 11990, *Protection of Wetlands*

This order directs Federal agencies to avoid new construction in wetlands unless there is no practicable alternative and unless the proposed action includes all practicable measures to minimize harm to wetlands that might result from such use. DOE requirements for compliance with wetlands activity review procedures are codified at 10 CFR Part 1022.

Executive Order 13112, *Invasive Species*

This order directs Federal agencies to act to prevent the introduction of or to monitor and control invasive (non-native) species, to provide for restoration of native species, to conduct research, to promote educational activities, and to exercise care in taking actions that could promote the introduction or spread of invasive species. If a repository were constructed at Yucca Mountain, DOE would comply with provisions of this Executive Order as part of construction, operation and monitoring, and closure activities.

11.2.8 USE OF LAND AND WATER BODIES

Coastal Zone Management Act (16 USC 1451 *et seq.*)

The purpose of the Coastal Zone Management Act is to preserve, protect, develop, restore, and enhance the resources of the Nation’s coastal zone. Resources include wetlands, floodplains, estuaries, beaches, dunes, barrier islands, coral reefs, and fish and wildlife and their habitat. This law provides for (1) management to minimize the loss of life and property caused by improper development and by the destruction of natural protective features such as beaches, dunes, wetlands, and barrier islands, and (2) improvement, safeguarding, and restoration of the quality of coastal waters, and for protection of existing uses of those waters. The Coastal Zone Management Act requires priority consideration to coastal-dependent uses and orderly processes for siting major facilities related to national defense, energy, fisheries development, recreation, ports and transportation, and the location of new commercial and industrial developments in or adjacent to areas where such development already exists.

The operation of a repository at Yucca Mountain could require the use of barges for transportation of spent nuclear fuel along portions of routes from some storage facilities. In addition, rail corridors, roads, and bridges from some storage facilities could require repair or enhancement before they could support shipment of spent nuclear fuel. DOE would ensure that its activities are consistent with state-specific coastal zone management plans promulgated in accordance with this Act, if applicable. The regulations promulgated under the Act are codified at 15 CFR Part 930.

Rivers and Harbors Act (33 USC 401 *et seq.*)

The transportation of spent nuclear fuel and high-level radioactive waste could require the construction or modification of road or rail bridges that span navigable waters. The Rivers and Harbors Act prevents the alteration or modification of the course, location, condition, or capacity of any channel of any navigable water of the United States without a permit from the U.S. Army Corps of Engineers. If DOE assumed responsibility for such construction or modifications, it would need to obtain a permit from the U.S. Army Corps of Engineers. Regulations implementing this Act are codified at 33 CFR Part 323.

National Forest Organic Administrative Act (16 USC 521)

The National Forest Organic Administrative Act establishes the functions and responsibilities of the Forest Service, an agency of the U.S. Department of Agriculture. The Forest Service would be requested to approve the construction of rail lines and roads in Nevada that would be associated with the operation of a repository at Yucca Mountain and that could cross land administered by the Service (16 USC 1600, 1611-14).

National Forest Management Act of 1976

The National Forest Management Act establishes decision planning and management practices for forests. This law could affect any proposed construction of rail lines or roads associated with the construction or operation of a repository at Yucca Mountain that could cross National Forest lands.

Materials Act of 1947 (30 USC 601-603)

The Materials Act authorizes land management agencies, such as the Bureau of Land Management and the Forest Service, to make common varieties of sand, stone, and gravel from public lands available to Federal and state agencies under a Free Use Permit (see Table 11-1, item 12). Regulations implementing the Materials Act are codified at 43 CFR Part 3600. DOE has received three free use permits from the Bureau of Land Management to obtain gravel for site characterization activities in a manner compliant with the Materials Act.

Taylor Grazing Act (43 USC 315-316)

The Taylor Grazing Act establishes the processes by which the Bureau of Land Management grants and administers grazing rights. If a decision is made to construct and operate a repository, a new rail line, or a new road on a Bureau of Land Management grazing allotment, DOE would have to acquire a right-of-way grant across the allotment or a withdrawal of the allotment. Regulations implementing this Act are codified at 43 CFR Part 4100.

Farmland Protection Policy Act (7 USC 4201 *et seq.*)

The Farmland Protection Policy Act seeks to minimize the extent to which Federal programs contribute to the unnecessary and irreversible conversion of farmlands to nonagricultural uses. Compliance with this law requires concurrence from the Natural Resources Conservation Service of the U.S. Department of Agriculture that proposed activities would not affect farmlands. DOE has completed a consultation with the Natural Resources Conservation Service that determined that a repository at Yucca Mountain would not affect prime or unique farmlands. This EIS assesses the potential construction of a rail line, new roads, or an intermodal transfer station in Nevada to determine if that construction could affect such lands. Regulations implementing the Farmland Protection Policy Act are codified at 7 CFR Part 658.

11.3 Department of Energy Orders

Under the authority of the Atomic Energy Act, DOE is responsible for establishing a comprehensive health, safety, and environmental program for its activities and facilities. The Department has established a framework for managing its facilities through the promulgation of regulations and the issuance of DOE Orders. In general, DOE Orders set forth policies, programs, and procedures for implementing policies. Many DOE Orders contain specific requirements in the areas of radiation protection, nuclear safety and safeguards, and security of nuclear material. Table 11-2 lists DOE Orders potentially relevant to the Civilian Radioactive Waste Management Program.

Table 11-2. DOE Orders potentially relevant to the Civilian Radioactive Waste Management Program (page 1 of 2).

Order	Subject	Description
151.1	Comprehensive Emergency Management System	Establishes requirements for emergency planning, preparedness, response, recovery, and readiness assurance activities and describes the approach for effectively integrating these activities under a comprehensive, all-emergency concept.
231.1	Environment, Safety and Health Reporting	Establishes the requirements and procedures for reporting information with environmental protection, safety, or health protection significance for DOE operations.
232.1	Occurrence Reporting and Processing of Operations Information	Establishes the requirements for reporting and processing occurrences related to safety, health, security, property, operations, and the environment, up to and including emergencies.
250.1	Civilian Radioactive Waste Management Facilities – Exemption from Departmental Directives	Establishes the relationship between DOE directives and Nuclear Regulatory Commission regulations for the Yucca Mountain Project.
420.1A	Facility Safety	Establishes facility safety requirements related to nuclear safety design, criticality safety, fire protection, and natural phenomena hazards mitigation.
425.1	Facility Startup and Restart	Establishes procedures to be followed when a facility is taken from a nonoperational to an operational state.
430.1	Life Cycle Asset Management	Establishes procedures to be followed in all phases of the management of DOE facilities.
440.1A	Worker Protection Management for DOE Federal and Contractor Employees	Establishes a comprehensive worker protection program that ensures that DOE and its contractor employees have an effective worker protection program that will reduce or prevent injuries, illnesses, and accidental losses by providing DOE, Federal, and contractor workers with a safe and healthful workplace.
451.1A	National Environmental Policy Act Compliance Program	Establishes DOE internal requirements and responsibilities for implementing the National Environmental Policy Act of 1969, as amended, the Council on Environmental Quality regulations implementing the procedural provisions of the Act (40 CFR Part 1500 *et seq.*), and the DOE procedures that implement it (10 CFR Part 1021).
460.1A	Packaging and Transportation Safety	Establishes requirements and assigns responsibilities for the safe transport of hazardous materials, hazardous substances, hazardous wastes, and radioactive materials.
1300.2A	Department of Energy Technical Standards Program	Establishes policy, assigns responsibility, and provides requirements for development and application of technical standards in DOE facilities, programs, and projects; provides for participation in non-Government standards bodies and for establishment of a DOE Technical Standards Program; and assigns responsibility for the management of the program.
1360.2B	Unclassified Computer Security Program	Establishes requirements, policies, responsibilities, and procedures for developing, implementing, and sustaining a DOE unclassified computer security program.

Table 11-2. DOE Orders potentially relevant to the Civilian Radioactive Waste Management Program (page 2 of 2).

Order	Subject	Description
3790.1B	Federal Employee Occupational Safety and Health Program	Establishes requirements and procedures to ensure that occupational safety and health standards prescribed pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974, and the DOE Organization Act of 1977 provide occupational safety and health protection for DOE contractor employees in Government-owned contractor-operated facilities.
5400.1	General Environmental Protection Program	Establishes environmental protection program requirements, authorities, and responsibilities for DOE operations to ensure compliance with applicable Federal, state, and local environmental protection laws and regulations and with internal DOE policies.
5400.5	Radiation Protection of the Public and the Environment	Establishes standards and requirements for operation of DOE and DOE contractors with respect to protection of members of the public and the environment against undue risk from radiation.
5480.19	Conduct of Operations Requirements for DOE Facilities	Provides requirements and guidelines for DOE elements to use in developing directives, plans, and procedures related to the conduct of operations at DOE facilities.
5484.1	Environmental Protection, Safety, and Health Protection Information Reporting Requirements	Establishes the requirements and procedures for the investigation of occurrences having environmental protection, safety, or health protection significance, and for efficient environmental monitoring of DOE operations.
5610.14	Transportation Safeguards System Program Operations	Establishes DOE policies for and implementation of the management and operation of the Transportation Safeguards System program.
5632.1C	Protection and Control of Safeguards and Security Interests	Establishes policy, responsibilities, and authorities for the protection and control of safeguards and security interests (for example, special nuclear material, vital equipment, classified matter, property, facilities, and unclassified irradiated reactor fuel in transit).
5633.3B	Control and Accountability of Nuclear Materials	Prescribes the minimum DOE requirements and procedures for control and accountability of nuclear materials at DOE-owned and -leased facilities and DOE-owned nuclear materials at facilities that are exempt from licensing by the Nuclear Regulatory Commission. Would apply to materials destined for a repository before the materials reached the repository.
5820.2A	Radioactive Waste Management	Establishes policies and guidelines by which DOE manages radioactive waste, waste byproducts, and radioactively contaminated surplus facilities.

The Nuclear Regulatory Commission is authorized to license the proposed Yucca Mountain repository. Some DOE Orders overlap or duplicate Nuclear Regulatory Commission repository licensing regulations in whole or in part. Recognizing this, the Department issued DOE HQ Order 250.1, *Civilian Radioactive Waste Management Facilities – Exemption from Departmental Directives.* This Order exempts geologic repository design, construction, operation, and decommissioning from compliance with the provisions of DOE Orders that overlap or duplicate Commission requirements related to radiation protection, nuclear safety (including quality assurance), and safeguard and security of nuclear material. The exemption would apply only to portions of a repository project for which DOE sought a Nuclear Regulatory Commission license. DOE Orders would continue to establish requirements for other activities associated with a repository that fall outside the scope of this exemption, for example in the area of computer security (Order 1360.28).

Through DOE Order 440.1A, *Worker Protection Management for DOE Federal and Contractor Employees*, the Department has prescribed the Occupational Safety and Health Act standards that contractors are to meet in their work at government-owned, contractor-operated facilities.

A monitored geologic repository at Yucca Mountain would be a nonreactor nuclear facility. DOE Orders 5480.21, *Unreviewed Safety Questions*, 5480.22, *Technical Safety Requirements*, and 5480.23, *Nuclear Safety Analysis Reports*, ordinarily apply to nonreactor nuclear facilities. Because DOE Order 250.1 gives precedence to Nuclear Regulatory Commission rules, DOE Orders 5480.21, 5480.22, and 5480.23, for example, probably would not apply to the repository.

11.4 Potentially Applicable Federal Regulations

Sections 11.2.1 through 11.2.3 identify major laws, regulations, and DOE Orders potentially applicable to the construction, operation and monitoring, and closure of a monitored geologic repository. Table 11-3 lists other potentially applicable regulations and orders.

Table 11-3. Potentially applicable Federal regulations, orders, standards, and memoranda (page 1 of 3).

Document Number	Title[a]
Code of Federal Regulations	
10 CFR 2	Rules of Practice for Domestic Licensing Proceedings and Issuance of Orders
10 CFR 19	Notices, Instructions and Reports to Workers: Inspection and Investigations
10 CFR 40	Domestic Licensing of Source Material
10 CFR 51	Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions
10 CFR 60	Licensing Requirements for Geologic Repository
10 CFR 61	Licensing Requirements for Land Disposal of Radioactive Waste
10 CFR 72	Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Waste
10 CFR 73	Physical Protection of Plants and Materials
10 CFR 75	Safeguards on Nuclear Material-Implementation of US/IAEA Agreement
10 CFR 100	Reactor Site Criteria
10 CFR 707	Workplace Substance Abuse Programs at DOE Sites
10 CFR 830	Nuclear Safety Management
10 CFR 835	Occupational Radiation Protection
10 CFR 960	General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories
10 CFR 1022	Compliance with Floodplain/Wetlands Environmental Review Requirements
29 CFR 1926	Safety and Health Regulations for Construction
29 CFR 1960	Basic Program Elements for Federal Employee Occupational Safety and Health Programs and Related Matters
30 CFR 57	Safety and Health Standards, Underground Metal and Nonmetal Mines
33 CFR 323	Permits for Discharges of Dredged or Fill Material into Waters of the United States
33 CFR Chapter I	Coast Guard Department of Transportation (Parts 1-199)
36 CFR 296	Permits to Proceed (Objects of Antiquity)
36 CFR 800	Protection of Historic and Cultural Properties
40 CFR 50	National Primary and Secondary Ambient Air Quality Standards
40 CFR 60	Standards of Performance for New Stationary Sources
40 CFR 61	National Emission Standards for Hazardous Air Pollutants
40 CFR 63	National Emission Standards for Hazardous Air Pollutants for Source Categories
40 CFR 122	EPA Administered Permit Programs: The National Pollutant Discharge Elimination System
40 CFR 125	Criteria and Standards for the National Pollutant Discharge Elimination System
40 CFR 133	Secondary Treatment Regulation
40 CFR 136	Guidelines Establishing Test Procedures for the Analysis of Pollutants

Table 11-3. Potentially applicable Federal regulations, orders, standards, and memoranda (page 2 of 3).

Document Number	Title[a]
Code of Federal Regulations (continued)	
40 CFR 141	National Primary Drinking Water Regulations
40 CFR 142	National Primary Drinking Water Regulations Implementation
40 CFR 143	National Secondary Drinking Water Regulations
40 CFR 246	Source Separation for Materials Recovery Guidelines
40 CFR 257	Criteria for Classification of Solid Waste Disposal Facilities and Practices
40 CFR 260	Hazardous Waste Management System: General
40 CFR 261	Identification and Listing of Hazardous Waste
40 CFR 262	Standards Applicable to Generators of Hazardous Waste
40 CFR 263	Standards Applicable to Transporters of Hazardous Waste
40 CFR 264	Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities
40 CFR 265	Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities
40 CFR 268	Land Disposal Restrictions
40 CFR 280	Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks
40 CFR 503	Standards for the Use or Disposal of Sewage Sludge
40 CFR 747	Metalworking Fluids
40 CFR 761	Polychlorinated Biphenyls Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions
40 CFR 1500	Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act
41 CFR 101	Federal Property Management Regulations
43 CFR 3 and 7	Preservation of Antiquities, Protection of Archaeological Resources
43 CFR 2300	Land Withdrawal
43 CFR 3600	Free Use Permit
43 CFR 4100	Right-of-Way Reservation
49 CFR 171	General Information, Regulations and Definitions
49 CFR 172	Hazardous Materials Table, Special Provisions, Hazardous Materials Communications Requirements and Emergency Response Information Requirements
49 CFR 173	Shippers – General Requirements for Shipments and Packagings
49 CFR 174	Carriage by Rail
49 CFR 176	Carriage by Vessel
49 CFR 177	Carriage by Public Highway
49 CFR 178	Shipping Container Specifications
49 CFR 180	Continuing Qualification and Maintenance of Packagings
49 CFR 392	Driving of Motor Vehicles
49 CFR 393	Parts and Accessories Necessary for Safe Operation
50 CFR 17	Endangered and Threatened Wildlife and Plants
50 CFR 400	Endangered Species Act
50 CFR 402	Interagency Cooperation – Endangered Species Act of 1973, as Amended
Executive Orders	
Executive Order 11514	National Environmental Policy Act, Protection and Enhancement of Environmental Quality
Executive Order 11593	National Historic Preservation
Executive Order 11988	Floodplain Management
Executive Order 11990	Protection of Wetlands
Executive Order 12856	Right to Know Laws and Pollution Prevention Requirements
Executive Order 12898	Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations
Executive Order 13007	Indian Sacred Sites
Executive Order 13084	Consultation and Coordination with Indian Tribal Governments
Executive Order13112	Invasive Species

Table 11-3. Potentially applicable Federal regulations, orders, standards, and memoranda (page 3 of 3).

Document Number	Title[a]
Other documents, orders, and directives	
AAR Rule 91	1993 Field Manual of Association of American Railroads Interchange Rules (AAR Interchange Rule 91, Weight Limitations)
BLM Manual, Sec. 9113	Bureau of Land Management Manual, Road Standards
DOE Order 430.1	Life Cycle Asset Management
DOE Order 3790.1	Federal Employees Occupational Safety and Health Program
DOE Order 5480.4	Environmental Protection, Safety, and Health Protection Standards
DOE Order 5632.1	Protection Program Operation
DOE/EA-0179	Environmental Assessment Waste Form Selection for Savannah River HLW
DOE/EH-0256T	DOE Radiological Control Manual
DOE/RW-0184	Characteristics of Potential Repository Wastes, Volumes 1-4
DOE/RW-0194P	Records Management Policies and Requirements
DOE/RW-0328P	Acceptance Priority Ranking
DOE/RW-0333P	OCRWM Quality Assurance Requirements and Description
DOE/RW-0457	1995 Acceptance Priority Ranking and Annual Capacity Report
DOE-STD-1020	Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities
DOE-STD-1021	Natural Phenomena Hazards Performance Categorization Criteria for Structures, Systems and Components
DOE-STD-1022	Natural Phenomena Hazards Site Characterization Criteria
DOE-STD-1023	Natural Phenomena Hazards Assessment Criteria (Draft)
DOE-STD-1024	Guidelines for Use of Probabilistic Seismic Hazard Curves at Department of Energy Sites
DOE-STD-1062	Ergonomic and Human Factors Design Criteria[b]
Fed-STD-795	Uniform Federal Accessibility Standards
GSA-FSS-W-A-450/1-17	General Service Administration Interim Federal Specification
MOA DP/RW	Policy for Shipping Defense High-Level Waste (DHLW) to a Civilian Radioactive Waste Repository
MOA RW/NS	Nuclear Safety Requirement
MOU DOE/DOL	Mining Safety
NRC RG 1.13	Spent Fuel Storage Facility Design Basis
NRC RG 1.76	Design Basis Tornado for Nuclear Power Plants
NRC RG 8.8	Information Relevant to Ensuring That Occupational Radiation Exposure at Nuclear Power Stations Will Be As Low As Is Reasonably Achievable
NRC RG 8.10	Operating Philosophy for Maintaining Occupational Radiation Exposure As Low As Is Reasonably Achievable
NUREG 0700	Guidelines for Control Room Design Reviews
NUREG 0856	Final Technical Position on Documentation of Computer Codes for High-Level Waste Management
Presidential Memo (04/30/85)	Dispose of Defense Waste in a Commercial Repository

a. IAEA = International Atomic Energy Agency; EPA = Environmental Protection Agency; HLW = high-level radioactive waste; OCRWM = Office of Civilian Radioactive Waste Management.

b. This standard is complete, but has not been formally published at this time. However, it is included here as a source because it consists of a compilation of requirements from accepted sources. Those sources include standards from the Code of Federal Regulations, Nuclear Regulatory Commission regulations, and military, American National Standards Institute, National Aeronautics and Space Administration, and Electric Power Research Institute standards, as well as recognized design handbooks and guides that govern standard engineering practice.

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References

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12. REFERENCES

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TRW 1999g TRW (TRW Environmental Safety Systems Inc.), 1999g, *Environmental Baseline File for Meteorology and Air Quality*, B00000000-01717-5705-00126, Revision 00, Las Vegas, Nevada. [MOL.19990302.0186]

TRW 1999h TRW (TRW Environmental Safety Systems Inc.), 1999h, *Geology/Hydrology Environmental Baseline File,* B00000000-01717-5700-00027, Revision 01, DCN1, Las Vegas, Nevada. [MOL.19990609.0156]

TRW 1999i TRW (TRW Environmental Safety Systems Inc.), 1999i, *Environmental Baseline File for Water Resources,* B00000000-01717-5705-00118, Revision 01, Las Vegas, Nevada. [MOL.19990608.0036]

TRW 1999j TRW (TRW Environmental Safety Systems Inc.), 1999j, *Yucca Mountain Site Characterization Project Environmental Baseline File for Utilities, Energy, and Site Services*, B00000000-01717-5705-00124, Revision 00, Las Vegas, Nevada. [MOL.19990302.0182]

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TRW 1999n	TRW (TRW Environmental Safety Systems Inc.), 1999n, *Yucca Mountain Site Characterization Project Environmental Baseline File for Socioeconomics*, B00000000-01717-5705-00125, Revision 01, Las Vegas, Nevada. [MOL.19990608.0037]
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Preparers, Contributors, and Reviewers

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13. PREPARERS, CONTRIBUTORS, AND REVIEWERS

13.1 Preparers and Contributors

This chapter lists the individuals who filled primary roles in the preparation of this environmental impact statement (EIS). Wendy R. Dixon of the U.S. Department of Energy (DOE) Yucca Mountain Project Office directed the preparation of the EIS. Primary support and assistance to DOE was provided by the EIS Preparation Team, led by Ted B. Doerr of Jason Technologies Corporation; other members of the team included Tetra Tech NUS Inc., Battelle, Dade Moeller & Associates, and H&R Technical Associates, Inc. Judith A. Shipman coordinated the work of the Jason Technologies Corporation production team (Dalene Glanz, Laura Hall, Virginia Hutchins, and Robin Klein). Paulette Brown, Christina Caprio, Glenn Caprio, Angela Drum, Heidi Guyot, Cindy Langdale, Terresa Orme, and Dawn Siekerman provided administrative, scheduling, and recordkeeping support.

DOE provided direction to the EIS Preparation Team, which was responsible for developing the analytical methodology and alternatives, coordinating the work tasks, performing the impact analyses, and producing the document. DOE was responsible for data quality, the scope and content of the EIS, and issue resolution and direction.

In addition, the Management and Operating Contractor to the DOE Yucca Mountain Site Characterization Office (TRW Environmental Safety Systems Inc. and its subcontractors) assisted in the preparation of supporting documentation and information for the EIS, as did Sandia, Argonne, and Oak Ridge National Laboratories. These organizations worked closely with the EIS Preparation Team under DOE direction.

DOE independently evaluated all supporting information and documentation prepared by these organizations. Further, DOE retained the responsibility for determining the appropriateness and adequacy of incorporating any data, analyses, and results of other work performed by these organizations in the EIS. The EIS Preparation Team was responsible for integrating such work into the EIS.

As required by Federal regulations (40 CFR 1506.5c), Jason Technologies Corporation and its subcontractors have signed NEPA Disclosure Statements in relation to the work they performed on this EIS. These statements appear at the end of this chapter.

Name	Education	Experience	Responsibility
U.S. Department of Energy			
Wendy R. Dixon	Postgraduate studies, Geology and Environmental Science M.B.A., Business B.A., Sociology	20 years – management of nuclear-related projects; 13 years – regulatory compliance and field management; 5 years – safety and health	EIS Project Manager, NEPA Compliance Officer
Kenneth J. Skipper	B.S., Geology, 1984	18 years – geotechnical/ environmental project management; Federal civil works projects planning, construction, operations, and performance monitoring	Document Manager

Name	Education	Experience	Responsibility
M. Jozette Booth	B.S., Business Administration	18 years – transportation and policy analysis, communications and public participation, intergovernmental and Native American consultations	Technical lead for transportation and American Indian Programs
EIS Preparation Team			
Ted B. Doerr Jason Technologies Corporation	Ph.D., Wildlife and Fisheries Sciences, 1988 M.S., Range Science, 1980 B.S., Wildlife and Fisheries Sciences, 1977	19 years – NEPA implementation, ecology, environmental and ecological risk assessments, mitigation development, and regulatory compliance	Project Manager
Ernest C. Harr, Jr. Jason Technologies Corporation	B.S., Zoology/Chemistry, 1977	10 years – preparation of NEPA documents; acted as DOE EM Headquarters NEPA Compliance Officer; reviewed many DOE waste management NEPA documents.	Deputy Project Manager
Jeffrey L. Weiler Jason Technologies Corporation	M.S., Resource Economics/Environmental Management, 1974 B.A., Political Science, 1970	28 years – management of large interdisciplinary project teams; interagency coordination; stakeholder involvement; NEPA compliance	Document Manager
John O. Shipman Tetra Tech NUS Inc.	B.A., English Literature, 1966	32 years – NEPA documentation, technical writing and editing, publications management; 10 years – public participation	Document Production Manager; technical editor of Draft EIS
Jeffrey P. McCann Jason Technologies Corporation	B.S., Geological Sciences, 1980	19 years – geological analyst; 5 years – preparation of NEPA documentation	Records/Data Manager
Rosanne L. Aaberg Battelle - Pacific Northwest National Laboratories	B.S., Chemical Engineering, 1976	20 years – nuclear-related projects; 9 years – environmental health physics	Air quality
William J. Berry Jason Technologies Corporation	Ph.D., Entomology, 1988 M.S., Biology, 1983 B. S., Biology, 1981	10 years – NEPA documents, ecological risk assessments, and habitat management plans	Biological resources
Ralph E. Best Jason Technologies Corporation	M.B.A., 1981 M.S., Electrical Engineering, 1970 B.S., Engineering Physics, 1964	34 years – energy, transportation, and environmental technology	Lead analyst, transportation

Name	Education	Experience	Responsibility
William J. Craig Tetra Tech NUS Inc.	M.S., Planning, 1977 B. S., Forestry, 1972	20 years – environmental project management, nuclear fuel planning and analyses, natural resource management, and nuclear powerplant siting and relicensing	Land use; socioeconomics
David Crowl Jason Technologies Corporation	B.A., Computer Science, 1985	15 years – editing and publications production	Editor
Keith D. Davis, PE Jason Technologies Corporation	M.S., Civil and Environmental Engineering, 1976 B.S., Civil Engineering, 1973	21 years – civil and environmental engineering; waste management; facility permitting and closure; site investigations, feasibility studies, and remedial action planning; 5 years – NEPA documentation experience	Hydrology; soils
Peter R. Davis Jason Technologies Corporation	Oak Ridge School of Reactor Technology, 1962 B.S. Physics, 1961	36 years – nuclear reactor and nuclear facility safety analysis and risk assessment	Accidents
Amy S. Duda Battelle Memorial Institute	B.A., English, 1996	7 years – technical editing; 4 years – NEPA documentation	Editor
Paul W. Eslinger Battelle – Pacific Northwest National Laboratories	Ph.D., Statistics, 1983 M.A., Mathematics, 1978 B.S., Mathematics, 1976	16 years – environmental risk and human and ecological risk analysis	Long-term performance analysis
Daniel M. Evans Tetra Tech NUS Inc.	M.S., Planning, 1985 B.A., Political Science, 1976	17 years – socioeconomic impact analysis and NEPA document management	EIS strategic planning, socioeconomics
Christian J. Fosmire Battelle – Pacific Northwest National Laboratories	M.S., Meteorology, 1993 B.S., Meteorology, 1990	4 years – atmospheric diffusion modeling and risk assessment	Air quality
Mary N. Hoganson Tetra Tech NUS Inc.	M.S. Biology, 1989 B.S., Biology, 1984	13 years – waste management and waste minimization; 5 years – NEPA document preparation	Waste management and hazardous materials
Richard H. Holder Jason Technologies Corporation	M.B.A., Business Administration, 1986 M.S., Electrical Engineering, 1970 B.S., Electrical Engineering, 1966	32 years – team and line management for nuclear utility, industrial, and overseas projects	EIS strategic planning; Deputy Project Manager, October 1996 to May 1998

Name	Education	Experience	Responsibility
R. Kingsley House, P.E. Jason Technologies Corporation	M.S., Engineering Science/Nuclear Option, 1963 B.S., Mechanical Engineering, 1960	38 years – nuclear and non-nuclear facility design, construction, testing, and operation; hazards analysis, safety analysis, and environmental impact analysis	Utilities, energy, materials, and site services; disposal container and shipping cask manufacturing.
Tracy A. Ikenberry, CHP Dade Moeller & Associates	M.S., Radiology & Radiation Biology, 1982 B.A., Biology, 1979	16 years – environmental and occupational radiation protection; 5 years – NEPA document management and technical analysis.	Air quality; health and safety
James P. Jessen Jason Technologies Corporation	Graduate Studies, Environmental Engineering, 1991-92 M.S., Nuclear Engineering and Health Physics, 1989 B.S., Chemical and Nuclear Engineering, 1988	11 years – environmental and nuclear safety studies of DOE and commercial nuclear facilities	Lead analyst – affected environment, short-term impacts
Douglas E. Kennemore, Jr. Tetra Tech NUS Inc.	M.S., Biology, 1995 B.S., Biology, 1991	7 years – biological consulting and impact assessment	Aesthetics
Lawrence J. Kripps H&R Technical Associates, Inc.	M.S., Nuclear Engineering, 1972 B.S., Nuclear Engineering, 1971	25 years – environmental evaluations, safety analyses, and risk assessments of nuclear and non-nuclear facilities and operations	Lead analyst – Proposed Action, cumulative impacts
Robert A. Lechel Battelle Memorial Institute	B.S., Environmental Studies and Planning: Hazardous Materials Management, 1995	3 years – transportation risk assessment and NEPA document production	Transportation
David H. Lester Jason Technologies Corporation	Ph.D., Chemical Engineering, 1969 M.S., Chemical Engineering, 1966 B.Che., Chemical Engineering, 1964	26 years – hazardous and nuclear waste management; nuclear Safety Analysis Reports, hazards analysis of waste storage operations, risk assessment of low-level nuclear waste burial operations, groundwater contamination transport modeling, performance assessment of high-level nuclear waste systems, design of treatment systems, design and analysis of high-level waste packages, and soil remediation studies	Lead analyst, long-term performance

Name	Education	Experience	Responsibility
Robert D. Long Tetra Tech NUS Inc.	M.S., Demography, 1994 B.A., Sociology, 1993	5 years – economic analysis and research	Socioeconomics
Thomas McSweeney, Battelle Memorial Institute	Ph.D., Chemical Engineering, 1967 M.A., Mathematics, 1964 M.S., Chemical Engineering, 1961 B.S., Chemical Engineering, 1960	30 years – risk and safety analysis; 12 years – transportation risk analysis	Transportation
Aparajita S. Morrison Tetra Tech NUS Inc.	B.S. Health Physics, 1985	13 years – radiation protection, facility startup, instrumentation testing, development of radiological controls program, monitoring and assessments, and health and safety analysis	Cumulative impacts
Elizabeth A. Nañez Battelle Memorial Institute	B.S., Industrial Engineering, 1990	6 years – environmental engineering; 4 years – NEPA document preparation; 1 year – transportation risk assessment	Transportation
William E. Nichols Battelle – Pacific Northwest National Laboratories	M.S., Civil Engineering, 1990 B.S., Agricultural Engineering, 1987	9 years – subsurface flow and transport modeling and model development, environmental dispersion modeling and model development, probabilistic risk assessment, total systems modeling for geologic radioactive waste disposal evaluation, and NEPA documents	Long-term performance analysis
Paul R. Nickens Battelle – Pacific Northwest National Laboratories	Ph.D., Anthropology, 1977 M.A., Anthropology, 1974 B.A., Anthropology, 1969	25 years – cultural resource management and Native American consultation	Cultural resources
Richard F. Orthen, CHMM, Tetra Tech NUS Inc.	B.S., Chemistry, 1979	20 years – occupational and environmental health physics; regulatory compliance; 9 years – radioactive/hazardous materials management; NEPA analysis	Health and safety, cumulative impacts; No-Action Alternative

Name	Education	Experience	Responsibility
W. Kent Ostler Jason Technologies Corporation	Ph.D., Plant Ecology, 1979 M.S., Botany, 1976 B.S., Botany, 1974	20 years – plant ecology and arid land reclamation; identification of techniques to mitigate human impacts on biotic communities; surveys and research on endangered and threatened species; mitigation strategies for recovery of species	Biological resources
Karen K. Patterson Tetra Tech NUS, Inc.	M.A., Biology, 1977 B.A., Biology, 1973	25 years – technology and environmental sciences; 10 years – technical editor; 5 years – preparing NEPA documents	Technical editor, No-Action Alternative
Peter J. Pelto, PE Battelle – Pacific Northwest National Laboratories	M.S., Chemical Engineering, 1980 B.S., Chemical Engineering, 1971	20 years – safety analysis, risk analysis, and systems analysis of nuclear powerplants, nuclear fuel cycle facilities, and radioactive waste management facilities	No-Action Alternative
W. Lee Poe Tetra Tech NUS Inc.	M.S., Chemical Engineering, 1951 B.S., Chemistry, 1949	48 years – working with nuclear materials at Savannah River Site	No-Action Alternative
Ted M. Poston Battelle – Pacific Northwest National Laboratories	M.S., Fisheries B.A., Biology	16 years – noise analysis; 22 years – environmental research and toxicology	Noise
Randy F. Reddick Battelle Memorial Institute	M.S., Environmental Health Engineering, 1983 B.S., Civil Engineering, 1982	14 years – NEPA compliance, document preparation, and safety studies	Affected environment
Joseph W. Rivers, Jr. Jason Technologies Corporation	B.S., Mechanical Engineering, 1982	16 years – commercial and DOE nuclear projects; design, systems engineering, safety analysis, and regulatory compliance	Lead analyst – inventory
Eugene M. Rollins Dade Moeller & Associates	M.S.P.H., Health Physics, 1976 B.S., Nuclear Engineering, 1973	22 years – technical and management experience in health physics and risk assessments related to the nuclear fuel cycle	Lead analyst – No-Action Alternative
Steven B. Ross Battelle Memorial Institute	M.S., Nuclear Engineering, 1987 B.S., Nuclear Engineering, 1985	10 years – safety analysis, risk assessment, transportation, regulatory analysis, and fire risk assessment	Transportation

Name	Education	Experience	Responsibility
Judith A. Shipman Jason Technologies Corporation	A.A., General Studies, 1991	21 years – document production; 14 years NEPA document production	Production Coordinator; editor
Diane S. Sinkowski Tetra Tech NUS Inc.	M.E., Environmental Engineering Sciences, 1994 B.S., Nuclear Engineering Sciences, 1990	4 years – calculating environmental impacts and health physics investigations and evaluations	No-Action Alternative
Dennis Strenge Battelle-Pacific Northwest National Laboratories	M.S. Chemical Engineering, 1968 B.S., Chemical Engineering+	31 years – environment exposure analysis and Dosimetry for accidental and chronic releases of radionuclides and chemicals	Accidents
Lucinda Low Swartz Battelle Memorial Institute	J.D., 1979 B.A., Political Science and Administrative Studies, 1976	19 years – environmental law and regulation, specializing in NEPA compliance	Summary
Desiree Thalley Battelle Memorial Institute	B.A., Journalism, 1983	14 years – technical editing; 8 years – NEPA documentation	Editor
Alan L. Toblin Tetra Tech NUS Inc.	M.S., Chemical Engineering, 1970 B.E., Chemical Engineering, 1968	27 years – analyzing radiological and chemical contaminant transport in water resources.	No-Action Alternative
John E. von Reis Jason Technologies Corporation	J.D., 1969 B.A., English (Prelegal), 1966	28 years – energy, environmental, resource and regulatory issues	Lead analyst – purpose and need, regulatory requirements, environmental justice
Dee H. Walker Jason Technologies Corporation	Ph.D., Chemical Engineering, 1963 M.S., Chemical Engineering, 1962 Oak Ridge School of Reactor Technology, 1954 B.S., Chemical Engineering, 1953	45 years – nuclear engineering; 10 years – effects of radiological releases on humans and the environment	Health and safety; Project Manager, October 1996 – May 1998
Paul F. Wise, CEA CHMM Tetra Tech NUS Inc.	M.S., Biology, 1984 B.S., Biology, 1982	3 years – preparing NEPA documents; 15 years – environmental and water quality, waste management, and environmental audits	Cumulative impacts

13.2 Reviewers

The DOE Yucca Mountain Project Office incorporated input into the preparation of this EIS from a number of other DOE offices that reviewed the document while it was under development. These included the Offices of Environmental Management, Naval Reactors, Nuclear Energy, Materials

Disposition, the National Spent Fuel Program, and the National High-Level Waste Program. The DOE Yucca Mountain Site Characterization Office, Nevada Operations Office, Idaho National Engineering and Environmental Laboratory, Hanford Site, and Savannah River Site also participated in the reviews of this EIS. In addition, personnel on assignment to the Yucca Mountain Project Office from the U.S. Department of the Interior Bureau of Reclamation provided technical review and other support, as did personnel from the DOE Office of Civilian Radioactive Waste Management Technical Support Services Contractor (Booz-Allen & Hamilton and its subcontractors).

QUALIFICATION CRITERION NO. 1

NEPA DISCLOSURE STATEMENT FOR PREPARATION OF THE ENVIRONMENTAL IMPACT STATEMENT FOR A GEOLOGIC REPOSITORY FOR THE DISPOSAL OF SPENT NUCLEAR FUEL AND HIGH-LEVEL RADIOACTIVE WASTE AT YUCCA MOUNTAIN, NYE COUNTY, NEVADA

CEQ Regulations at 40 CFR 1506.5(c), which have been adopted by the DOE (10 CFR 1021), require contractors who will prepare and EIS to execute a disclosure specifying that they have no financial or other interest in the outcome of the project. The term "financial interest or other interest in the outcome of the project" for purpose of this disclosure is defined in the March 23, 1981, guidance "Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations", 46 FR 18026-18038 at Question 17a and b.

"Financial or other interest in the outcome of the project" includes "any financial benefit such as a promise of future construction or design work in the project, as well as indirect benefits the contractor is aware of (e.g., if the project would aid proposals sponsored by the firm's other clients)". See 46 FR 18026-18031.

In accordance with these requirements, the offeror and the proposed subcontractors hereby certify as follows. (check either (a) or (b) and list financial or other interest if (b) is checked)

(a) ☑ Contractor has no financial or other interest in the outcome of the project.

(b) ☐ Offeror and any proposed subcontractor have the following financial or other interest in the outcome of the project and hereby agree to divest themselves of such interest prior to award of this contract.

Financial or Other Interest

1.

2.

3.

Certified By:

Signature

James S. Holm

Name (Printed)

Director of Contracts

Title

Jason Associates Corporation

Company

June 7, 1999

Date

QUALIFICATION CRITERION NO. 1

NEPA DISCLOSURE STATEMENT FOR PREPARATION OF THE ENVIRONMENTAL IMPACT STATEMENT FOR A GEOLOGIC REPOSITORY FOR THE DISPOSAL OF SPENT NUCLEAR FUEL AND HIGH-LEVEL RADIOACTIVE WASTE AT YUCCA MOUNTAIN, NYE COUNTY, NEVADA

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"Financial or other interest in the outcome of the project" includes "any financial benefit such as a promise of future construction or design work in the project, as well as indirect benefits the contractor is aware of (e.g., if the project would aid proposals sponsored by the firm's other clients)". See 46 FR 18026-18031.

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(b) ☐ Offeror and any proposed subcontractor have the following financial or other interest in the outcome of the project and hereby agree to divest themselves of such interest prior to award of this contract.

Financial or Other Interest

1.

2.

3.

Certified by:

Janet Mandel
Signature

Janet M. Mandel
Name (Printed)

Manager, Contract Operations
Title

Tetra Tech NUS, Inc.
Company

June 4, 1999
Date

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3.

Certified By:

Signature

RALPH K. HENRICKS
Name (Printed)

CONTRACTING OFFICER
Title

BATTELLE MEMORIAL INSTITUTE
COLUMBUS OPERATIONS
Company

June 7, 1999
Date

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Financial or Other Interest

1.

2.

3.

Certified By:

Signature

Matthew P. Moeller
Name (Printed)

Vice President
Title

Dade Moeller & Assoc.
Company

June 4, 1999
Date

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Financial or Other Interest

1.

2.

3.

Certified By:

Laura A Hof
Signature

Laura A. Hofman
Name (Printed)

Vice President
Title

H&R Technical Associates, Inc.
Company

June 4, 1999
Date

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14

Glossary

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14. GLOSSARY

(Note: A number of the terms in the Glossary emphasize their project-specific relationship to the Yucca Mountain Repository EIS. Words in *italics* refer to other words in the glossary.)

100-year flood

A flood event of such magnitude that it occurs, on average, every 100 years; this equates to a 1-percent chance of its occurring in a given year.

500-year flood

A flood event of such magnitude that it occurs, on average, every 500 years; this equates to a 0.2-percent chance of its occurring in a given year.

A-weighted decibel scale

See *decibel, A-weighted*.

accessible environment

(1) The atmosphere, land surfaces, and surface waters beyond a *controlled area* that humans or animals can contact. (2) The area surrounding a *nuclear waste* disposal site.

accident

An unplanned sequence of events that results in undesirable consequences. Examples in this EIS include an inadvertent release of *radioactive* or hazardous materials from their containers or *confinement* to the *environment*; vehicular accidents during the transportation of highly radioactive materials; and industrial accidents that could affect workers in the facilities.

acre-foot

The volume of water required to cover 1 acre to a depth of 1 foot (about 1,200 cubic meters or 330,000 gallons).

actinide

Any of a series of chemically similar, mostly synthetic, *radioactive* elements with *atomic numbers* ranging from actinium-89 through lawrencium-103.

active institutional control

Continued Federal control of the Yucca Mountain Repository site including access control, maintenance, monitoring, and surveillance of facilities and waste. See *institutional control*.

affected environment

For an EIS, a description of the existing *environment* (that is, site description) covering information that relates directly to the scope of the *Proposed Action*, the *No-Action Alternative*, and the *implementing alternatives* being analyzed; in other words, the information necessary to assess or understand the *impacts*. This description must contain enough detail to support the impact analysis. The information must highlight “environmentally sensitive resources,” if present; these include floodplains and wetlands, *threatened* and *endangered species*, prime and unique agricultural lands, and property of historic, archaeological, or architectural significance.

air lock

A chamber or room in which air pressure can be regulated, usually between two regions of unequal pressure. The isolation air locks each consist of two *bulkheads* with doors that open and close in sequence.

air quality

A measure of the quantity of pollutants, measured individually, in the air.

ALARA

See *as low as reasonably achievable.*

alcove

A small excavation (room) off the main tunnel of a repository used for scientific study or for installing equipment.

alkali flat

A level area or plain in an *arid* or semiarid region encrusted with alkali salts that become concentrated by evaporation and poor drainage. *Cap.* (Alkali Flat): An example of such terrain, approximately 25 miles south of Amargosa Valley along the Amargosa River.

alluvial fan

A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream where it issues from a narrow mountain valley on a plain or broad valley.

alluvium

Sedimentary material deposited by flowing water.

alpha particle

A positively charged particle ejected spontaneously from the *nuclei* of some *radioactive* elements. It is identical to a helium nucleus and has a mass number of 4 and an electrostatic charge of +2. It has low penetrating power and a short range (a few centimeters in air). See *ionizing radiation.*

alternative

One of two or more actions, processes, or propositions from which a *decisionmaker* will determine the course to be followed. The *National Environmental Policy Act*, as amended, states that in preparing an EIS, an agency “shall ... (s)tudy, develop, and describe appropriate alternatives to recommended courses of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources” [42 USC 4321, Title I, Section 102 (E)]. The regulations of the Council on Environmental Quality that implement the National Environmental Policy Act indicate that the alternatives section in an EIS is “the heart of the environmental impact statement” (40 CFR 1502.14), and include rules for presenting the alternatives, including no action, and their estimated impacts.

This EIS has two alternatives: the *Proposed Action* under which DOE would construct, operate and monitor, and eventually close a *monitored geologic repository* for the *disposal* of *spent nuclear fuel* and *high-level radioactive waste* at Yucca Mountain, and the *No-Action Alternative* under which DOE would end *site characterization* activities at Yucca Mountain and continue to accumulate spent nuclear fuel and high-level radioactive waste at commercial storage sites and DOE facilities. The *Nuclear Waste Policy Act* states that this EIS does not have to discuss alternatives to geologic disposal or alternative sites to Yucca Mountain; DOE included the analysis of the No-Action Alternative to provide a basis for comparison with the Proposed Action. See *implementing alternative*.

DOE will base its decision on whether the repository program should proceed toward a site recommendation for Yucca Mountain in part on the Final EIS.

Amargosa Desert

A broad northwest-trending basin between the Yucca Mountain area on the north and the Death Valley area to the south.

Amargosa River

The main drainage system of the *Amargosa Desert*. The Amargosa River drainage basin originates in the Pahute Mesa-Timber Mountain area north of Yucca Mountain and includes the main tributary systems of *Beatty Wash* and *Fortymile Wash*. The river, which is frequently dry along much of its length, flows southeastward through the Amargosa Desert and ends in the internal drainage system of Death Valley. In southwestern Nevada, the river flows though the Amargosa Valley.

ambient

(1) Undisturbed, natural conditions such as ambient temperature caused by climate or natural *subsurface* thermal gradients. (2) Surrounding conditions.

ambient air

The surrounding atmosphere, usually the outside air, as it exists around people, plants, and structures. It is not the air in the immediate proximity to emission sources.

ambient air quality standards

Standards established on a Federal or state level that define the limits for airborne concentrations of designated *criteria pollutants* [nitrogen dioxide, *sulfur dioxide*, *carbon monoxide*, *particulate matter* with aerodynamic diameters less than 10 microns (PM_{10}), *ozone*, and lead] to protect public health with an adequate margin of safety (primary standards) and to protect public welfare, including plant and animal life, visibility, and materials (secondary standards). See *criteria pollutants.*

analyzed land withdrawal area

See *land withdrawal area.*

aquifer

A *subsurface* saturated rock unit (formation, group of formations, or part of a formation) of sufficient *permeability* to transmit *groundwater* and yield usable quantities of water to wells and springs.

aquitard

A leaky confining bed that transmits water at a very slow rate to or from an adjacent *aquifer*.

areal mass loading

The amount of *heavy metal* (usually expressed in metric tons of uranium or equivalent) emplaced per unit area in the proposed repository.

arid

Very dry, lacking moisture. Lacking in vegetation.

as low as reasonably achievable

A process that applies a graded approach to reducing *dose* levels to workers and the public, and releases of *radioactive* materials to the *environment*. The goal of this process, often referred to as *ALARA*, is not merely to reduce doses, but to reduce them to levels that are as low are reasonable achievable.

assembly

See *fuel assembly*.

atmospheric dispersion

Movement of a *contaminant* as a result of the cumulative effect of the wind patterns and random motions of the air.

atomic mass

The mass of a neutral atom, based on a relative scale, usually expressed in atomic mass units. See *atomic weight.*

atomic number

The number of protons in an atom's nucleus.

atomic weight

The relative mass of an atom based on a scale in which a specific carbon atom (carbon-12) is assigned a mass value of 12. Also known as relative *atomic mass*.

backfill

(1) The general fill placed in excavated areas of an underground facility; backfill for the proposed repository would be *tuff*. (2) The material or process used to refill an excavation.

background radiation

Radiation from cosmic sources, naturally occurring *radioactive* materials such as granite, and global fallout from nuclear testing.

Bare Mountain

An upfaulted mountain block that bounds the west side of *Crater Flat*.

barrier

Any material, structure, or condition (as a thermal barrier) that prevents or substantially delays the movement of water or *radionuclides*. See *natural barrier*.

basalt

A dark gray to black, dense to fine-grained *igneous* rock.

baseline

Documentation of current conditions so that changes can be identified.

Beatty Wash

A tributary drainage to the *Amargosa River*; drains the west and north sides of the Yucca Mountain area.

berm

A mound or wall of earth.

beta particle

A negative or positive *electron* emitted from a *nucleus* during beta decay, which is a radioactive transformation of a nuclide in which the atomic number increases or decreases by 1 and the mass number remains unchanged. See *ionizing radiation.*

biosphere

The ecosystem of the Earth and the living *organisms* inhabiting it.

block-bounding fault

A high-angle, normal fault with relatively large displacement that bounds one or both sides of the fault-block mountains typical of the Basin and Range province.

boiling-water reactor (BWR)

A *nuclear reactor* that uses boiling water to produce steam to drive a turbine.

borehole

A hole made with a drill, auger, or other tool for exploring *strata* in search of minerals, supplying water for blasting, emplacing waste, proving the position of old workings or faults, or releasing accumulations of gas or water. Boreholes include core holes, dry-well-monitoring holes, waste emplacement holes, and test holes for geophysical or *groundwater* characterization.

borosilicate glass

High-level radioactive waste matrix material in which boron takes the place of the lime used in ordinary glass mixtures.

borrow areas

Areas outside the rail corridor where construction personnel could obtain materials to be used in the establishment of a stable platform (subgrade) for the rail track. Aggregate crushing operations could occur in these areas.

buffer cars

Railcars in front of or in back of those carrying *spent nuclear fuel* and *high-level radioactive waste* to provide additional distance to possibly occupied railcars or to railcars carrying hazardous materials other than *radioactive* materials. Federal regulations require the separation of a railcar carrying spent nuclear fuel and high-level radioactive waste from a locomotive, occupied caboose, carload of undeveloped film, or railcar carrying another class of hazardous material by at least one buffer car. These could be DOE railcars or, in the case of general freight service, commercial railcars.

bulkhead

A wall or embankment in a mine or tunnel that protects against earthslide, fire, water, or gas.

burnup

A measure of *nuclear reactor* fuel consumption expressed either as the percentage of fuel atoms that have undergone *fission* or as the amount of energy produced per unit weight of fuel.

caldera

An enlarged volcanic crater formed by explosion or collapse of the original crater.

cancer

A malignant tumor of potentially unlimited growth, capable of invading surrounding tissue or spreading to other parts of the body.

candidate species

Species for which the Fish and Wildlife Service has enough substantive information on biological status and threats to support proposals to list them as threatened or endangered under the Endangered Species Act. Listing is anticipated but has been precluded temporarily by other listing activities.

canister

A thin-walled, unshielded metal container used as: (1) a pour mold in which molten vitrified *high-level radioactive waste* can solidify and cool; (2) the container in which DOE and electric utilities place intact *spent nuclear fuel*, loose rods, or nonfuel components for shipping or storage; or (3) in general, a container used to provide radionuclide *confinement*. Canisters are used in combination with specialized overpacks that provide structural support, shielding or confinement for storage, transportation, and *emplacement*; overpacks are sometimes referred to as *casks*.

capillary barrier

A contact in the *unsaturated zone* between a *geologic* unit containing relatively small-diameter openings and a unit containing relatively large-diameter openings across which water does not flow.

carbon monoxide

A colorless, odorless, poisonous gas produced by incomplete fossil-fuel combustion; one of the six pollutants for which there is a national *ambient air quality standard*.

carbon steel

A steel that is tough but malleable and contains a small percentage of carbon. The outer *barrier* of *waste packages* is composed of carbon steel.

carcinogen

An agent capable of producing or inducing *cancer*.

carcinogenic

Capable of producing or inducing *cancer*.

cask

(1) A heavily shielded container that meets applicable regulatory requirements used to ship *spent nuclear fuel* or *high-level radioactive waste*; (2) a heavily shielded container used by DOE and utilities for the *dry storage* of spent nuclear fuel; usable only for storage, not for transportation to or *emplacement* in a repository.

chain reaction

A process in which some of the *neutrons* released in one *fission* event cause other fissions.

characterization

Activities in the laboratory or the field undertaken to establish the geologic conditions and the ranges of the parameters of a candidate site relevant to the location of a repository. These activities include borings, surface excavations, excavations of exploratory shafts, limited *subsurface* lateral excavations and borings, and *in situ* testing to evaluate the suitability of a candidate site for the location of a repository, but do not include preliminary borings and geophysical testing to assess if *site characterization* should be undertaken.

Civilian Radioactive Waste Management System

The organizational system of the DOE Office of Civilian Radioactive Waste Management; it is the composite of the sites and all facilities, systems, equipment, materials, information, activities, and personnel required to perform the activities necessary to manage *radioactive* waste *disposal*.

cladding

The metallic outer sheath of a fuel element generally made of stainless steel or a *zirconium alloy*. It is intended to isolate the fuel element from the external *environment*.

clastic

Describing a rock or sediment composed mainly of broken fragments of preexisting minerals or rocks that have been transported from their places of origin.

climate states

Representations of climate conditions. Three different climate states are used to represent changes in climate over the periods of interest: present-day dry climate, long-term-average climate (about twice the precipitation of dry climate), and superpluvial climate (about three times the precipitation of dry climate).

closure

See *repository phases*.

co-disposal

A packaging method for *disposal* of *radioactive* waste in which two types of waste, such as *commercial spent nuclear fuel* and defense *high-level radioactive waste*, are combined in *disposal containers*. Co-disposal takes advantage of otherwise unused space in disposal containers and is more cost-effective than other methods to limit the reactivity of individual *waste packages*.

collective dose

See *population dose*.

colloid

Small particles in the size range of 10^{-9} to 10^{-6} meters that are suspended in a solvent. Naturally occurring colloids in *groundwater* arise from clay minerals.

colluvium

Loose earth material that has accumulated at the base of a hill, through the action of gravity.

commercial spent nuclear fuel

Commercial nuclear fuel rods that have been removed from *reactor* use. See *spent nuclear fuel* and *DOE spent nuclear fuel.*

conceptual model

A set of *qualitative* assumptions used to describe a system or subsystem for a given purpose. Assumptions for the model should be compatible with one another and fit the existing data within the context of the given purpose of the model.

confinement

As it pertains to *radioactivity*, the retention of *radioactive* material within some specified bounds. Confinement differs from containment in that there is no absolute physical *barrier* in the former.

construction

See *repository phases*.

construction/demolition debris

Discarded solid wastes resulting from the construction, remodeling, repair, and demolition of structures, road building, and land clearing that are inert or unlikely to create an environmental hazard or threaten the health of the general public. Such debris from repository construction would include materials such as soil, rock, masonry materials, and lumber.

construction support areas

Areas along the rail route that could be used as temporary residences for construction crews, material and equipment storage areas, and concrete production areas. Such camps probably would be for the construction of routes far from population centers.

contaminant

A substance that contaminates (pollutes) air, soil, or water. Also, a hazardous substance that does not occur naturally or that occurs at levels greater than those that occur naturally in the surrounding *environment*.

contaminant flux

Movement of a *contaminant* across a surface boundary per unit time (for example, *curies* per year; milligrams per year).

contamination

The intrusion of undesirable elements (unwanted physical, chemical, biological, or radiological substances, or matter that has an adverse effect) to air, water, or land.

controlled area

A surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers (6 miles) in any direction from the outer boundary of the underground facility, and the underlying *subsurface*, which area has been committed to use as a *geologic repository* and from which incompatible activities would be prohibited before and after *permanent closure*.

convection

(1) Thermally driven *groundwater* flow or a heat-transfer mechanism for a gas phase. The bulk motion of a flowing fluid (gas or liquid) in the presence of a gravitational field, caused by temperature differences that, in turn, cause different areas of the fluid to have different densities (for example, warmer is less dense). (2) One of the processes that moves solutes in *groundwater*.

corridor

A strip of land in Nevada that encompasses one of several possible routes through which DOE could build a rail line or truck route to transport *spent nuclear fuel*, *high-level radioactive waste*, and other material to and from the Yucca Mountain Repository site.

corrosion

The process of dissolving or wearing away gradually, especially by chemical action.

corrosion-allowance material

Disposal container material, such as *carbon steel*, that oxidizes at a predictable rate in a corrosive environment.

corrosion-resistant material

Disposal container material, such as Alloy 22, that oxidizes slowly in a corrosive environment.

Crater Flat

A north-trending, 6- to 11-kilometer (4- to 7-mile)-wide area west of Yucca Mountain; bounded by *Bare Mountain* on the west and Yucca Mountain on the east.

credible event/credible accident

An event or *accident* scenario that the design of the *geologic repository* must consider.

criteria pollutants

Six common pollutants (*ozone*, *carbon monoxide*, *particulates*, *sulfur dioxide*, lead, and nitrogen dioxide) known to be hazardous to human health and for which the U.S. Environmental Protection Agency sets National Ambient Air Quality Standards under the Clean Air Act. See *toxic air pollutants*.

critical group

With regard to annual *dose*, the *maximally exposed individuals*. A group of members of the public whose *exposure* is reasonably homogeneous and includes individuals receiving the highest dose. The individuals making up the critical group may change with changes in *source term* and *pathway*.

criticality

The condition in which nuclear fuel sustains a *chain reaction*. It occurs when the number of neutrons present in one generation cycle equals the number generated in the previous cycle.

criticality control

Set of measures taken to maintain nuclear materials, including *spent nuclear fuel*, in a *subcritical* condition during storage, transportation, and *disposal*, so no self-sustaining nuclear *chain reaction* can occur. Subcriticality is maintained by loading spent nuclear fuel in specific configurations that meet requirements related to fuel age, enrichment, and reduction in nuclear fuel reactivity through *burnup*.

cross drift

An approximately 2,800-meter (9,200-foot)-long *drift* excavated to provide researchers new opportunities to study the geologic profile of the rock in the proposed repository area beneath Yucca Mountain. Researchers will conduct a new battery of tests in the cross drift as part of ongoing studies to determine if Yucca Mountain would be a suitable host for a deep *monitored geologic repository* for *spent nuclear fuel* and *high-level radioactive waste*. The cross drift begins inside the *Exploratory Studies Facility* approximately 2,000 meters (6,600 feet) from the northern entrance and cuts through the entire stratigraphic section of the potential Upper Block emplacement area.

cumulative impact

The *impact* on the *environment* that results from the incremental impact(s) of an action when added to other past, present, and reasonably foreseeable future actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

curie

A unit of *radioactivity* equal to 37 billion *disintegrations* per second.

decay (radioactive)

The process in which one radionuclide spontaneously transforms into one or more different radionuclides called decay products.

decibel (dB)

A standard unit for measuring sound-pressure levels based on a reference sound pressure of 0.0002 dyne per square centimeter. This is the smallest sound a human can hear.

decibel, A-weighted (dBA)

A measurement of sound approximating the sensitivity of the human ear and used to characterize the intensity or loudness of sound.

decisionmaker

The group or individual responsible for making a decision on constructing and operating a *monitored geologic repository* for the disposal of *spent nuclear fuel* and *high-level radioactive waste* at Yucca Mountain.

decommissioning

The process of removing from service a facility in which nuclear materials are handled. It usually involves decontaminating the facility so that it may be dismantled or dedicated to other purposes.

decontamination

A process that removes, destroys, or neutralizes chemical, biological, or radiological contamination from a person, object, or area.

dedicated freight rail service

A train that handles only one commodity (in this case, *spent nuclear fuel* or *high-level radioactive waste*); this separate train with its own crew would limit switching between trains of the railcars carrying these materials.

defense in depth

A strategy based on a system of multiple, independent, and redundant *barriers*, designed to ensure that failure in any one barrier does not result in failure of the entire system.

deformation

A change in the shape and size of a body.

design alternative

A fundamentally different conceptual design for a repository, which could stand alone as the License Application repository design concept.

design-basis event

Naturally or humanly induced events that are reasonably likely to occur one or more times before permanent closure of the *geologic repository's* operations area; in addition, any other natural or human-induced event that is unlikely, but is sufficiently credible to warrant consideration, taking into account the potential for significant radiological impacts on public health and safety.

design enhancement

An engineered *barrier* system feature that DOE is considering for possible inclusion in the *Viability Assessment* design for the Yucca Mountain Repository. Design enhancements are not considered to be essential to the successful performance of the repository. The EIS analysis of the *Proposed Action* will not include design enhancements, but will identify them as possible means of *mitigation*. If a design enhancement is added to the reference design in time for inclusion in the EIS, it will be evaluated as part of the Proposed Action design.

design feature

A specific element or attribute of the repository for which postclosure (long-term) performance could be evaluated independently of a specific repository design alternative or other design features.

deterministic

A single calculation using only a single value for each of the model parameters. A deterministic system is governed by definite rules of system behavior leading to cause and effect relationships and predictability. Deterministic calculations do not account for *uncertainty* in the physical relationships or parameter values.

dip-slip fault

A fault in which the relative displacement is along the direction of dip of the fault plane. If the block above the fault has moved downward it is a *normal fault*; upward movement indicates a *reverse fault*.

direct impact

Effect that results solely from the construction or operation of a proposed action without intermediate steps or processes. Examples include habitat destruction, soil disturbance, air emissions, and water use.

disintegration

Any transformation of a *nucleus*, whether spontaneous or induced by *irradiation*, in which the nucleus emits one or more particles or *photons*.

disposable canister

A canister for *spent nuclear fuel* or *high-level radioactive waste* with specialized overpacks to enable storage, transportation, and *emplacement* in a repository.

disposal

The *emplacement* in a repository of *high-level radioactive waste*, *spent nuclear fuel*, or other highly *radioactive* material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste, and the *isolation* of such waste from the *accessible environment*.

disposal container

The *barrier* or shell, spacing structures or baskets, integral shielding, and packing and other absorbent materials inside or immediately surrounding the container (that is, attached to its outer surface). The disposal container would contain *spent nuclear fuel* and *high-level radioactive waste*, but would exist only after the outer lid weld is complete and accepted. The disposal container would not include the waste form or the encasing containers or canisters (high-level radioactive waste canisters, *DOE spent nuclear fuel* canisters, disposable canisters of *commercial spent nuclear fuel,* etc.).

disproportionately high and adverse human health effects

Effects that occur when *impacts* to a *minority population* or *low-income population* from exposure to an environmental hazard significantly exceed the impacts to the general population and, where available, to an appropriate comparison group.

disproportionately high and adverse environmental impacts

An environmental *impact* that is unacceptable or above generally accepted norms; these would include economic impacts of the *Proposed Action*. A disproportionately high impact is one (or the risk of one) to a *low-income population* or *minority population* that significantly exceeds the impact to the general population. In assessing cultural and aesthetic impacts, agencies consider impacts that would have unique effects on geographically dislocated or dispersed low-income or minority populations.

disruptive event

An unexpected event which, in the case of the repository, includes *human intrusion*, volcanic activity, *seismic* activity, and nuclear *criticality*. Disruptive events have two possible effects; (1) direct release of *radioactivity* to the surface, or (2) alteration of the expected behavior of the system.

dissolution

Change from a solid to a liquid state. Dissolving a substance in a solvent.

DOE spent nuclear fuel

Radioactive waste created by defense activities that consists of over 250 different types of *spent nuclear fuel* and is expected to contribute 2,333 *metric tons of heavy metal* (*MTHM*) to the total repository. The major contributor to this waste form is the N-reactor fuel currently stored at the Hanford Site. This waste form also includes 65 MTHM of *naval spent nuclear fuel*.

dose

The amount of *radioactive* energy that passes the exchange boundaries of an *organism* (skin, mucous membrane, etc.) and is taken into living tissues. Dose arises from a combination of the energy imparted by the *radiation* and the absorption efficiency of the affected organism or tissues. It is expressed in terms of units of the radiation taken in, the body weight or mass impacted, and the time over which the dose occurs or the *impact* is measured.

dose equivalent

(1) The number (corrected for background) zero and above that is recorded as representing an individual's *dose* from external *radiation* sources or internally deposited *radioactive* materials; (2) the product of the absorbed dose in *rads* and a quality factor; (3) the product of the absorbed dose, the quality factor, and any other modifying factors. The dose equivalent quantity is used for comparing the biological effectiveness of different kinds of radiation (based on the quality of radiation and its spatial distribution in the body) on a common scale; it is expressed in *rem*.

drift

From mining terminology, a horizontal underground passage. The nearly horizontal underground passageways from the *shaft(s)* to the *alcoves* and rooms. Includes excavations for *emplacement* (emplacement drifts) and access (access mains).

drip shield

A sheet of impermeable material placed above the *waste package* to prevent seeping water from directly contacting the waste packages.

dry storage

Storage of *spent nuclear fuel* without immersing the fuel in water for cooling or shielding; it involves the encapsulation of spent fuel in a steel cylinder that might be in a concrete or massive steel *cask* or structure.

dual-purpose canister

A containment vessel structure specifically designed to store and transport *commercial spent nuclear fuel*.

earthquake

A series of elastic waves in the crust of the Earth caused by abrupt movement easing strains built up along *geologic* faults or by volcanic action and resulting in movement of the Earth's surface.

electron

A stable elementary particle that is the negatively charged constituent of ordinary matter.

emplacement

The act of placing *waste packages* in prepared positions.

endangered species

A species that is in danger of extinction throughout all or a significant part of its range; a formal listing of the Fish and Wildlife Service under the Endangered Species Act.

Energy Policy Act of 1992

Legislation that amends the *Nuclear Waste Policy Act* by directing (1) the Environmental Protection Agency to set site-specific public health and safety radiation protection standards from Yucca Mountain, and (2) the Nuclear Regulatory Commission to modify its technical requirements and licensing criteria to be consistent with the Environmental Protection Agency site-specific standards.

engineered barrier system

The *waste packages* and the underground facility. These are the designed, or engineered, components of the disposal system and the waste package.

enhanced design alternative

A combination (or variation) of one or more design alternatives and design features.

environment

(1) Includes water, air, and land and all plants and humans and other animals living therein, and the interrelationship existing among these. (2) The sum of all external conditions affecting the life, development, and survival of an *organism*.

environmental impact statement (EIS)

A detailed written statement to support a decision to proceed with major Federal actions affecting the quality of the human *environment*. This is required by the *National Environmental Policy Act*. The EIS describes:

> “...the environmental impact of the proposed action; any adverse environmental effects which cannot be avoided should the proposal be implemented; alternatives to the proposed action (although the Nuclear Waste Policy Act, as amended, precludes consideration of certain alternatives); the relationship between local short-term uses of man’s environment and the maintenance and enhancement of long-term productivity; and any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.”

Preparation of an EIS requires a public process that includes public meetings, reviews, and comments, as well as agency responses to the public comments. A Final EIS for the Yucca Mountain site is scheduled for publication in Fiscal Year 2000.

environmental justice

The fair treatment of people of all races, cultures, incomes, and educational levels with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. Fair treatment implies that no population of people should subject to disproportionate negative environmental *impacts* of pollution or environmental hazards.

environmental monitoring

The process of sampling and analyzing environmental media in and around a facility to (1) confirm compliance with performance objectives and (2) detect *contamination* entering the *environment* to facilitate timely remedial action.

equilibrium

The state of a chemical system in which the phases do not undergo any spontaneous change in properties or proportions with time; a dynamic balance.

erionite

A natural fibrous *zeolite* in the rocks at Yucca Mountain that is listed as a known human carcinogen by recognized international agencies such as the International Agency for Research on Cancer.

escort cars

Railcars in which escort personnel would travel on trains carrying *spent nuclear fuel* or *high-level radioactive waste*.

evapotranspiration

The combined processes of evaporation and plant *transpiration* that remove water from the soil and return it to the air.

Exploratory Studies Facility

An underground laboratory at Yucca Mountain that includes an 8-kilometer (5-mile) main loop (tunnel), a 3-kilometer (2-mile) *cross drift*, and a research *alcove* system constructed for performing underground studies during *site characterization*. The data collected will contribute toward determining the suitability of the Yucca Mountain site as a repository. Some or all of the facility could be incorporated into the proposed repository.

exposure (to radiation)

The incidence of *radiation* on living or inanimate material by accident or intent. Background exposure is the exposure to natural *ionizing radiation*. Occupational exposure is the exposure to ionizing radiation that occurs during a person's working hours. Population exposure is the exposure to a number of persons who inhabit an area.

exposure pathway

The course a chemical or physical agent takes from the source to the exposed *organism*; describes a unique mechanism by which an individual or population can become exposed to chemical or physical agents at or originating from a release site. Each exposure pathway includes a source or a release from a source, an exposure point, and an exposure route.

far-field

The area of the geosphere and *biosphere* far enough away from the repository that, when numerically modeled, releases from the repository are represented as a homogeneous, single-source effect.

fault

A fracture in rock along which movement of one side relative to the other has occurred.

Fiscal Year

A 12-month period to which a jurisdiction's annual budget applies and at the end of which its financial position and the results of its operations are determined. For example, the Fiscal Year for Clark and Nye Counties, the Cities of Las Vegas and North Las Vegas, the Towns of Tonopah and Pahrump, and the Clark County and Nye County School Districts runs from July 1 through the following June 30; the Federal Fiscal Year runs from October 1 through the following September 30.

fission

The splitting of a *nucleus* into at least two other nuclei, resulting in the release of two or three *neutrons* and a relatively large amount of energy.

fission products

A complex mixture of radionuclides produced by the process of *fission* that includes *radioactive* and nonradioactive radionuclides as well as the decay products of the *radioactive decay* of these nuclides. This can result in more than 200 *isotopes*.

Fortymile Wash

A major tributary to the *Amargosa River*; drains *Jackass Flats* to the east of Yucca Mountain; usually dry along most of its length.

fracture

A general term for any break in a rock, whether or not it causes displacement, caused by mechanical failure from stress. Fractures include cracks, joints, and *faults*. Fractures can act as pathways for rapid *groundwater* movement.

fuel assembly

A number of fuel elements held together by structural materials, used in a *nuclear reactor*. Sometimes called a fuel bundle.

fugitive dust

Particulate matter composed of soil; can include emissions from haul roads, wind erosion of exposed soil surfaces, and other activities in which soil is removed or redistributed.

fugitive emissions

Emissions released directly into the *atmosphere* that could not reasonably pass through a stack, chimney, vent, or other functionally equivalent opening.

GENII

A *deterministic* computer software code that evaluates *dose* from the migration of radionuclides introduced into the *accessible environment*, or *biosphere*, that may eventually affect humans through ingestion, inhalation, or direct *radiation*. It is used to develop biosphere dose conversion factors.

gamma ray

The most penetrating type of radiant nuclear energy. It does not contain particles and can be stopped by dense materials such as concrete or lead. *See ionizing radiation.*

general freight rail service

Railroad line service that uses trains that move railcars, each of which might contain a different commodity. Railcars carrying *spent nuclear fuel* or *high-level radioactive waste* could be switched (in railyards or on sidings) successively from one general freight train to another as they traveled from the commercial and DOE locations to Nevada.

geologic

Of or related to a natural process acting as a dynamic physical force on the Earth (faulting, erosion, mountain building resulting in rock formations, etc.).

geologic repository

A system for disposing of *radioactive* waste in excavated *geologic* media, including surface and *subsurface* areas of operation, and the adjacent part of the geologic setting that provides *isolation* of the radioactive waste in the *controlled area*.

Great Basin

A subprovince of the Basin and Range province, generally characterized by north-trending mountain ranges and intervening basins, stretching from eastern Oregon to southern California.

Greater-Than-Class-C waste

Low-level nuclear waste generated by the commercial sector that exceeds U.S. Nuclear Regulatory Commission concentration limits for Class-C low-level waste, as specified in 10 CFR Part 61. DOE is responsible for disposing of this type of waste from its nondefense programs.

ground support

The system (rock bolt with wire mesh, steel cast, cast or precast concrete sections) used to line the main and emplacement *drifts* to minimize rock or earth falling into the drifts.

groundwater

Water contained in pores or fractures in either the *unsaturated zone* or *saturated zone* below ground level.

habitat

Area in which a plant or animal lives and reproduces.

half-life (radiological)

The time in which half the atoms of a *radioactive* substance decay to another nuclear form. Half-lives range from millionths of a second to billions of years depending on the stability of the nuclei.

hazardous chemical

As defined under the Occupational Safety and Health Act and the Community Right-to-Know Act, a chemical that is a physical or health hazard.

hazardous pollutant

Hazardous chemical that can cause serious health and environmental hazards, and listed on the Federal list of hazardous air pollutants (42 USC 7412). See *toxic air pollutants*.

hazardous waste

Waste designated as hazardous by the Environmental Protection Agency or State of Nevada regulations. Hazardous waste, defined under the Resource Conservation and Recovery Act, is waste that poses a potential hazard to human health or the environment when improperly treated, stored, or disposed of. Hazardous wastes appear on special Environmental Protection Agency lists or possess at least one of the following characteristics: ignitability, corrosivity, toxicity, or reactivity. Hazardous waste streams from the repository could include certain used rags and wipes contaminated with solvents.

heavy-haul truck

An overweight, overdimension vehicle that must have permits from state highway authorities to use public highways; a vehicle DOE would use on public highways to move *spent nuclear fuel* or *high-level radioactive waste shipping casks* designed for a railcar.

heavy metal

All uranium, plutonium, and thorium used in a manmade *nuclear reactor*.

high-efficiency particulate air filter

A filter with an efficiency of at least 99.95 percent that separates particles from an air exhaust stream before the air is released to the atmosphere.

high-level radioactive waste

(1) The highly *radioactive* material that resulted from the reprocessing of *spent nuclear fuel*, including liquid waste produced directly in reprocessing, and any solid material derived from such liquid waste that contains *fission* products in sufficient concentrations. (2) Other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent *isolation*.

Highway Route-Controlled Quantities of Radioactive Material

Thresholds for certain quantities of *radioactive* materials above which shipments are subject to specific routing controls that apply to the highway carrier. These thresholds are defined by U.S. Department of Transportation regulations (49 CFR Part 177). (49 CFR Part 397 Subpart D defines routing requirements.)

horizon

See *repository horizon*.

human intrusion

The inadvertent disturbance of a *disposal* system by the activities of humans that could result in release of *radioactive* waste. 40 CFR Part 191 Subpart B requires that *performance assessments* consider the possibility of human intrusion.

hydrogeology

A study that encompasses the interrelationships of *geologic* materials and processes involving water.

hydrographic area

A groundwater basin.

hydrology

(1) The study of water characteristics, especially the movement of water. (2) The study of water, involving aspects of geology, oceanography, and meteorology.

igneous

(1) A type of rock formed from a molten, or partially molten, material. (2) An activity related to the formation and movement of molten rock either in the *subsurface* (plutonic) or on the surface (volcanic).

impact

For an EIS, the positive or negative effect of an action (past, present, or future) on the natural *environment* (land use, air quality, water resources, geological resources, ecological resources, aesthetic and scenic resources) and the human environment (infrastructure, economics, social, and cultural).

implementing alternative

An action or proposition by DOE necessary to implement the *Proposed Action* and to enable the estimation of the range of reasonably foreseeable *impacts* of that action or proposition.

- The implementing rail/intermodal alternatives for Nevada transportation are the five corridors for a new rail spur:
  - Carlin
  - Caliente
  - Caliente-Chalk Mountain
  - Jean
  - Valley Modified
- The five *intermodal transfer station*/heavy-haul route combinations:
  - Caliente intermodal transfer station, Caliente route
  - Caliente intermodal transfer station, Caliente-Chalk Mountain route
  - Caliente intermodal transfer station, Caliente-Las Vegas route
  - Sloan/Jean intermodal transfer station, Sloan/Jean route
  - Apex/Dry Lake intermodal transfer station, Apex/Dry Lake route

DOE decisions on implementing alternatives will be made when they are ripe for decisionmaking, which might occur after a decision to construct and operate the Yucca Mountain Repository.

inadvertent intrusion

The disturbance of a *disposal* facility or its immediate *environment* by a future occupant that could result in a loss of *containment* of the waste or *exposure* of people.

indirect impact

An effect that is related to but removed from a proposed action by an intermediate step or process. Examples include surface-water quality changes resulting from soil erosion at construction sites, and reductions in productivity resulting from changes in soil temperature.

industrial wastewater

Liquid wastes from industrial processes that do not include sanitary sewage. Repository industrial wastewater would include water used for dust suppression and process water from building heating, ventilation, and air conditioning systems.

inert

Lacking active thermal, chemical, or biological properties. An inert atmosphere is incapable of supporting combustion.

infiltration

The process of water entering the soil at the ground surface and the ensuing movement downward when the water input at the soil surface is adequate. Infiltration becomes *percolation* when water has moved below the depth at which it can return to the atmosphere by evaporation or *evapotranspiration*.

infrastructure

Basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communication systems. These include surface and *subsurface* facilities (for example, service drifts, transporters, electric power supplies, waste handling buildings, administrative facilities).

in situ

In its natural position or place. The phrase distinguishes in-place experiments, conducted in the field or underground facility, from those conducted in the laboratory.

institutional control

Monitoring and maintenance of storage facilities to ensure that radiological releases to the *environment* and *radiation* doses to workers and the public remain within Federal limits and DOE Order requirements.

intermodal transfer station

A facility at the juncture of rail and road transportation used to transfer *shipping casks* containing *spent nuclear fuel* and *high-level radioactive waste* from rail to truck and empty casks from truck to rail.

intermodal transfer station candidate area

Area near one or more existing main rail lines that DOE is considering for the location of an *intermodal transfer station*.

intrusive sound

A new sound that, either because of its loudness in relation to the local *ambient* sound level, or because of such characteristics as tone content, impulsive or unexpected nature, or high information content, is annoying or detracts from the usual ambiance of the receptor location. See *noise*.

invert

(1) The low point of something such as a tunnel, *drift*, or drainage channel. (2) An engineered structure or material placed on excavated drift floors (the low points) to serve as structural support for drift transportation or *emplacement* systems. (For precast concrete, the proper name is invert segments, but they are commonly referred to simply as inverts.) Typical inverts (segments) convert rounded excavated floors to flat level surfaces for transportation system use. Emplacement drift inverts may be specially designed to enhance the waste *isolation* and *criticality* prevention capabilities of the proposed repository through choice of invert materials or invert shape. Inverts might also be used to help channel water to improve repository drainage.

involved worker

A worker who would be directly involved in the activities related to facility construction and operations, including excavation activities; receipt, handling, packaging, and *emplacement* of waste materials; and *monitoring* of the condition and performance of the *waste packages*. See *noninvolved worker*.

ion

(1) An atom that contains excess *electrons* or is deficient in electrons, causing it to be chemically active. (2) An electron not associated with a *nucleus*.

ionizing radiation

(1) *Alpha particles*, *beta particles*, *gamma rays*, *X-rays*, *neutrons*, high-speed *electrons*, high-speed *protons*, and other particles capable of producing *ions*. (2) Any radiation capable of displacing electrons from an atom or molecule, thereby producing ions.

irradiation

Exposure to *radiation*.

isolation

Inhibiting the transport of *radioactive* material so that the amounts and concentrations of this material entering the *accessible environment* stay within prescribed limits.

isotope

One of two or more atomic *nuclei* with the same number of *protons* (that is, the same *atomic number*) but with a different number of *neutrons* (that is, a different *atomic weight*). For example, uranium-235 and uranium-238 are both isotopes of uranium.

Jackass Flats

A broad asymmetric basin 8 to 10 kilometers (5 to 6 miles) wide and 20 kilometers (12 miles) long that is east of Yucca Mountain and is drained by *Fortymile Wash*.

juvenile failure

Premature failure of a *waste package* because of material imperfections or damage by rockfall during *emplacement*.

land withdrawal area

An area of Federal property set aside for the exclusive use of a Federal agency. For the analyses in this EIS, DOE used an assumed land withdrawal area of 600 square kilometers, or 150,000 acres.

Las Vegas Valley shear zone

A major right-lateral strike-slip zone of faulting.

latent cancer fatalities

Deaths resulting from *cancer* that has become active after a latent period (that is, the period after exposure).

legal-weight truck

A truck with a gross vehicle weight (both truck and cargo weight) of less than 36,300 kilograms (80,000 pounds), the loaded weight limit for commercial vehicles operated on public highways without special state-issued permits. In addition, the dimensions, axle spacing, and, if applicable, axle loads of these vehicles must be within Federal and state regulations.

License Application

An application to the Nuclear Regulatory Commission for a license to construct a repository.

lithology

The study and description of the general, gross physical characteristics of a rock, especially sedimentary *clastics*, including color, grain size, and composition.

lost workday cases

Incidents that result in injuries that cause the loss of work time.

low-income population

One in which 25 percent or more of the persons in the population live in poverty, as reported by the Bureau of the Census in accordance with Office of Management and Budget requirements.

low-level radioactive waste

Radioactive waste that is not classified as *high-level radioactive waste*, *transuranic waste*, or byproduct tailings containing uranium or thorium from processed ore. Usually generated by hospitals, research laboratories, and certain industries.

maintenance

Activities during the repository operation and monitoring phase including maintenance of *subsurface* monitoring and instrumentation systems and utilities (compressed air, water supply, fire water, wastewater system, power supply, and lights), maintenance of the main ventilation fan installations and surface facilities related to underground activities, and site security. Maintenance also preserves the capability to retrieve emplaced *disposal containers*. See *repository phases*.

matrix (geology)

The solid, but porous, portion of rock.

maximally exposed individual

A hypothetical individual whose location and habits result in the highest total radiological or chemical *exposure* (and thus *dose*) from a particular source for all *exposure* routes (for example, inhalation, ingestion, direct exposure). For evaluating the potential postclosure radiological impacts to the public, "maximally exposed individual" is interchangeable with "reasonably maximally exposed individual."

Maximum Contaminant Level

Under the Safe Drinking Water Act, the maximum permissible concentrations of specific constituents in drinking water that is delivered to any user of a public water system that serves 15 or more connections and 25 or more people; the standards established as maximum contaminant levels consider the feasibility and cost of attaining the standard.

maximum reasonably foreseeable accidents

Accidents characterized by extremes of mechanical (impact) forces, heat (fire), and other conditions that would lead to the highest foreseeable consequences. In general, accidents with conditions that have a chance of occurring more often than 1 in 10 million in a year are considered to be reasonably foreseeable.

metamorphic

Rock in which the original mineralogy, texture, or composition has changed due to the effects of pressure, temperature, or the gain or loss of chemical components.

metric tons of heavy metal (MTHM)

Quantities of *spent nuclear fuel* without the inclusion of other materials such as *cladding* (the tubes containing the fuel) and structural materials. A metric ton is 1,000 kilograms (1.1 tons or 2,200 pounds). Uranium and other metals in spent nuclear fuel (such as thorium and plutonium) are called *heavy metals* because they are extremely dense; that is, they have high weights per unit volume.

millirem

One one-thousandth (0.001) of a *rem*.

minority population

A community in which the percent of the population of a racial or ethnic minority is 20 points higher than the percent found in the population as a whole.

mitigation

Actions and decisions that (1) avoid *impacts* altogether by not taking a certain action or parts of an action, (2) minimize impacts by limiting the degree or magnitude of an action, (3) rectify the impact by repairing, rehabilitating, or restoring the *affected environment*, (4) reduce or eliminate the impact over time by preservation and maintenance operations during the life of the action, or (5) compensate for an impact by replacing or providing substitute resources or *environments*.

mixed-oxide fuel

A mixture of uranium oxide and plutonium oxide that could be used to power commercial nuclear reactors.

monitored geologic repository

A system, requiring licensing by the U.S. Nuclear Regulatory Commission, intended or used for the permanent underground *disposal* of *radioactive* waste (including *spent nuclear fuel*). A *geologic repository* includes (1) the geologic repository operations area, and (2) the geologic setting in the *controlled area* that provides *isolation* of the radioactive waste. The repository would be monitored between *emplacement* of the last *waste package* and closure.

monitoring

Activities during the repository operation and monitoring phase including the surveillance and testing of *waste packages* and the repository for *performance confirmation*. See *repository phases*.

National Environmental Policy Act

The Federal statute that is the national charter for protection of the *environment*. The Act is implemented by procedures issued by the Council on Environmental Quality and DOE. The National Environmental Policy Act of 1969 appears at 42 USC 4321 *et seq*.

natural barrier

The physical, mechanical, chemical, and hydrologic characteristics of the geologic *environment* that individually and collectively act to minimize or prevent radionuclide transport. See *barrier*.

natural system

A host rock suitable for repository construction and waste *emplacement* and the surrounding rock formations. It includes *natural barriers* that provide *containment* and *isolation* by limiting radionuclide transport through the geohydrologic *environment* to the *biosphere* and provide conditions that will minimize the potential for *human intrusion* in the future.

naval spent nuclear fuel

Spent nuclear fuel discharged from reactors in surface ships, submarines, and training reactors operated by the U.S. Navy.

near-field

The area of and conditions in the repository including the *drifts* and *waste packages* and the rock immediately surrounding the drifts. The region around the repository where the natural hydrogeologic system would be significantly impacted by the excavation of the repository and the *emplacement* of waste.

neutron

An atomic particle with no charge and an atomic mass of 1; a component of all atoms except hydrogen; frequently released as *radiation*.

nitrogen oxides

Gases formed in great part from atmospheric nitrogen and oxygen when combustion occurs under conditions of high temperature and high pressure; a major air pollutant. Two primary nitrogen oxides, nitric oxide (NO) and nitrogen dioxide (NO_2), are important airborne *contaminants*. In the presence of sunlight, nitric oxide combines with atmospheric oxygen to produce nitrogen dioxide, which in high concentrations can cause lung damage.

No-Action Alternative

One of the *alternatives* to be assessed in an EIS. The regulations of the Council on Environmental Quality (40 CFR Parts 1500 through 1508) direct Federal agencies to use the process established by the *National Environmental Policy Act* to identify and assess reasonable alternatives, including “no action.” For this EIS, under the No-Action Alternative DOE would end *site characterization* activities at Yucca Mountain and continue to accumulate *spent nuclear fuel* and *high-level radioactive waste* at commercial storage sites and DOE facilities.

noble gas

Any of a group of rare gases that include helium, neon, argon, krypton, xenon, and sometimes radon and that exhibit great stability and extremely low reaction rates; also called *inert* gas.

noise

Any sound that is undesirable because it interferes with speech and hearing; if intense enough, it can damage hearing.

noninvolved worker

A worker who would perform managerial, technical, supervisory, or administrative activities but would not be directly involved in construction, excavation, or operations activities. See *involved worker*.

normal fault

A fault in which the relative displacement is along the direction of dip of the fault plane (*dip-slip fault*) where the block above the fault has moved downward in relation to the block below the fault. See *reverse fault*.

nuclear radiation

Radiation that emanates from an unstable atomic *nucleus*.

nuclear reactor

A device in which a nuclear *fission chain reaction* can be initiated, sustained, and controlled to generate heat or to produce useful radiation.

nuclear waste

Unusable by-products of nuclear power generation, nuclear weapons production, and research, including *spent nuclear fuel, high-level radioactive waste*.

Nuclear Waste Policy Act (42 USC 10101 *et seq.*)

The Federal statute enacted in 1982 that established the Office of Civilian Radioactive Waste Management and defined its mission to develop a Federal system for the management and geologic disposal of *commercial spent nuclear fuel* and other *high-level radioactive wastes*, as appropriate. The Act also specified other Federal responsibilities for nuclear waste management, established the Nuclear Waste Fund to cover the cost of geologic *disposal*, authorized interim storage under certain circumstances, and defined interactions between Federal agencies and the states, local governments, and Native American tribes. The Act was substantially amended in 1987 (see *Nuclear Waste Policy Act Amendments of 1987*) and 1992 (see Energy Policy Act of 1992)

Nuclear Waste Policy Act Amendments of 1987 (Public Law 100-203)

Legislation that amended the *Nuclear Waste Policy Act* to limit repository *site characterization* activities to Yucca Mountain, Nevada; establish the Office of Nuclear Waste Negotiator to seek a state or Native American tribe willing to host a repository or monitored retrievable storage facility; create the *Nuclear Waste Technical Review Board*; and increase state and local government participation in the waste management program.

Nuclear Waste Technical Review Board

An independent body established within the executive branch, created by the *Nuclear Waste Policy Amendments Act of 1987* to evaluate the technical and scientific validity of activities undertaken by the U.S. Department of Energy, including *site characterization* activities and activities relating to the packaging or transportation of *high-level radioactive waste* or *spent nuclear fuel*. Members of this Board are appointed by the President from a list prepared by the National Academy of Sciences.

nucleus

The central, positively charged, dense portion of an atom. Also known as atomic nucleus.

nuclide

An atomic *nucleus* specified by its *atomic weight*, *atomic number*, and energy state; a radionuclide is a *radioactive* nuclide.

oblique-slip fault

A *fault* that combines some purely horizontal motion (*strike-slip fault*) with some, along the direction of the dip of the fault plane (*dip-slip fault*).

offsite

Physically not in a repository-related area managed by DOE.

onsite

Physically in an area managed by DOE where access can be limited for any reason. The site boundary encompasses *controlled areas*. The site comprises the various Operations Areas and the areas between and immediately surrounding them.

operational storage

A storage capacity DOE could use to collect material shipped to the repository before (or after) its insertion in *waste packages* and *emplacement* in the repository.

operations

See *repository phases*.

organism

An individual constituted to carry on the activities of life by means of organs separate but mutually dependent; a living being.

overburden

Geologic material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials. As used by the Yucca Mountain Project, this is geologic material overlying the mined *repository horizon*.

overweight, overdimension truck

Semi- and tandem tractor-trailer trucks with gross weights over 80,000 pounds that must obtain permits from state highway authorities to use public highways.

ozone (O_3)

The triatomic form of oxygen; in the *stratosphere*, ozone protects the Earth from the Sun's *ultraviolet radiation*, but in lower levels of the atmosphere it is an air pollutant.

Paleozoic Era

A geologic era extending from the end of the Precambrian to the beginning of the Mesozoic, dating from about 600 to 230 million years ago.

particulate matter

Fine liquid or solid particles such as dust, smoke, mist, fumes, or smog, found in air or emissions. See *PM_{10}.*

pathway

A potential route by which radionuclides might reach the *accessible environment* and pose a threat to humans.

pediment

A planar sloping rock surface forming a ramp to a front of a mountain range in an arid region. It might be covered locally by a thin *alluvium*.

perched water

A *saturated zone* condition that is not continuous with the *water table*, because there is an impervious or semipervious layer underlying the perched zone or a *fault* zone that creates a *barrier* to water movement and perches water. See *permeable.*

percolation

The passage of a liquid through a porous substance. In rock or soil it is the movement of water through the interstices and pores under hydrostatic pressure and the influence of gravity. The downward or lateral flow of water that becomes net *infiltration* in the *unsaturated zone*.

performance assessment

An analysis that predicts the behavior of a system or system component under a given set of conditions. Performance assessments include estimates of the effects of *uncertainties* in data and modeling. See *Total System Performance Assessment.*

performance confirmation

The program of tests, experiments, and analyses conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after *permanent closure* will be met.

permanent closure

Final sealing of *shafts* and *boreholes* of the underground facility.

permeable

Pervious; a permeable rock is a rock, either porous or cracked, that allows water to soak into and pass through it freely.

permeability

In general terms, the capacity of such mediums as rock, sediment, and soil to transmit liquid or gas. Permeability depends on the substance transmitted (oil, air, water, etc.) and on the size and shape of the pores, joints, and fractures in the medium and the manner in which they interconnect. “Hydraulic conductivity” is equivalent to “permeability” in technical discussions relating to *groundwater*.

person-rem

A unit used to measure the *radiation* exposure to an entire group and to compare the effects of different amounts of radiation on groups of people; it is the product of the average *dose equivalent* (in *rem*) to a given organ or tissue multiplied by the number of persons in the population of interest.

pH

A number indicating the acidity or alkalinity of a solution. A pH of 7 indicates a neutral solution. Lower pH values indicate more acidic solutions while higher pH values indicate alkaline solutions.

photon

A massless particle, the quantum of an electromagnetic field, carrying energy, momentum, and angular momentum.

picocurie

One one-trillionth (1×10^{-12}) of a *curie*.

$PM_{2.5}$

All *particulate matter* in the air with an aerodynamic diameter less than or equal to a nominal 2.5 micrometers (0.0001 inch). A standard for this material as a *criteria pollutant* has been defined but not yet implemented.

PM_{10}

All *particulate matter* in the air with an aerodynamic diameter less than or equal to a nominal 10 micrometers (0.0004 inch). Particles less than this diameter are small enough to be breathable and could be deposited in lungs.

population dose

A summation of the radiation doses received by individuals in an exposed population; equivalent to *collective dose*; expressed in *person-rem*.

portal

Surface entrance to a mine, particularly in a *drift* or tunnel. The North and South Portals are the two primary entrances to the *subsurface* facilities.

preferred route

A public highway route that satisfies the requirements of U.S. Department of Transportation regulations (49 CFR Part 397, Subpart D) to be acceptable for shipments of *Highway Route-Controlled Quantities of Radioactive Material*.

pressurized-water reactor (PWR)

A nuclear power *reactor* that uses water under pressure as a coolant. The water boiled to generate steam is in a separate system.

probabilistic

(1) Based on or subject to *probability*. (2) Involving a variable factor, such as temperature or porosity. At each instance of time, the factor may take on any of the values of a specified set with a certain probability. Data from a probabilistic process is an ordered set of observations, each of which is one item in a probability distribution.

probability

The relative frequency at which an event can occur in a defined period. Statistical probability is about what actually happens in the real world and can be verified by observation or sampling. Knowing the exact probability of an event is usually limited by the inability to know, or compile the complete set of, all possible outcomes over time or space. Probability is measured on a scale of 0 (event will *not* occur) to 1 (event *will* occur).

probable maximum flood

The hypothetical flood (peak discharge, volume, and hydrographic shape) that is considered to be the most severe reasonably possible, based on comprehensive hydrometeorological application of probable maximum precipitation and other hydrologic factors, such as sequential storms and snowmelts, that are favorable for maximum flood runoff.

proposed action

The activity proposed to accomplish a Federal agency’s purpose and need. An EIS analyzes the environmental *impacts* of the Proposed Action. A proposed action includes the project and its related support activities (preconstruction, construction, and operation, along with postoperational requirements). The Proposed Action in this EIS is the construction, operation and monitoring, and eventual closure of a *monitored geologic repository* for *spent nuclear fuel* and *high-level radioactive waste* at Yucca Mountain in Nevada (see *repository project phases*).

proton

An elementary particle that is the positively charged component of ordinary matter and, together with the *neutron*, is a building block of all atomic *nuclei*.

pyroclastic

Of or relating to individual particles or fragments of *clastic* rock material of any size formed by volcanic explosion or ejected from a volcanic vent.

qualitative

With regard to a variable, a parameter, or data, an expression or description of an aspect in terms of non-numeric qualities or attributes. See *quantitative*.

quantitative

A numeric expression of a variable. See *qualitative.*

rad

The unit of measure for the absorbed dose of *radiation*.

radiation

The emitted particles or *photons* from the *nuclei* of *radioactive* atoms. Some elements are naturally radioactive; others are induced to become radioactive by *irradiation* in a *reactor*. Naturally occurring radiation is indistinguishable from induced radiation.

radioactive

Emitting *radioactivity*.

radioactive decay

The process in which one *radionuclide* spontaneously transforms into one or more different radionuclides, which are called decay products.

radioactivity

The property possessed by some elements (for example, uranium) of spontaneously emitting alpha, beta, or *gamma rays* by the *disintegration* of atomic *nuclei*.

radionuclide

See *nuclide*.

rail route

Route from point of origin to the repository.

reactor

See *nuclear reactor*.

reasonably maximally exposed individual

See *maximally exposed individual*.

recharge

The movement of water from an *unsaturated zone* to a *saturated zone*.

recordable cases

Occupational injuries or occupation-related illnesses that result in (1) a fatality, regardless of the time between the injury or the onset of the illness and death, (2) lost workday cases (nonfatal), and (3) the transfer of a worker to another job, termination of employment, medical treatment, loss of consciousness, or restriction of motion during work activities.

Record of Decision

A document that provides a concise public record of a decision made by a government agency.

region of influence

The physical area that bounds the environmental, sociologic, economic, or cultural features of interest for the purpose of analysis.

rem

The unit of a *dose equivalent* from *ionizing radiation* to the human body. It is used to measure the amount of radiation to which a person has been exposed (rem means Roentgen Equivalent in Man).

remediation

Action taken to permanently remedy a release or threatened release of a hazardous substance to the *environment*, instead of or in addition to removal.

repository

See *geologic repository*.

repository horizon

The near-horizontal plane in the host rock stratum where DOE proposes to locate the repository emplacement area(s).

repository phases

The development of a monitored geologic repository at Yucca Mountain, if approved, would have three phases, as follows:

- *Construction:* The repository construction phase would begin in 2005 and end in 2010. Activities during this phase would include preparing the site, constructing surface waste handling and support facilities, excavating and equipping a portion of the repository *subsurface* for initial waste *emplacement*, and conducting initial verification testing of components and systems.

- *Operation and monitoring:* Repository operations activities would include waste receipt, repackaging, and emplacement in the repository; continuing subsurface development for waste *emplacement; monitoring; and maintenance*. Waste receipt, repackaging, and emplacement activities, along with continued construction activities, would begin in about 2010 and would take about 24 years. Monitoring would begin with the initial emplacement of waste in the repository and would end at repository closure. In addition, the maintenance of repository facilities would continue until the closure of the repository. See *monitoring*, *maintenance*.

- *Closure:* The closure of the *subsurface* repository facilities would include the removal and salvage of equipment and materials; filling of the main *drifts*, access ramps, and ventilation shafts; and sealing of openings, including ventilation shafts, access ramps, and *boreholes*. Surface closure activities would include the construction of monuments to mark the repository location, *decommissioning* and demolition of facilities, and restoration of the site to its approximate condition before the construction of the repository facilities. Closure would begin in 2060 at the earliest or as late as 2310 (that is, from 50 to 300 years after the start of emplacement).

restricted area

An area of the surface repository enclosed by security fences, control gates, lighting, and detection systems established to prevent the spread of radiological contamination. The area would include the facilities and transportation systems required to receive and ship rail and truck waste shipments, prepare *shipping casks* for handling, and load *waste forms* into disposal containers for *emplacement* in the repository. It would also include the facility and systems required to treat and package site-generated *low-level radioactive waste* for offsite disposal. (Other documents related to the Yucca Mountain Repository refer to this as the Radiologically Controlled Area.)

retrieval

The act of removing *radioactive* waste from the underground location at which the waste had been previously emplaced for disposal. Retrieval would be a contingency action, performed only if *monitoring* indicated that the waste needed to be retrieved in order to protect the public health and safety or the environment or to recover resources from *spent nuclear fuel*.

reverse fault

A *fault* in which the relative displacement is along the direction of the dip of the fault plane (*dip-slip fault*), and in which the block above the fault has moved upward in relation to the block below the fault.

riprap

Broken stones or chunks of concrete used as foundation material or in embankments to control water flow or prevent erosion.

risk

The product of the probability that an undesirable event will occur multiplied by the consequences of the undesirable event.

roentgen

The international unit of quantity for X-rays and gamma rays.

safe haven

Designated safe parking locations along transportation routes.

sanitary and industrial solid waste

Solid waste that is neither hazardous nor radioactive. Sanitary waste streams include paper, glass, and discarded office material. State of Nevada waste regulations identify this waste stream as household waste.

sanitary waste

Domestic wastewater from toilets, sinks, showers, kitchens, and floor drains from restrooms, change rooms, and food preparation and storage areas.

saturated zone

The area below the *water table* where all spaces (*fractures* and rock pores*)* are completely filled with water.

scenario

A specific set of actions, activities, and assumptions. Scenarios are identified and analyzed to enable the estimation of the range of environmental impacts associated with the *Proposed Action* and the *No-Action Alternative*. Scenarios evaluated in this EIS include the high, intermediate, and low *thermal load* scenarios, No-Action Alternative Scenario 1 (continued *institutional control*) and Scenario 2 (no effective institutional controls after 100 years). The environmental impacts identified from these scenarios provide environmental information to support Departmental decisions about the *alternatives* and *implementing alternatives*.

seismic

Pertaining to, characteristic of, or produced by *earthquakes* or earth vibrations.

seismicity

A seismic event or activity such as an *earthquake* or earth tremor; *seismic* action.

shaft

An excavation or vertical passage of limited area, compared to its depth, used to lower personnel and material or to ventilate underground facilities.

shielding

Any material that provides *radiation* protection.

shipment

The movement of a properly prepared (loaded, unloaded, or empty) *cask* from one site to another and associated activities to ensure compliance with applicable regulations.

shipping cask

A heavily shielded massive container that meets regulatory requirements for shipping *spent nuclear fuel* or *high-level radioactive waste*. See *cask*.

single-purpose (storage or transportation) cask

A heavily shielded massive container for the dry storage of *spent nuclear fuel*; it is usable for either storage or transportation but not for *emplacement* in a repository. See *cask*.

site boundary

The boundary of the land withdrawal area used for analytical purposes in this EIS. See *land withdrawal area*.

site characterization

Activities from 1986 to 2000 associated with the determination of the suitability of the Yucca Mountain site as a *monitored geologic repository*. DOE constructed the *Exploratory Studies Facility* to support the following activities related to the determination of site suitability, including surface facilities and *subsurface* ramps and *drifts*:

- Gather and evaluate surface and subsurface site data
- Predict the performance of the repository
- Prepare the repository design
- Assess the performance of the system against the required Code of Federal Regulations and program performance criteria

Some of the exploratory surface and subsurface facilities would be enhanced during the repository construction phase (see *repository phases*); others would be removed, demolished, or relocated, as necessary. Data gathering associated with site characterization would end with the beginning of the construction phase.

site-generated waste

Waste or wastewater generated at the *monitored geologic repository* and related transportation facilities.

soil recovery

The return of disturbed land to a relatively stable condition with a form and productivity similar to that which existed before any disturbance.

sound barrier

Natural or artificial structures that block or interfere with the propagation of sound; examples include terrain features and manmade structures (buildings, walls, etc.).

source term

Types and amounts of radionuclides that are the source of a potential release of *radioactivity*.

spalling

(1) Flaking off of corrosion products from the metal *substrate* as it undergoes corrosion. The layer of corroded material thickens. The spalling could be caused by an expansive action of the corrosion products because they occupy a greater volume than the uncorroded metal substrate. (2) Flaking, chipping, or cracking at the opening of a *borehole, shaft*, or other rock excavation.

Special-Performance-Assessment-Required (SPAR) wastes

Low-level radioactive wastes generated in DOE production reactors, research reactors, reprocessing facilities, and research and development activities that exceed the Nuclear Regulatory Commission Class C shallow-land burial disposal limits.

spent nuclear fuel

Fuel that has been withdrawn from a nuclear *reactor* following *irradiation*, the component elements of which have not been separated by reprocessing. For this project, this refers to (1) intact, nondefective *fuel assemblies*, (2) failed fuel assemblies in canisters, (3) fuel assemblies in canisters, (4) consolidated fuel rods in canisters, (5) nonfuel assembly hardware inserted in *pressurized-water reactor* fuel assemblies, (6) fuel channels attached to *boiling-water reactor* fuel assemblies, and (7) nonfuel assembly hardware and structural parts of assemblies resulting from consolidation in *canisters*.

spoils areas

Areas outside the rail corridor for the deposition of excavated materials from rail line development.

stakeholder

A person or organization with an interest in or affected by DOE actions (representatives from Federal, state, tribal, or local agencies; members of Congress or state legislatures; unions, educational groups, environmental groups, industrial groups, etc.; and members of the general public).

storage

The collection and containment of waste or *spent nuclear fuel* in a way that does not constitute *disposal* of the waste or *spent nuclear fuel* for the purposes of awaiting treatment or disposal capacity.

storage cask

See *cask*.

storage container

See *cask*.

stratigraphy

The branch of geology that deals with the definition and interpretation of rock strata, the conditions of their formation, character, arrangement, sequence, age, distribution, and especially their correlation by the use of fossils and other means of identification. See *stratum*.

stratosphere

The atmospheric shell above the troposphere and below the mesosphere. It extends from 10 to 20 kilometers (6 to 12 miles) to about 53 kilometers (33 miles) above the surface.

stratum

A sheetlike mass of sedimentary rock or earth of one kind lying between beds of other kinds.

stream tube

A modeling method used to represent the *groundwater* flow path from the *water table* to the *biosphere*. There are six stream tubes used for *saturated zone* modeling with one tube associated with and having the cross-sectional shape of one of six regions designated at the water table. Each stream tube takes in *groundwater* flux and radionuclide mass flux data at the water table representing flux from the repository that would pass through the *unsaturated zone*.

strike-slip fault

A fault with purely horizontal relative displacement.

subcritical

Having an effective multiplication constant less than 1, so that a self-supporting *chain reaction* cannot be maintained in a *nuclear reactor*.

substrate

Basic surface on which a material adheres.

subsurface

A zone below the surface of the Earth, the *geologic* features of which are principally layers of rock that have been tilted or faulted and are interpreted on the basis of drill hole records and geophysical (*seismic* or rock vibration) evidence. In general, it is all rock and solid materials lying beneath the Earth’s surface.

sulfur dioxide

A toxic gas produced from the burning of fossil fuels. It is the main pollutant involved in the formation of acid rain. Coal-burning electric utilities are the major source of sulfur dioxide in the United States. See *criteria pollutants, ambient air quality standards*.

sulfur oxides

Pungent, colorless gases formed primarily by the combustion of fossil fuels; considered major air pollutants; sulfur oxides can damage the human respiratory tract and vegetation. See *criteria pollutants*, *ambient air quality standards*.

supernate

A concentrated form of *radioactive* waste that floats to the top of an undisturbed container of liquid *high-level radioactive waste*.

thermal load

The application of heat to a system, usually measured in terms of watts per unit area. The thermal load for a repository is the watts per acre produced by the *radioactive* waste in the active *disposal* area. The spatial density at which waste packages are emplaced within the repository as characterized by the areal power density and the *areal mass loading*.

threatened species

A species that is likely to become an *endangered species* within the foreseeable future throughout all or a significant part of its range.

thrust fault

A *reverse fault* in which the angle of the fault plane is less than 45 degrees.

Total System Performance Assessment

A risk assessment that quantitatively estimates how the proposed Yucca Mountain Repository system would perform under the influence of specific features, events, and processes, incorporating *uncertainty* in the models and data. See *performance assessment*.

toxic air pollutants

Hazardous pollutants not listed as either *criteria pollutants* or *hazardous pollutants*.

transpiration

The process by which water enters a plant through its root system, passes through its vascular system, and is released into the atmosphere through openings in its outer covering. It is an important process for removal of water that has infiltrated below the zone where it could be removed by evaporation.

transuranic waste

Waste materials (excluding high-level radioactive waste and certain other waste types) contaminated with alpha-emitting radionuclides that are heavier than uranium with half-lives greater than 20 years and that occur in concentrations greater than 100 nanocuries per gram. Transuranic waste results primarily from treating and fabricating plutonium as well as research activities at DOE defense installations.

tuff

Igneous rock formed from compacted volcanic fragments from *pyroclastic* (explosively ejected) flows with particles generally smaller than 4 millimeters (about 0.16 inch) in diameter. The most abundant type of rock at the Yucca Mountain site.

ultraviolet radiation

Electromagnetic radiation with wavelengths from 4 to 400 nanometers. This range begins at the short wavelength limit of visible light and overlaps the wavelengths of long *x-rays* (some scientists place the lower limit at higher values, up to 40 nanometers). Also known as ultraviolet light.

uncanistered spent nuclear fuel

Fuel placed directly into storage containers or shipping casks without first being placed in a canister.

uncertainty

A measure of how much a calculated or estimated value that is used as a reasonable guess or prediction might vary from the unknown true value.

unsaturated zone

The area between the surface and the *water table* where only some of the spaces (*fractures* and rock pores) are filled with water. See *saturation zone*.

vadose zone

See *unsaturated zone*.

Viability Assessment

An assessment of the prospects for geologic disposal at the Yucca Mountain site, based on repository and *waste package* design, a *Total System Performance Assessment*, a *License Application* plan, and repository cost and schedule estimates. DOE issued the *Viability Assessment of a Repository at Yucca Mountain* in December 1998.

vicinity (in relation to the Yucca Mountain Repository)

A general term used in nonspecific discussions in this EIS about the area around the Yucca Mountain site.

vitrification

A waste treatment process that uses glass (for example, *borosilicate glass*) to encapsulate or immobilize *radioactive* wastes.

waste form

A generic term that refers to *radioactive* waste materials and any encapsulating or stabilizing matrix.

waste package

The *waste form* and any containers (that is, *disposal container* barriers and other canisters), spacing structure or baskets, *shielding* integral to the container, packing inside the container, and other absorbent materials immediately surrounding an individual waste container placed internally to the container or attached to the outer surface of the disposal container. The waste package begins its existence when the outer lid welds are complete and accepted.

water table

The upper limit of the *saturated zone* (the portion of the ground wholly saturated with water).

welded tuff

A *tuff* deposited under conditions where the particles making up the rock were heated sufficiently to cohere. In contrast to nonwelded tuff, welded tuff is denser, less porous, and more likely to be fractured (which increases *permeability*).

wet storage

Storage of *radioactive* material that uses water for cooling or *shielding*.

X-rays

Penetrating electromagnetic *radiation* having a wavelength much shorter than that of visible light. X-rays are identical to *gamma rays* but originate outside the *nucleus*, either when the inner orbital *electrons* of an excited atom return to their normal state or when a metal target is bombarded with high-speed electrons.

Yucca Mountain Repository EIS

See *environmental impact statement (EIS).*

Yucca Mountain site (the site):

The area on which DOE has built or would build the majority of facilities or cause the majority of land disturbances related to the proposed repository.

zeolite

Any of a group of hydrated silicates of aluminum with alkali metals, commonly occurring as secondary minerals in cavities in basic volcanic rocks.

zirconium alloy

An alloy material containing the element zirconium that might have any of several compositions. It is used as a *cladding* material.

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Appendix A

Inventory and Characteristics of Spent Nuclear Fuel, High-Level Radioactive Waste, and Other Materials

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APPENDIX A. INVENTORY AND CHARACTERISTICS OF SPENT NUCLEAR FUEL, HIGH-LEVEL RADIOACTIVE WASTE, AND OTHER MATERIALS

A.1 Introduction

This appendix describes the inventory and characteristics of the spent nuclear fuel and high-level radioactive waste that the U.S. Department of Energy (DOE) anticipates it would place in a monitored geologic repository at Yucca Mountain. It includes information about other highly radioactive material that DOE could dispose of in the proposed repository. It also provides information on the background and sources of the material, present storage conditions, the final disposal forms, and the amounts and characteristics of the material. The data provided in this appendix are the best available estimates of projected inventories.

The Proposed Action inventory evaluated in this environmental impact statement (EIS) consists of 70,000 metric tons of heavy metal (MTHM), comprised of 63,000 MTHM of commercial spent nuclear fuel and 7,000 MTHM of DOE materials. The DOE materials consist of 2,333 MTHM of spent nuclear fuel and 8,315 canisters (4,667 MTHM) of solidified high-level radioactive waste. The inventory includes approximately 50 metric tons (55 tons) of surplus weapons-usable plutonium as spent mixed-oxide fuel and immobilized plutonium.

The Nuclear Waste Policy Act, as amended (also called the NWPA), prohibits the U.S. Nuclear Regulatory Commission from approving the emplacement of more than 70,000 MTHM in the first repository until a second repository is in operation [Section 114(d)]. However, in addition to the Proposed Action, this EIS evaluates the cumulative impacts for two additional inventories (referred to as Inventory Modules 1 and 2):

- The Module 1 inventory consists of the Proposed Action inventory plus the remainder of the total projected inventory of commercial spent nuclear fuel, high-level radioactive waste, and DOE spent nuclear fuel. Emplacement of Inventory Module 1 wastes in the repository would raise the total amount emplaced above 70,000 MTHM. As mentioned above, emplacement of more than 70,000 MTHM of spent nuclear fuel and high-level radioactive waste would require legislative action by Congress unless a second licensed repository was in operation.

- Inventory Module 2 includes the Module 1 inventory plus the inventories of the candidate materials, commercial Greater-Than-Class-C low-level radioactive waste and DOE Special-Performance-Assessment-Required waste. There are several reasons to evaluate the potential for disposing of these candidate materials in a monitored geologic repository in the near future. Because both materials exceed Class C low-level radioactive limits for specific radionuclide concentrations as defined in 10 CFR Part 61, they are generally unsuitable for near-surface disposal. Also, the Nuclear Regulatory Commission specifies in 10 CFR 61.55(a)(2)(iv) the disposal of Greater-Than-Class-C waste in a repository unless the Commission approved disposal elsewhere. Further, during the scoping process for this EIS, several commenters requested that DOE evaluate the disposal of other radioactive waste types that might require isolation in a repository. Disposal of Greater-Than-Class-C and Special-Performance-Assessment-Required wastes at the proposed Yucca Mountain Repository could require a determination by the Nuclear Regulatory Commission that these wastes require permanent isolation. In addition, the present 70,000-MTHM limit on waste at the Yucca Mountain Repository could have to be addressed either by legislation or by opening a second licensed repository.

A.1.1 INVENTORY DATA SUMMARY

There are six general inventory categories, as follows:

- Commercial spent nuclear fuel
- DOE spent nuclear fuel
- High-level radioactive waste
- Surplus weapons-usable plutonium
- Commercial Greater-Than-Class-C waste
- DOE Special-Performance-Assessment-Required waste

This section summarizes the detailed inventory data in Section A.2. The data provide a basis for the impact analysis in this EIS. Data are provided for the candidate materials included in the initial 70,000 MTHM for the Proposed Action and other inventory that is not currently proposed but might be considered for repository disposal in the foreseeable future.

This summary provides general descriptive and historic information about each waste type, including the following:

- Primary purpose and use of the data
- General comparison of the data between waste types
- Potential for change in inventory data

Table A-1 lists the inventory data that DOE used in the EIS analyses and their descriptions throughout the document.

A.1.1.1 Sources

Figure A-1 shows the locations of generators or sources of spent nuclear fuel and high-level radioactive waste. Spent nuclear fuel is fuel that has been withdrawn from a nuclear reactor following irradiation. The Proposed Action includes the disposal of 63,000 MTHM of commercial spent nuclear fuel in the repository. More than 99 percent of the commercial spent nuclear fuel would come from commercial nuclear reactor sites in 33 states (DOE 1995a, all). In addition, DOE manages an inventory of spent nuclear fuel. The Proposed Action includes 2,333 MTHM of spent nuclear fuel from four DOE locations: the Savannah River Site in South Carolina, the Hanford Site in Washington, the Idaho National Engineering and Environmental Laboratory, and Fort St. Vrain in Colorado.

High-level radioactive waste is the highly radioactive material resulting from the reprocessing or treatment of spent nuclear fuel. The Proposed Action includes disposing of 8,315 canisters of high-level radioactive waste in the repository. High-level radioactive waste is stored at the Savannah River Site, the Hanford Site, the Idaho National Engineering and Environmental Laboratory, and the West Valley Demonstration Project in New York.

The President has declared approximately 50 metric tons (55 tons) of plutonium to be surplus to national security needs (DOE 1998a, page 1-1). This surplus weapons-usable plutonium includes purified plutonium, nuclear weapons components, and plutonium residues. This inventory is included in the Proposed Action, and the Department would dispose of it as either spent mixed oxide fuel from a commercial nuclear reactor (that is, commercial spent nuclear fuel) or immobilized plutonium in a high-level radioactive waste canister (that is, as high-level radioactive waste), or a combination of these two inventory categories (DOE 1998a, page 1-3). Spent mixed-oxide fuel would come from one or more of

Table A-1. Use of Appendix A radioactivity inventory data in EIS chapters and appendixes (page 1 of 2).

Item[a]	Appendix A	EIS section
Number of commercial nuclear sites	Table A-3	1.1, 2.2, 2.2.2, 2.4.1, 2.4.2.3, 2.4.2.4, 2.4.2.8, 2.4.3, 6.1, 7.0, 7.2.1, 7.3, J.1.3.1.1
Number of DOE sites	A.1.1	1.1, 2.2, 2.2.2, 2.4.1, 2.4.2.3, 2.4.2.4, 2.4.2.8, 2.4.3, 6.1, 7.0, 7.2.1, 7.3
Mapped location of sites	Figure A-1	Figure 1-1, Several Chapter 6, 7, App. J and K figures
Commercial SNF material	A.2.1.5.3	1.1.1
Commercial SNF dimensions	Table A-15	1.1.1, Figure 1-3, H.2.1.4
Commercial SNF cladding material	A.2.1.5.3	1.1.2.1.1, 5.2.2, K.2.1.4.1
Percentage of commercial SNF with stainless-steel cladding	A.2.1.5.3	1.1.2.1.1, 1.5.3, 5.2.2, 5.5.1, K.2.1.4.1
MOX SNF part of commercial SNF Proposed Action	A.2.4.5.1.1	1.1.2.1.1
Number of sites with existing or planned ISFSIs	Table A-4	1.1.2.1.1
Amount of commercial SNF projected for each site	Tables A-6 and A-7	1.1.2.1.1, 6.1.1, K.2.1.6
List of commercial SNF sites, state, operations period	Table A-3	Table 1-1
DOE SNF storage locations	Table A-17	1.1.2.1.2, K.2.1.6
HLW includes immobilized Pu	A.2.4.5.2.1	1.1.2.2
HLW generators	A.2.3.2	1.1.2.2, K.2.1.6
HLW vitrification status	A.2.3.4	1.1.2.2
Weapons-usable Pu declared surplus	A.2.4.1	1.1.2.3
Two forms: MOX and immobilized Pu	A.2.4.1	1.1.2.3
Proposed Action inventory	A.1	1.1.2.5, 1.3.2, 1.6.3.1, 2.1, Figure 2-3, 2.1.4, 2.2.2, 2.2.3, 5.1, 5.2.2, 5.6.3, 6.1.1.1, 7.0, 7.2, 8.1.2.1, J.1.3.1.1, J.1.3.1.2, K.2.1.6
Total projected inventory commercial SNF	Figure A-2	1.1.2.5, 1.6.3.1, 7.2, 7.3, 8.1.2.1, J.1.3.1.1, K.2.1.6
Total projected inventory DOE SNF	Figure A-2	1.1.2.5, 1.6.3.1, 6.1.1.1, 7.2, 7.3, 8.1.2.1, J.1.3.1.2, K.2.1.6
Total projected inventory HLW	Figure A-2	1.1.2.5, 1.6.3.1, 7.2, 7.3, 8.1.2.1, K.2.1.6
Total projected GTCC waste	Table A-51	1.6.3.1, 7.3, 8.1.2.1, I.3.1.2.4, J.1.3.1.3
Total projected SPAR waste	Table A-56	1.6.3.1, 7.3, 8.1.2.1, I.3.1.2.4, J.1.3.1.3
HLW canister dimensions	A.2.3.5.6	Figure 2-3
Thermal generation of 1 MTHM of commercial SNF at time of emplacement	Table A-14	2.1.1.2
Commercial SNF, DOE SNF, and immobilized Pu contain fissile material	A.2.1.5.2 A.2.2.5.2 A.2.4.5.2.2	2.1.2.2.2
Kr-85 (gas) is contained in fuel gap of commercial SNF	A.2.1.5.2	4.1, 4.1.2.3.2
Typical radionuclide inventory for commercial SNF	Tables A-8 and A-9	4.1.8.1, 6.1.3.2.1, H.2.1.4, Table H-4, I.3.1.1, I.3.1.2.1, J.1.5.2.1, K.2.1.6

Table A-1. Use of Appendix A radioactivity inventory data in EIS chapters and appendixes (page 2 of 2).

Item[a]	Appendix A	EIS section
Amount of chromium per SNF assembly	A.2.1.5.3	5.1.2
Commercial SNF comprises at least 92% of radioactivity in Proposed Action	A.1.1.4.2	5.2.2, 5.2.3.3
DOE SNF has a variety of cladding	A.2.2.5.3	5.2.2
Commercial SNF has higher radionuclide content than DOE SNF or HLW	Table A-2	6.1.2.1
Cs-137, actinide, and total curies contained in a rail shipping cask for commercial SNF, HLW, DOE SNF, and naval fuel	Derived from Tables A-8, A-27, and A-18	Table 6-2, Table J-17
Radiological inventory of GTCC and SPAR waste much less than commercial SNF or HLW	Derived from Tables A-8, A-27, A-18, A-54, and Section A.2.6.4	8.2.7, 8.2.8, 8.4.1.1, F.3
Average radionuclide inventory per package for SPAR and GTCC waste	Derived from Table A-54 and Section A.2.6.4	8.3.1.1, Table I-9
C-14 (gas) is contained in fuel gap of commercial SNF	Tables A-8 and A-9	5.5, 8.3.1.1, I.3.3, I.7
Typical PWR burnup, initial enrichment, and average cooling time	A.2.1.5	G.2.3.2, H.2.1.4, J.1.4.2.5
Typical BWR burnup, initial enrichment, and average cooling time	A.2.1.5	G.2.3.2, H.2.1.4
N-reactor radionuclide inventory per canister is larger than HLW radionuclide per canister.	Tables A-18 and A-27	H.2.1.1
21 PWR assemblies contain a higher radionuclide content than 44 BWR assemblies	Tables A-8 and A-9	H.2.1.1
DOE would emplace twice as many PWR assemblies as BWR	A.2.1.5.1	H.2.1.1
N-reactor fuel represents a large quantity of DOE SNF	Table A-17	H.2.1.1
Mass of N-reactor fuel per canister	Table A-17	H.2.1.1
Immobilized Pu disk dimensions	A.2.4.5.2.1	I.3
Number of immobilized Pu cans per HLW canister	A.2.4.5.2.1	I.3
DOE SNF radionuclide inventory	Table A-18	I.3.1.1, I.3.1.2.1
Assumed packaging method for GTCC and SPAR	A.2.5.4, A.2.6.4	I.3.1.2.4
Chemical makeup of waste inventory	Tables A-12, -13, -19, -29, -30, -31, -32, -33, and -34	Table I-10
MTU per assembly for PWR and BWR	Table A-15	J.1.4.1.1
Most HLW stored in underground vaults	A.2.3.3	K.2.1.5.2

a. Abbreviations: SNF = spent nuclear fuel; MOX = mixed oxide; ISFSI = independent spent fuel storage installation; HLW = high-level radioactive waste; Pu = plutonium; GTCC = Greater-Than-Class-C; SPAR = Special-Performance-Assessment-Required; MTHM = metric tons of heavy metal; Kr = krypton; Cs = cesium; PWR = pressurized-water reactor; BWR = boiling-water reactor; MTU = metric tons of uranium.

the existing commercial reactor sites. Although the location of the plutonium immobilization facility has not been decided, DOE (1998a, page 1-9) has identified the Savannah River Site as the preferred alternative. For purposes of analysis, this EIS assumes that the high-level radioactive waste canisters, which would contain immobilized plutonium and borosilicate glass, would come from the Savannah River Site.

Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

Symbols do not reflect precise locations.

Source: Modified from DOE (1998b, Overview, page 5).

Figure A-1. Locations of commercial and DOE sites and Yucca Mountain.

Greater-Than-Class-C waste is waste with concentrations of certain radionuclides that exceed the Class C limits stated in 10 CFR Part 61, thereby making it unsuitable for near-surface disposal. Greater-Than-Class-C waste is generated by a number of sources including commercial nuclear utilities, sealed radioactive sources, and wastes from “other generators.” These other generators include carbon-14 users, industrial research and development applications, fuel fabricators, university reactors, and others. These wastes are currently stored at the commercial and DOE sites and exist in most states. They are included in Inventory Module 2 of the EIS but are not part of the Proposed Action.

Special-Performance-Assessment-Required wastes are also Greater-Than-Class-C wastes managed by DOE and are stored primarily at the Hanford Site, Idaho National Engineering and Environmental Laboratory, West Valley Demonstration Project, and Oak Ridge National Laboratory in Tennessee. These wastes are included in Inventory Module 2 of the EIS but are not part of the Proposed Action.

A.1.1.2 Present Storage and Generation Status

Commercial spent nuclear fuel is stored at reactor sites in either a spent fuel pool or in a dry storage configuration generally referred to as an independent spent fuel storage installation. Through 1995, approximately 32,000 MTHM of commercial spent nuclear fuel has been discharged from reactors (Heath 1998, Appendix C). DOE spent nuclear fuel is also stored either underwater in basins or in a dry storage configuration similar to that used for commercial spent nuclear fuel.

As discussed in the next section, DOE would receive high-level radioactive waste at the repository in a solidified form in stainless-steel canisters. Until shipment to the repository, the canisters would be stored at the commercial and DOE sites. With the exception of the West Valley Demonstration Project, the filled canisters would be stored in below-grade facilities. The West Valley canisters would be stored in an above-ground shielded facility.

A.1.1.3 Final Waste Form

Other than drying or potential repackaging, processing is not necessary for commercial spent nuclear fuel. Therefore, the final form would be spent nuclear fuel either as bare intact assemblies or in sealed canisters. Bare intact fuel assemblies are those that do not have any disruption of their cladding and could be shipped to the repository in an approved shipping container for repackaging in a waste package in the Waste Handling Building. Other assemblies would be shipped to the repository in canisters that were either intended or not intended for disposal. Canisters not intended for disposal would be opened and repackaged in waste packages in the Waste Handling Building.

For most of the DOE spent nuclear fuel categories, the fuel would be shipped in disposable canisters (canisters that can be shipped and are suitable for direct insertion into waste packages without being opened) in casks licensed by the Nuclear Regulatory Commission. Uranium oxide fuels with intact zirconium alloy cladding are similar to commercial spent nuclear fuel and could be shipped either in DOE standard canisters or as bare intact assemblies. Uranium metal fuels from Hanford and aluminum-based fuels from the Savannah River Site could require additional treatment or conditioning before shipment to the repository. If treatment was required, these fuels would be packaged in DOE disposable canisters. Category 14 sodium-bonded fuels are also expected to require treatment before disposal.

High-level radioactive waste shipped to the repository would be in stainless-steel canisters. The waste would have undergone a solidification process that yielded a leach-resistant material, typically a glass form called borosilicate glass. In this process, the high-level radioactive waste is mixed with glass-forming materials, heated and converted to a durable glass waste form, and poured into stainless-steel canisters (Picha 1997, Attachment 4, page 2). Depending on future decisions stemming from other EISs, ceramic and metal waste matrices could be sent to the repository from Argonne National Laboratory-West in Idaho. The ceramic and metal matrices would be different solidified mixtures that also would be in stainless-steel canisters. These wastes would be the result of the proposed electrometallurgical treatment of sodium bonded fuels.

As briefly described in Section A.1.1.1, the surplus weapon-usable plutonium would probably be sent to the repository in two different waste forms—spent mixed-oxide fuel assemblies or an immobilized plutonium ceramic form in a high-level radioactive waste canister and surrounded by high-level radioactive waste. The spent mixed-oxide fuel assemblies would be very similar to conventional low-enriched uranium assemblies and DOE would treat them as such. The immobilized plutonium would be placed in small cans, inserted in the high-level radioactive waste canisters, and covered with molten borosilicate glass (can-in-canister technique). The canisters containing immobilized plutonium and high-level radioactive waste would be externally identical to the normal high-level radioactive waste canisters.

A.1.1.4 Waste Characteristics

A.1.1.4.1 *Mass and Volume*

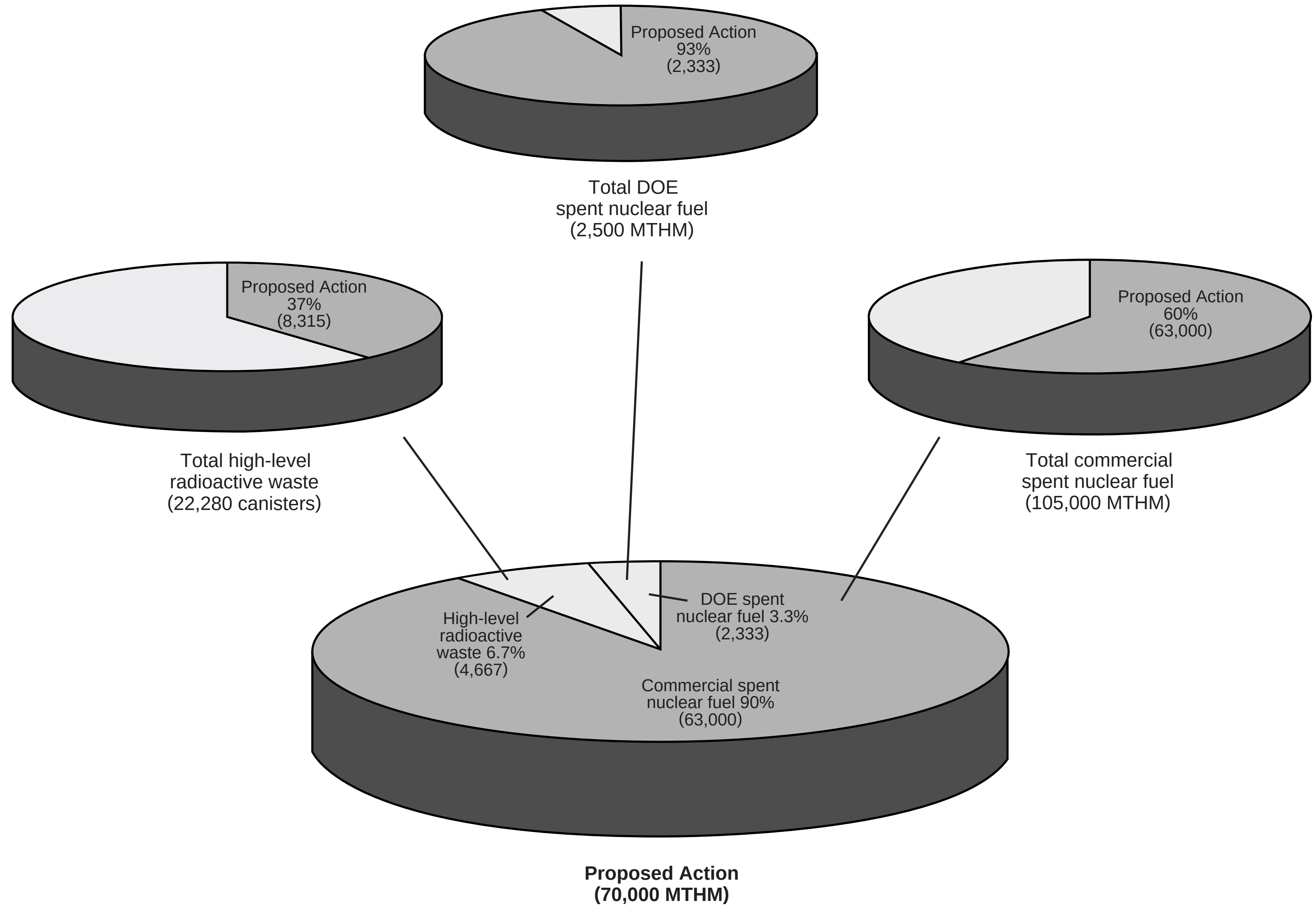
As discussed in Section A.1, the Proposed Action includes 70,000 MTHM in the forms of commercial spent nuclear fuel, DOE spent nuclear fuel, high-level radioactive waste, and surplus weapons-usable plutonium. Figure A-2 shows percentages of MTHM included in the Proposed Action and the relative amounts of the totals of the individual waste types included in the Proposed Action. As stated above, the remaining portion of the wastes is included in Inventory Module 1. Because Greater-Than-Class-C and Special-Performance-Assessment-Required wastes are measured in terms of volume, Figure A-3 shows the relative volume of the wastes in Inventory Module 2 compared to the inventory in Module 1.

The No-Action Alternative (see Chapter 7 and Appendix K) used this information to estimate the mass and volume of the spent nuclear fuel and high-level radioactive waste at commercial and DOE sites in five regions of the contiguous United States.

The mass and volume data for commercial spent nuclear fuel is the result of several years of annual tracking and projections by DOE, which anticipates few changes in the overall mass and volume projections for this waste type. The data projections for DOE spent nuclear fuel are fairly stable because most of the projected inventory already exists, as opposed to having a large amount projected for future generation. Mass and volume data for high-level radioactive waste estimates are not as reliable. Most high-level radioactive waste currently exists as a form other than solidified borosilicate glass. The solidification processes at the Savannah River Site and West Valley Demonstration Project are under way; therefore, the resulting mass and volume are known. However, the processes at the Idaho National Engineering and Environmental Laboratory and the Hanford Site have not started. Therefore, there is some uncertainty about the mass and volume that would result from those processing operations. For this analysis, DOE assumed that the high-level radioactive waste from the Hanford Site and the Idaho National Engineering and Environmental Laboratory would represent 65 and 6 percent of the total high-level radioactive waste inventory, respectively, in terms of the number of canisters.

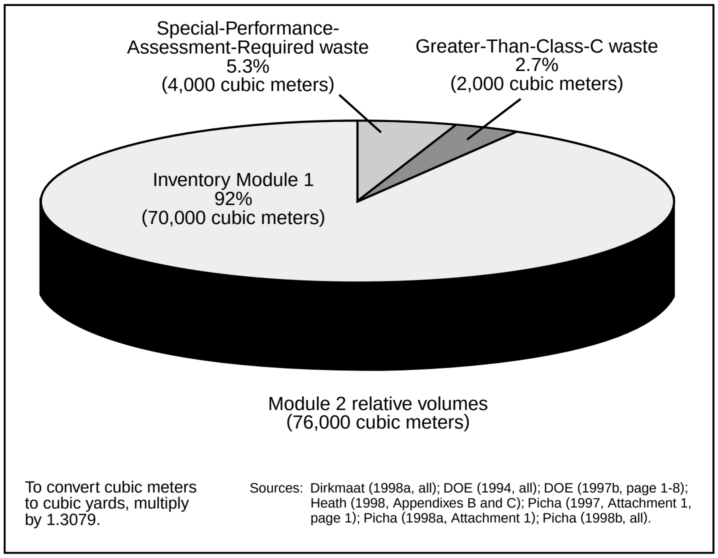
A.1.1.4.2 *Amount and Nature of Radioactivity*

The primary purpose of presenting these data is to quantify the isotopic inventory expected in the projected waste types. These data were used for accident scenario analyses associated with transportation, handling, and repository operations. The data were also used to develop the source term associated with accident scenarios and long-term effects for the Proposed Action and the No-Action Alternative.



Sources: DOE (1997a, page 32); Dirkmaat (1998a, all); Picha (1997, Attachment 1, page 1); Picha (1998a, Attachment 1).

Figure A-2. Proposed Action spent nuclear fuel and high-level radioactive waste inventory.



To convert cubic meters to cubic yards, multiply by 1.3079.

Sources: Dirkmaat (1998a, all); DOE (1994, all); DOE (1997b, page 1-8); Heath (1998, Appendixes B and C); Picha (1997, Attachment 1, page 1); Picha (1998a, Attachment 1); Picha (1998b, all).

Figure A-3. Inventory Module 2 volume.

In a comparison of the relative amounts of radioactivity in a particular waste type, radionuclides of concern depend on the analysis being performed. For example, cesium-137 is the primary radionuclide of concern when reviewing preclosure impacts and shielding requirements. For postclosure impacts, the repository performance assessment evaluated nine radionuclides (see Appendix I) and identified technetium-99 and neptunium-237 as the nuclides that provide the greatest impacts. Plutonium-238 and -239 are shown in Chapter 7 to contribute the most to doses for the No-Action Alternative. Table A-2 presents the inventory of each of these radionuclides included in the Proposed Action. Figure A-4 shows that at least 92 percent of the total inventory of each of these radionuclides is in commercial spent nuclear fuel.

Table A-2. Selected nuclide inventory for the Proposed Action (curies).

	Commercial spent nuclear fuel	DOE spent nuclear fuel	High-level radioactive waste	Surplus plutonium	Totals
Cesium-137	4.0×10^{9}	1.7×10^{8}	1.7×10^{8}	NA[a]	4.3×10^{9}
Technetium-99	9.2×10^{5}	2.9×10^{4}	2.1×10^{4}	NA	9.7×10^{5}
Neptunium-237	2.8×10^{4}	1.1×10^{3}	4.5×10^{2}	NA	3.0×10^{4}
Plutonium-238	2.1×10^{8}	5.6×10^{6}	3.0×10^{6}	7.6×10^{4}	2.2×10^{8}
Plutonium -239	2.3×10^{7}	3.8×10^{5}	4.4×10^{4}	1.0×10^{6}	2.5×10^{7}

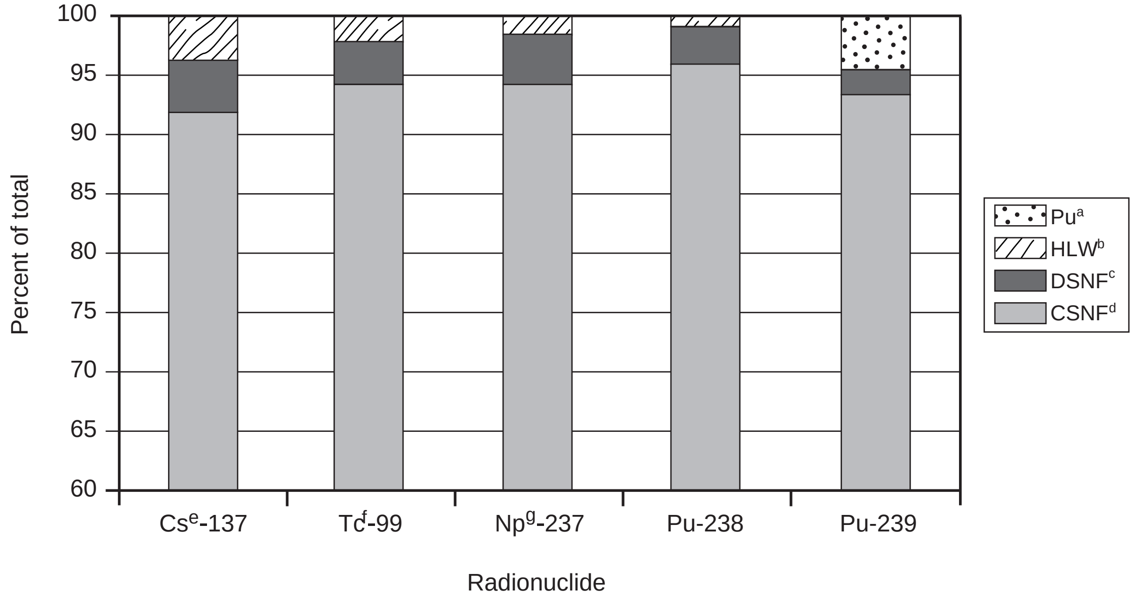
a. NA = not applicable.

A.1.1.4.3 *Chemical Composition*

The appendix presents data for the chemical composition of the primary waste types. For commercial spent nuclear fuel, the elemental composition of typical pressurized-water and boiling-water reactor fuel is provided on a per-assembly basis. Data are also provided on the number of stainless-steel clad assemblies in the current inventory.

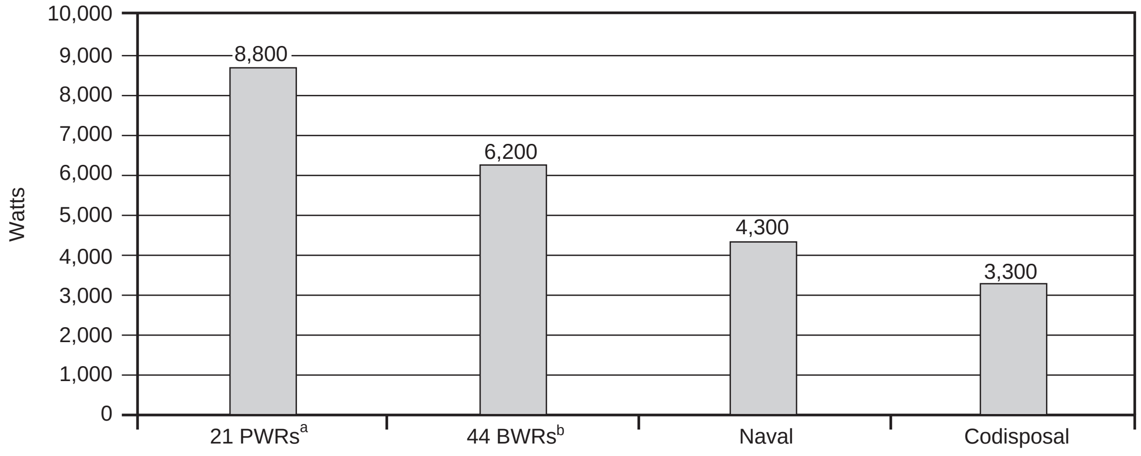
For DOE spent nuclear fuel and high-level radioactive waste, this appendix contains tables that describe the composition of the total inventory of the spent nuclear fuel (by representative category) or high-level radioactive waste (by site).

The chemical composition data were used primarily in the repository performance assessment (see Chapter 5 and Appendix I) to evaluate the relative amounts of materials that would need further study.



a. Pu = surplus weapons-usable plutonium; included in Proposed Action as spent nuclear fuel and high-level radioactive waste.
b. HLW = high-level radioactive waste.
c. DSNF = DOE spent nuclear fuel.
d. CSNF = commercial spent nuclear fuel
e. Cs = Cesium
f. Tc = Technetium
g. Np = Neptunium

Figure A-4. Proposed Action radionuclide distribution by material type.



a. PWR = pressurized-water reactor.
b. BWR = boiling-water reactor.

Figure A-5. Thermal generation (watts per waste package).

As a result of an initial screening, the repository performance assessment evaluated the long-term impacts of molybdenum, uranium, and chromium in the repository.

A.1.1.4.4 *Thermal Output*

Thermal generation data associated with each material type are provided in this appendix. These data were used to develop the thermal loads associated with the repository design. Chapter 2 describes the thermal load scenarios. The thermal data demonstrate that the EIS analysis can make simplifying assumptions that the thermal output of the commercial spent nuclear fuel waste packages, particularly the pressurized-water reactor assemblies, would bound the thermal output of all other waste packages (see Figure A-5).

The data presented in the thermal output sections of this appendix for each waste type are presented as watts per assembly or MTHM for commercial spent nuclear fuel, and watts per canister for DOE spent nuclear fuel or high-level radioactive waste. Figure A-5 normalizes these data into a common, watts-per-waste-package comparison. The following waste packages are compared: one containing 21 typical pressurized-water reactor assemblies, one containing 44 typical boiling-water reactor assemblies, a co-disposal waste package containing five high-level radioactive waste canisters and one DOE spent nuclear fuel canister, and a waste package containing one dual-purpose canister of naval spent nuclear fuel (also a DOE spent fuel). Another potential waste package containing four multi-canister overpacks of DOE uranium metal fuels is not included in Figure A-5 because its estimated maximum thermal generation is only 72 watts per waste package.

Figure A-5 uses conservative assumptions to illustrate the bounding nature of the thermal data for commercial spent nuclear fuel. The commercial spent nuclear fuel data represent typical assemblies that are assumed to have cooled for nearly 30 years. The naval spent nuclear fuel data are a best estimate of the thermal generation of 5-year old spent nuclear fuel. The thermal data selected for the high-level radioactive waste are conservatively represented by the canisters from the Savannah River Site and are combined with the highest values of thermal output from all projected DOE spent nuclear fuel categories.

A.1.1.4.5 *Canister Data*

Typically, DOE spent nuclear fuel and high-level radioactive waste would be sent to the repository in disposable canisters. The design specifications for DOE spent nuclear fuel canisters are in DOE (1998c, all). These canisters are generally of two diameters—46 and 61 centimeters (18 and 24 inches). They also would be designed for two different lengths, nominally 3 and 4.6 meters (10 and 15 feet), to enable co-disposal with high-level radioactive waste canisters. Certain DOE spent nuclear fuel categories require specific disposal canister designs. Naval fuels would be sent to the repository in Navy dual-purpose canisters, which are described in Dirkmaat (1997a, Attachment, pages 86 to 88) and USN (1996, pages 3-1 to 3-11). N-Reactor fuels from the Hanford Site would be sent to the repository in multicanister overpacks 64 centimeters (25.3 inches) in diameter, which are described in Parsons (1999, all).

High-level radioactive waste would be sent to the repository in stainless-steel canisters, 61 centimeters (25 inches) in diameter and either 3 or 4.6 meters (10 or 15 feet) in length, depending on the DOE site. The canister design specifications are contained in Marra, Harbour, and Plodinec (1995, all) and WVNS (1996, WQR-2.2, all) for the operating vitrification processes at Savannah River Site and West Valley Demonstration Project, respectively. The other sites would use canister designs similar to those currently in use (Picha 1997, all).

These data were for analysis of the No-Action Alternative (see Chapter 7 and Appendix K) to determine the time required to breach the canisters after they are exposed to weather elements.

A.2 Materials

This section describes the characteristics of the materials DOE has considered for disposal in the proposed Yucca Mountain Repository. All candidate materials would have to meet approved acceptance criteria.

A.2.1 COMMERCIAL SPENT NUCLEAR FUEL

A.2.1.1 Background

Spent nuclear fuel is fuel that has been withdrawn from a nuclear reactor following irradiation. Spent nuclear fuel from light-water reactors (pressurized-water and boiling-water reactors) would be the primary source of radioactivity and thermal load in the proposed monitored geologic repository. Spent nuclear fuels from civilian research reactors (General Atomics, Aerotest, etc.) account for less than 0.001 percent of the projected total in the Proposed Action (DOE 1995a, all). The fuels addressed in this section are those discharged from commercial light-water reactors.

Section A.2.2 discusses the spent nuclear fuel from the Fort St. Vrain reactor in Colorado as part of DOE spent nuclear fuels, as are the fuels from Shippingport, Three Mile Island-2, and other fuels from commercial facilities that DOE is managing at its facilities.

A.2.1.2 Sources

The sources of commercial spent nuclear fuel are the commercial nuclear powerplants throughout the country. Table A-3 lists the individual reactors, reactor type, state, and actual or projected years of operation. The operation period is subject to change if a utility pursues extension of the operating license or shuts down early.

A.2.1.3 Present Status

Nuclear power reactors store spent nuclear fuel in spent fuel pools under U.S. Nuclear Regulatory Commission licenses, but they can use a combination of storage options: (1) in-pool storage and (2) above-grade dry storage in an independent spent fuel storage installation. When a reactor is refueled, spent fuel is transferred to the spent fuel pool, where it typically remains until the available pool capacity is reached. When in-pool storage capacity has been fully used, utilities have turned to dry cask storage in an independent spent fuel storage installation to expand their onsite spent fuel storage capacities. In 1990, the Nuclear Regulatory Commission amended its regulations to authorize licensees to store spent nuclear fuel at reactor sites in approved storage casks (Raddatz and Waters 1996, all).

Commercial nuclear utilities currently use three Nuclear Regulatory Commission-approved general dry storage system design types—metal storage casks and metal canisters housed in concrete casks and concrete vaults—for use in licensed independent spent fuel storage installations. Raddatz and Waters (1996, all) contains detailed information on models currently approved by the Commission. Table A-4 lists existing and planned independent spent fuel storage installations in the United States.

A.2.1.4 Final Spent Nuclear Fuel Form

The final form of commercial spent nuclear fuel to be disposed of in the proposed repository would be the current reactor fuel assemblies. The repository would receive bare spent nuclear fuel assemblies, spent nuclear fuel packaged in canisters not intended for disposal, and spent nuclear fuel packaged in canisters intended for disposal.

Table A-3. Commercial nuclear power reactors in the United States and their projected years of operation.[a]

Unit name	Reactor type[b]	State	Operations period[c]
Arkansas Nuclear One 1	PWR	AR	1974-2014
Arkansas Nuclear One 2	PWR	AR	1978-2018
Beaver Valley 1	PWR	PA	1976-2016
Beaver Valley 2	PWR	PA	1978-2018
Big Rock Point	BWR	MI	1963-1997
Braidwood 1	PWR	IL	1987-2026
Braidwood 2	PWR	IL	1988-2027
Browns Ferry 1	BWR	AL	1973-2013
Browns Ferry 2	BWR	AL	1974-2014
Browns Ferry 3	BWR	AL	1976-2016
Brunswick 1	BWR	NC	1976-2016
Brunswick 2	BWR	NC	1974-2014
Byron 1	PWR	IL	1985-2024
Byron 2	PWR	IL	1987-2026
Callaway	PWR	MO	1984-2024
Calvert Cliffs 1	PWR	MD	1974-2014
Calvert Cliffs 2	PWR	MD	1976-2016
Catawba 1	PWR	SC	1985-2024
Catawba 2	PWR	SC	1986-2026
Clinton	BWR	IL	1987-2026
Comanche Peak 1	PWR	TX	1990-2030
Comanche Peak 2	PWR	TX	1993-2033
Cooper Station	BWR	NE	1974-2014
Crystal River 3	PWR	FL	1977-2016
D. C. Cook 1	PWR	MI	1974-2014
D. C. Cook 2	PWR	MI	1977-2017
Davis-Besse	PWR	OH	1977-2017
Diablo Canyon 1	PWR	CA	1984-2021
Diablo Canyon 2	PWR	CA	1985-2025
Dresden 1	BWR	IL	1959-1978
Dresden 2	BWR	IL	1969-2006
Dresden 3	BWR	IL	1971-2011
Duane Arnold 1	BWR	IA	1974-2014
Edwin I. Hatch 1	BWR	GA	1974-2014
Edwin I. Hatch 2	BWR	GA	1978-2018
Fermi 2	BWR	MI	1985-2025
Fort Calhoun 1	PWR	NE	1973-2013
Ginna	PWR	NY	1969-2009
Grand Gulf 1	BWR	MS	1984-2022
Haddam Neck	PWR	CT	1968-1996
Hope Creek	BWR	NJ	1986-2026
Humboldt Bay	BWR	CA	1962-1976
H.B. Robinson 2	PWR	SC	1970-2010
Indian Point 1	PWR	NY	1962-1974
Indian Point 2	PWR	NY	1973-2013
Indian Point 3	PWR	NY	1976-2015
James A. FitzPatrick/ Nine Mile Point	BWR	NY	1974-2014
Joseph M. Farley 1	PWR	AL	1977-2017
Joseph M. Farley 2	PWR	AL	1981-2021
Kewaunee	PWR	WI	1973-2013
LaCrosse	BWR	WI	1967-1987
LaSalle 1	BWR	IL	1970-2022
LaSalle 2	BWR	IL	1970-2023
Limerick 1	BWR	PA	1985-2024
Limerick 2	BWR	PA	1989-2029
Maine Yankee	PWR	ME	1972-1996
McGuire 1	PWR	NC	1981-2021
McGuire 2	PWR	NC	1983-2023
Millstone 1	BWR	CT	1970-2010
Millstone 2	PWR	CT	1975-2015
Millstone 3	PWR	CT	1986-2025
Monticello	BWR	MN	1971-2010
Nine Mile Point 1	BWR	NY	1969-2009
Nine Mile Point 2	BWR	NY	1987-2026
North Anna 1	PWR	VA	1978-2018
North Anna 2	PWR	VA	1980-2020
Oconee 1	PWR	SC	1973-2013
Oconee 2	PWR	SC	1973-2013
Oconee 3	PWR	SC	1974-2014
Oyster Creek	BWR	NJ	1969-2009
Palisades	PWR	MI	1972-2007
Palo Verde 1	PWR	AZ	1985-2024
Palo Verde 2	PWR	AZ	1986-2025
Palo Verde 3	PWR	AZ	1987-2027
Peach Bottom 2	BWR	PA	1973-2013
Peach Bottom 3	BWR	PA	1974-2014
Perry 1	BWR	OH	1986-2026
Pilgrim 1	BWR	MA	1972-2012
Point Beach 1	PWR	WI	1970-2010
Point Beach 2	PWR	WI	1973-2013
Prairie Island 1	PWR	MN	1974-2013
Prairie Island 2	PWR	MN	1974-2014
Quad Cities 1	BWR	IL	1972-2012
Quad Cities 2	BWR	IL	1972-2012
Rancho Seco	PWR	CA	1974-1989
River Bend 1	BWR	LA	1985-2025
Salem 1	PWR	NJ	1976-2016
Salem 2	PWR	NJ	1981-2020
San Onofre 1	PWR	CA	1967-1992
San Onofre 2	PWR	CA	1982-2013
San Onofre 3	PWR	CA	1983-2013
Seabrook 1	PWR	NH	1990-2026
Sequoyah 1	PWR	TN	1980-2020
Sequoyah 2	PWR	TN	1981-2021
Shearon Harris	PWR	NC	1987-2026
Shoreham	BWR	NY	1989[d]
South Texas Project 1	PWR	TX	1988-2016
South Texas Project 2	PWR	TX	1989-2023
St. Lucie 1	PWR	FL	1976-2016
St. Lucie 2	PWR	FL	1983-2023
Summer 1	PWR	SC	1982-2022
Surry 1	PWR	VA	1972-2012
Surry 2	PWR	VA	1973-2013
Susquehanna 1	BWR	PA	1982-2022
Susquehanna 2	BWR	PA	1984-2024
Three Mile Island 1	PWR	PA	1974-2014
Trojan	PWR	OR	1975-1992
Turkey Point 3	PWR	FL	1972-2012
Turkey Point 4	PWR	FL	1973-2013
Vermont Yankee	BWR	VT	1973-2012
Vogtle 1	PWR	GA	1987-2027
Vogtle 2	PWR	GA	1989-2029
Washington Public Power Supply System 2	BWR	WA	1984-2023
Waterford 3	PWR	LA	1985-2024
Watts Bar 1	PWR	TN	1996-2035
Wolf Creek	PWR	KS	1985-2025
Yankee-Rowe	PWR	MA	1963-1991
Zion 1	PWR	IL	1973-1997
Zion 2	PWR	IL	1974-1996

a. Source: DOE (1997a, Appendix C).

b. PWR = pressurized-water reactor; BWR = boiling-water reactor.

c. As defined by current shutdown or full operation through license period (as of 1997).

d. Shoreham is no longer a licensed plant and has transferred all fuel to Limerick.

Table A-4. Sites with existing or planned independent spent fuel storage installations.[a]

Reactor	Status	Reactor	Status
Prairie Island	Existing	Rancho Seco	Planned
Point Beach	Existing	Trojan	Planned
Palisades	Existing	Washington Public Power Supply System	Planned
Surry	Existing	Big Rock Point	Planned
Calvert Cliffs	Existing	Oyster Creek	Planned
Arkansas Nuclear	Existing	Duane Arnold	Planned
H. B. Robinson	Existing	McGuire	Planned
Oconee	Existing	Yankee Rowe	Planned
Davis-Besse	Existing	Maine Yankee	Planned
North Anna	Planned	Peach Bottom	Planned
James A. FitzPatrick/Nine Mile Point	Planned	Palo Verde	Planned
Dresden	Planned	Humboldt Bay	Planned
Susquehanna	Planned		

a. Sources: Raddatz and Waters (1996, all); Cole (1998a, all).

A.2.1.5 Spent Nuclear Fuel Characteristics

There are 22 classes of nuclear fuel assemblies, with 127 individual fuel types in those classes. Seventeen of the classes are for pressurized-water reactor fuels and 5 are for boiling-water reactors (DOE 1992, Appendix 2A). For this EIS, the typical assemblies chosen for analysis represent an assembly type being used in the more recently built reactors. This results in physical characteristics that might be slightly higher than average (size, uranium per assembly, etc.), but that, however, provide a realistic estimate for EIS analyses. Specifically chosen to represent the typical fuel types were the Westinghouse 17 × 17 LOPAR fuel assembly for the pressurized-water reactor and the General Electric BWR/4-6, 8 × 8 fuel assembly for the boiling-water reactor. Table A-5 lists the fissile content and performance parameters selected to define the radiological characteristics of these typical fuel assemblies.

Table A-5. Typical spent nuclear fuel parameters.[a]

Fuel type[b]	Burnup (MWd/MTHM)[c]	Initial enrichment (percent of U-235 by weight)	Age (years)
Typical PWR	39,560	3.69	25.9
Typical BWR	32,240	3.00	27.2

a. Source: TRW (1998, page 3-15).

b. PWR = pressurized-water reactor; BWR = boiling-water reactor.

c. MWd/MTHM = megawatt-days per metric ton of heavy metal; to convert metric tons to tons, multiply by 1.1023.

A.2.1.5.1 *Mass and Volume*

As discussed in Section A.1, the Proposed Action includes 63,000 MTHM of commercial spent nuclear fuel. For the No-Action Alternative (continued storage) analysis, Table A-6 lists the distribution of this expected inventory by reactor site. The historic and projected spent nuclear fuel discharge and storage information in Table A-6 is consistent with the annual projections provided by the Energy Information Administration (DOE 1997a, page 32). The “1995 Actual” data presented in Table A-6 represents the amount of spent nuclear fuel stored at a particular site regardless of the reactor from which it was discharged. For analysis purposes, the table lists spent nuclear fuel currently stored at the General Electric Morris, Illinois, facility to be at Dresden, because these facilities are located near each other.

For analyses associated with the Proposed Action, the projected spent nuclear fuel from pressurized-water reactors comprises 65 percent of the 63,000 metric tons of heavy metal (TRW 1997, page A-2). The

Table A-6. Proposed Action spent nuclear fuel inventory (MTHM).[a]

Site	Fuel type[b]	1995 actual	1996-2011[c]	Total[d]	Equivalent assemblies	Site	Fuel type[b]	1995 actual	1996-2011[c]	Total[d]	Equivalent assemblies
Arkansas Nuclear One	PWR	643	466	1,109	2,526	Monticello	BWR	147	280	426	2,324
Beaver Valley	PWR	437	581	1,018	2,206	North Anna	PWR	570	613	1,184	2,571
Big Rock Point	BWR	44	14	58	439	Oconee	PWR	1,098	767	1,865	4,028
Braidwood	PWR	318	711	1,029	2,424	Oyster Creek	BWR	374	325	699	3,824
Browns Ferry	BWR	840	1,092	1,932	10,402	Palisades	PWR	338	247	585	1,473
Brunswick	Both	448	448	896	4,410	Palo Verde	PWR	556	1,118	1,674	4,082
Byron	PWR	404	664	1,068	2,515	Peach Bottom	BWR	908	645	1,554	8,413
Callaway	PWR	280	422	702	1,609	Perry	BWR	178	274	452	2,470
Calvert Cliffs	PWR	641	501	1,142	2,982	Pilgrim	BWR	326	201	527	2,853
Catawba	PWR	465	683	1,148	2,677	Point Beach	PWR	529	347	876	2,270
Clinton	BWR	174	303	477	2,588	Prairie Island	PWR	518	348	866	2,315
Comanche Peak	PWR	176	821	998	2,202	Quad Cities	BWR	813	464	1,277	6,953
Cooper	BWR	175	277	452	2,435	Rancho Seco	PWR	228	--[e]	228	493
Crystal River	PWR	280	232	512	1,102	River Bend	BWR	176	356	531	2,889
D. C. Cook	PWR	777	656	1,433	3,253	Salem/Hope Creek	Both	793	866	1,659	7,154
Davis-Besse	PWR	243	262	505	1,076	San Onofre	PWR	722	701	1,423	3,582
Diablo Canyon	PWR	463	664	1,126	2,512	Seabrook	PWR	133	292	425	918
Dresden	BWR	1,557	590	2,146	11,602	Sequoyah	PWR	452	570	1,023	2,218
Duane Arnold	BWR	258	208	467	2,545	Shearon Harris	Both	498	252	750	2,499
Edwin I. Hatch	BWR	755	692	1,446	7,862	South Texas Project	PWR	290	722	1,012	1,871
Fermi	BWR	155	368	523	2,898	St. Lucie	PWR	601	419	1,020	2,701
Fort Calhoun	PWR	222	157	379	1,054	Summer	PWR	225	301	526	1,177
Ginna	PWR	282	180	463	1,234	Surry	PWR	660	534	1,194	2,604
Grand Gulf	BWR	349	506	856	4,771	Susquehanna	BWR	628	648	1,276	7,172
H. B. Robinson	PWR	145	239	384	903	Three Mile Island	PWR	311	236	548	1,180
Haddam Neck	PWR	355	65	420	1,017	Trojan	PWR	359	--	359	780
Humboldt Bay	BWR	29	--	29	390	Turkey Point	PWR	616	458	1,074	2,355
Indian Point	PWR	678	486	1,164	2,649	Vermont Yankee	BWR	387	222	609	3,299
James A. FitzPatrick/ Nine Mile Point	BWR	882	930	1,812	9,830	Vogtle	PWR	335	745	1,080	2,364
Joseph M. Farley	PWR	644	530	1,174	2,555	Washington Public Power Supply System 2	BWR	243	338	581	3,223
Kewaunee	PWR	282	169	451	1,172						
La Crosse	BWR	38	--	38	333	Waterford	PWR	253	247	500	1,217
La Salle	BWR	465	487	952	5,189	Watts Bar	PWR	--	251	251	544
Limerick	BWR	432	711	1,143	6,203	Wolf Creek	PWR	226	404	630	1,360
Maine Yankee	PWR	454	82	536	1,421	Yankee-Rowe	PWR	127	--	127	533
McGuire	PWR	714	725	1,439	3,257	Zion	PWR	841	211	1,052	2,302
Millstone	Both	959	749	1,709	6,447	**Totals**		**31,926**	**31,074**	**63,000**	**218,700**

a. Source: Heath (1998, Appendixes B and C).
b. PWR = pressurized-water reactor; BWR = boiling-water reactor.
c. Projected.
d. To convert metric tons to tons, multiply by 1.1023.
e. -- = no spent nuclear fuel production.

balance consists of spent nuclear fuel from boiling-water reactors. Using the nominal volume for the spent nuclear fuel assemblies described in Section A.2.1.5.5, the estimated volume of spent nuclear fuel in the Proposed Action, exclusive of packaging, is 29,000 cubic meters.

Section A.1 also discusses the additional inventory modules evaluated in this EIS. Inventory Modules 1 and 2 both include the maximum expected discharge inventory of commercial spent nuclear fuel. Table A-7 lists historic and projected amounts of spent nuclear fuel discharged from commercial reactors through 2046. The estimated unpackaged volume of spent nuclear fuel for these modules is approximately 47,000 cubic meters. For conservatism, these data were derived from the Energy Information Administration "high case" assumptions. The high case assumes that all currently operating nuclear units would renew their operating licenses for an additional 10 years (DOE 1997a, page 32).

Table A-7. Inventory Modules 1 and 2 spent nuclear fuel inventory (MTHM).[a]

Site	Fuel type[b]	1995 actual	1996-2046[c]	Total[d]	Equivalent assemblies
Arkansas Nuclear One	PWR	643	1,007	1,650	3,757
Beaver Valley	PWR	437	1,395	1,832	3,970
Big Rock Point	BWR	44	14	58	439
Braidwood	PWR	318	1,969	2,287	5,385
Browns Ferry	BWR	840	2,508	3,348	18,024
Brunswick	Both	448	992	1,440	7,355
Byron	PWR	404	1,777	2,181	5,139
Callaway	PWR	280	1,008	1,288	2,953
Calvert Cliffs	PWR	641	1,069	1,710	4,466
Catawba	PWR	465	1,752	2,217	5,168
Clinton	BWR	174	910	1,084	5,876
Comanche Peak	PWR	176	2,459	2,635	5,816
Cook	PWR	777	1,379	2,155	4,892
Cooper	BWR	175	587	762	4,106
Crystal River	PWR	280	525	805	1,734
Davis-Besse	PWR	243	582	825	1,757
Diablo Canyon	PWR	463	1,725	2,187	4,878
Dresden	BWR	1,557	984	2,541	13,740
Duane Arnold	BWR	258	434	692	3,776
Fermi	BWR	155	1,005	1,160	6,429
Fort Calhoun	PWR	222	312	534	1,485
Ginna	PWR	282	283	565	1,507
Grand Gulf	BWR	349	1,261	1,610	8,976
H. B. Robinson	PWR	145	364	509	1,197
Haddam Neck	PWR	355	65	420	1,017
Hatch	BWR	755	1,517	2,272	12,347
Humboldt Bay	BWR	29	--	29	390
Indian Point	PWR	678	1,005	1,683	3,787
James A. FitzPatrick/ Nine Mile Point	BWR	882	2,018	2,900	15,732
Joseph M. Farley	PWR	644	1,225	1,869	4,070
Kewaunee	PWR	282	330	612	1,591
La Crosse	BWR	38	--	38	333
La Salle	BWR	465	1,398	1,863	10,152
Limerick	BWR	432	1,958	2,390	12,967
Maine Yankee	PWR	454	82	536	1,421
McGuire	PWR	714	1,813	2,527	5,720
Millstone	Both	959	1,695	2,655	8,930
Monticello	BWR	147	390	537	2,924
North Anna	PWR	570	1,384	1,955	4,246
Oconee	PWR	1,098	1,576	2,674	5,774
Oyster Creek	BWR	374	470	844	4,619
Palisades	PWR	338	395	733	1,845
Palo Verde	PWR	556	3,017	3,573	8,712
Peach Bottom	BWR	908	1,404	2,312	12,523
Perry	BWR	178	732	910	4,974
Pilgrim	BWR	326	444	770	4,170
Point Beach	PWR	529	614	1,143	2,961
Prairie Island	PWR	518	692	1,210	3,234
Quad Cities	BWR	813	1,020	1,834	9,982
Rancho Seco	PWR	228	--[e]	228	493
River Bend	BWR	176	956	1,132	6,153
Salem/Hope Creek	Both	793	2,452	3,245	11,584
San Onofre	PWR	722	1,321	2,043	5,144
Seabrook	PWR	133	831	964	2,083
Sequoyah	PWR	452	1,393	1,845	4,001
Shearon Harris	Both	498	707	1,205	3,535
South Texas Project	PWR	290	2,029	2,319	4,286
St. Lucie	PWR	601	1,010	1,611	4,265
Summer	PWR	225	732	958	2,141
Surry	PWR	660	1,029	1,689	3,682
Susquehanna	BWR	628	1,745	2,373	13,338
Three Mile Island	PWR	311	513	825	1,777
Trojan	PWR	359	--	359	780
Turkey Point	PWR	616	905	1,520	3,334
Vermont Yankee	BWR	387	434	822	4,451
Vogtle	PWR	335	2,122	2,458	5,378
Washington Public Power Supply System 2	BWR	243	924	1,167	6,476
Waterford	PWR	253	685	938	2,282
Watts Bar	PWR	--	893	893	1,937
Wolf Creek	PWR	226	1,052	1,278	2,759
Yankee-Rowe	PWR	127	--	127	533
Zion	PWR	841	211	1,052	2,302
Totals		**31,926**	**73,488**	**105,414**	**359,963**

a. Source: Heath (1998, Appendixes B and C).
b. PWR = pressurized-water reactor; BWR = boiling-water reactor.
c. Projected.
d. To convert metric tons to tons, multiply by 1.1023.
e. -- = no spent nuclear fuel production.

A.2.1.5.2 *Amount and Nature of Radioactivity*

DOE derived radionuclide inventories for the typical pressurized-water reactor and boiling-water reactor fuel assemblies from the Light-Water Reactor Radiological Database (DOE 1992, page 1.1-1). The inventories are presented at the average decay years for each of the typical assemblies. Tables A-8 and A-9 list the inventories of the nuclides of interest for the typical assemblies for both reactor types.

Table A-10 combines the typical inventories (curies per MTHM) with the projected totals (63,000 MTHM and 105,000 MTHM) to provide a total projected radionuclide inventory for the Proposed Action and additional modules.

A.2.1.5.3 *Chemical Composition*

Commercial spent nuclear fuel consists of the uranium oxide fuel itself (including actinides, fission products, etc.), the cladding, and the assembly hardware.

Table A-8. Radionuclide activity for typical pressurized-water reactor fuel assemblies.[a,b]

Isotope	Curies per assembly	Isotope	Curies per assembly	Isotope	Curies per assembly
Hydrogen-3	9.8×10^{1}	Cesium-134	1.6×10^{1}	Neptunium-237	2.3×10^{-1}
Carbon-14	6.4×10^{-1}	Cesium-135	2.5×10^{-1}	Plutonium-238	1.7×10^{3}
Chlorine-36	5.4×10^{-3}	Cesium-137	3.1×10^{4}	Plutonium-239	1.8×10^{2}
Cobalt-60	1.5×10^{2}	Samarium-151	1.9×10^{2}	Plutonium-240	2.7×10^{2}
Nickel-59	1.3	Lead-210	2.2×10^{-7}	Plutonium-241	2.0×10^{4}
Nickel-63	1.8×10^{2}	Radium-226	9.3×10^{-7}	Plutonium-242	9.9×10^{-1}
Selenium-79	2.3×10^{-1}	Radium-228	1.3×10^{-10}	Americium-241	1.7×10^{3}
Krypton-85	9.3×10^{2}	Actinium-227	7.8×10^{-6}	Americium-242/242m	1.1×10^{1}
Strontium-90	2.1×10^{4}	Thorium-229	1.7×10^{-7}	Americium-243	1.3×10^{1}
Zirconium-93	1.2	Thorium-230	1.5×10^{-4}	Curium-242	8.7
Niobium-93m	8.2×10^{-1}	Thorium-232	1.9×10^{-10}	Curium-243	8.3
Niobium-94	5.8×10^{-1}	Protactinium-231	1.6×10^{-5}	Curium-244	7.0×10^{2}
Technetium-99	7.1	Uranium-232	1.9×10^{-2}	Curium-245	1.8×10^{-1}
Rhodium-102	1.2×10^{-3}	Uranium-233	3.3×10^{-5}	Curium-246	3.8×10^{-2}
Ruthenium-106	4.8×10^{-3}	Uranium-234	6.6×10^{-1}	Curium-247	1.3×10^{-7}
Palladium-107	6.3×10^{-2}	Uranium-235	8.4×10^{-3}	Curium-248	3.9×10^{-7}
Tin-126	4.4×10^{-1}	Uranium-236	1.4×10^{-1}	Californium-252	3.1×10^{-8}
Iodine-129	1.8×10^{-2}	Uranium-238	1.5×10^{-1}		

a. Source: DOE (1992, page 1.1-1).

b. Burnup = 39,560 MWd/MTHM, enrichment = 3.69 percent, decay time = 25.9 years.

Table A-9. Radionuclide activity for typical boiling-water reactor fuel assemblies.[a,b]

Isotope	Curies per assembly	Isotope	Curies per assembly	Isotope	Curies per assembly
Hydrogen-3	3.4×10^{1}	Cesium-134	3.4	Neptunium-237	7.3×10^{-2}
Carbon-14	3.0×10^{-1}	Cesium-135	1.0×10^{-1}	Plutonium-238	5.5×10^{2}
Chlorine-36	2.2×10^{-3}	Cesium-137	1.1×10^{4}	Plutonium-239	6.3×10^{1}
Cobalt-60	3.7×10^{1}	Samarium-151	6.6×10^{1}	Plutonium-240	9.5×10^{1}
Nickel-59	3.5×10^{-1}	Lead-210	9.4×10^{-8}	Plutonium-241	7.5×10^{3}
Nickel-63	4.6×10^{1}	Radium-226	3.7×10^{-7}	Plutonium-242	4.0×10^{-1}
Selenium-79	7.9×10^{-2}	Radium-228	4.7×10^{-11}	Americium-241	6.8×10^{2}
Krypton-85	2.9×10^{2}	Actinium-227	3.1×10^{-6}	Americium-242/242m	4.6
Strontium-90	7.1×10^{3}	Thorium-229	6.1×10^{-8}	Americium-243	4.9
Zirconium-93	4.8×10^{-1}	Thorium-230	5.8×10^{-5}	Curium-242	3.8
Niobium-93m	3.5×10^{-1}	Thorium-232	6.9×10^{-11}	Curium-243	3.1
Niobium-94	1.9×10^{-2}	Protactinium-231	6.0×10^{-6}	Curium-244	2.5×10^{2}
Technetium-99	2.5	Uranium-232	5.5×10^{-3}	Curium-245	6.3×10^{-2}
Rhodium-102	2.8×10^{-4}	Uranium-233	1.1×10^{-5}	Curium-246	1.3×10^{-2}
Ruthenium-106	6.7×10^{-4}	Uranium-234	2.4×10^{-1}	Curium-247	4.3×10^{-8}
Palladium-107	2.4×10^{-2}	Uranium-235	3.0×10^{-3}	Curium-248	1.2×10^{-7}
Tin-126	1.5×10^{-1}	Uranium-236	4.8×10^{-2}	Californium-252	6.0×10^{-9}
Iodine-129	6.3×10^{-3}	Uranium-238	6.2×10^{-2}		

a. Source: DOE (1992, page 1.1-1).

b. Burnup = 32,240 MWd/MTHM, enrichment = 3.00 percent, decay time = 27.2 years.

Typical pressurized-water and boiling-water reactor fuels consist of uranium dioxide with a zirconium alloy cladding. Some assemblies, however, are clad in stainless-steel 304. Specifically, 2,187 assemblies, or 727 MTHM (1.15 percent of the MTHM included in the Proposed Action) are stainless-steel clad (Cole 1998b, all). These assemblies have been discharged from Haddam Neck, Yankee-Rowe, Indian Point, San Onofre, and LaCrosse. Table A-11 lists the number of assemblies discharged, MTHM, and storage sites for each plant.

Tables A-12 and A-13 list the postirradiation elemental distributions for typical fuels. The data in these tables include the fuel, cladding material, and assembly hardware.

Table A-10. Total projected radionuclide inventories.[a]

	Pressurized-water reactor			Boiling-water reactor				
		Total curies			Total curies		Grand totals (curies)	
Isotope	Curies per MTHM[b]	Proposed Action	Additional modules	Curies per MTHM	Proposed Action	Additional modules	Proposed Action	Additional modules
Hydrogen-3	2.1×10^{2}	8.6×10^{6}	1.4×10^{7}	1.7×10^{2}	3.8×10^{6}	6.4×10^{6}	1.2×10^{7}	2.1×10^{7}
Carbon-14	1.4	5.7×10^{4}	9.5×10^{4}	1.5	3.4×10^{4}	5.7×10^{4}	9.1×10^{4}	1.5×10^{5}
Chlorine-36	1.2×10^{-2}	4.7×10^{2}	7.9×10^{2}	1.1×10^{-2}	2.5×10^{2}	4.1×10^{2}	7.2×10^{2}	1.2×10^{3}
Cobalt-60	3.2×10^{2}	1.3×10^{7}	2.2×10^{7}	1.9×10^{2}	4.2×10^{6}	7.0×10^{6}	1.7×10^{7}	2.9×10^{7}
Nickel-59	2.8	1.1×10^{5}	1.9×10^{5}	1.8	4.0×10^{4}	6.6×10^{4}	1.5×10^{5}	2.6×10^{5}
Nickel-63	3.8×10^{2}	1.6×10^{7}	2.6×10^{7}	2.3×10^{2}	5.1×10^{6}	8.6×10^{6}	2.1×10^{7}	3.5×10^{7}
Selenium-79	4.9×10^{-1}	2.0×10^{4}	3.3×10^{4}	4.0×10^{-1}	8.9×10^{3}	1.5×10^{4}	2.9×10^{4}	4.8×10^{4}
Krypton-85	2.0×10^{3}	8.2×10^{7}	1.4×10^{8}	1.5×10^{3}	3.3×10^{7}	5.5×10^{7}	1.1×10^{8}	1.9×10^{8}
Strontium-90	4.6×10^{4}	1.9×10^{9}	3.1×10^{9}	3.6×10^{4}	8.0×10^{8}	1.3×10^{9}	2.7×10^{9}	4.5×10^{9}
Zirconium-93	2.5	1.0×10^{5}	1.7×10^{5}	2.4	5.4×10^{4}	9.0×10^{4}	1.6×10^{5}	2.6×10^{5}
Niobium-93m	1.8	7.3×10^{4}	1.2×10^{5}	1.8	3.9×10^{4}	6.6×10^{4}	1.1×10^{5}	1.9×10^{5}
Niobium-94	1.3	5.1×10^{4}	8.6×10^{4}	9.8×10^{-2}	2.2×10^{3}	3.6×10^{3}	5.3×10^{4}	8.9×10^{4}
Technetium-99	1.5×10^{1}	6.3×10^{5}	1.1×10^{6}	1.3×10^{1}	2.9×10^{5}	4.8×10^{5}	9.2×10^{5}	1.5×10^{6}
Rhodium-102	2.6×10^{-3}	1.1×10^{2}	1.8×10^{2}	1.4×10^{-3}	3.2×10^{1}	5.3×10^{1}	1.4×10^{2}	2.3×10^{2}
Ruthenium-106	1.0×10^{-2}	4.2×10^{2}	7.0×10^{2}	3.4×10^{-3}	7.5×10^{1}	1.3×10^{2}	5.0×10^{2}	8.3×10^{2}
Palladium-107	1.4×10^{-1}	5.6×10^{3}	9.4×10^{3}	1.2×10^{-1}	2.7×10^{3}	4.5×10^{3}	8.3×10^{3}	1.4×10^{4}
Tin-126	9.4×10^{-1}	3.8×10^{4}	6.4×10^{4}	7.9×10^{-1}	1.7×10^{0}	2.9×10^{4}	5.6×10^{4}	9.3×10^{4}
Iodine-129	3.8×10^{-2}	1.5×10^{3}	2.6×10^{3}	3.2×10^{-2}	7.0×10^{2}	1.2×10^{3}	2.2×10^{3}	3.8×10^{3}
Cesium-134	3.5×10^{1}	1.4×10^{6}	2.4×10^{6}	1.7×10^{1}	3.8×10^{5}	6.4×10^{5}	1.8×10^{6}	3.0×10^{6}
Cesium-135	5.5×10^{-1}	2.3×10^{4}	3.8×10^{4}	5.1×10^{-1}	1.1×10^{4}	1.9×10^{4}	3.4×10^{4}	5.6×10^{4}
Cesium-137	6.7×10^{4}	2.8×10^{9}	4.6×10^{9}	5.4×10^{4}	1.2×10^{9}	2.0×10^{9}	4.0×10^{9}	6.6×10^{9}
Samarium-151	4.0×10^{2}	1.6×10^{7}	2.7×10^{7}	3.4×10^{2}	7.4×10^{0}	1.2×10^{7}	2.4×10^{7}	4.0×10^{7}
Lead-210	4.8×10^{-7}	2.0×10^{-2}	3.3×10^{-2}	4.8×10^{-7}	1.1×10^{-2}	1.8×10^{-2}	3.0×10^{-2}	5.1×10^{-2}
Radium-226	2.0×10^{-6}	8.2×10^{-2}	1.4×10^{-1}	1.9×10^{-6}	4.2×10^{-2}	7.0×10^{-2}	1.2×10^{-1}	2.1×10^{-1}
Radium-228	2.8×10^{-10}	1.1×10^{-5}	1.9×10^{-5}	2.4×10^{-10}	5.3×10^{-6}	8.9×10^{-6}	1.7×10^{-5}	2.8×10^{-5}
Actinium-227	1.7×10^{-5}	6.9×10^{-1}	1.2	1.6×10^{-5}	3.5×10^{-1}	5.8×10^{-1}	1.0	1.7
Thorium-229	3.8×10^{-7}	1.5×10^{-2}	2.6×10^{-2}	3.1×10^{-7}	6.9×10^{-3}	1.2×10^{-2}	2.2×10^{-2}	3.7×10^{-2}
Thorium-230	3.3×10^{-4}	1.4×10^{1}	2.3×10^{1}	3.0×10^{-4}	6.6×10	1.1×10^{1}	2.0×10^{1}	3.4×10^{1}
Thorium-232	4.1×10^{-10}	1.7×10^{-5}	2.8×10^{-5}	3.5×10^{-10}	7.8×10^{-6}	1.3×10^{-5}	2.5×10^{-5}	4.1×10^{-5}
Protactinium-231	3.4×10^{-5}	1.4	2.3	3.1×10^{-5}	6.8×10^{-1}	1.1	2.1	3.5
Uranium-232	4.0×10^{-2}	1.6×10^{3}	2.7×10^{3}	2.8×10^{-2}	6.2×10^{2}	1.0×10^{3}	2.3×10^{3}	3.8×10^{3}
Uranium-233	7.1×10^{-5}	2.9	4.9	5.4×10^{-5}	1.2	2.0	4.1	6.9
Uranium-234	1.4	5.8×10^{4}	9.7×10^{4}	1.2	2.7×10^{4}	4.5×10^{4}	8.5×10^{4}	1.4×10^{5}
Uranium-235	1.8×10^{-2}	7.4×10^{2}	1.2×10^{3}	1.5×10^{-2}	3.4×10^{2}	5.6×10^{2}	1.1×10^{3}	1.8×10^{3}
Uranium-236	3.0×10^{-1}	1.2×10^{4}	2.1×10^{4}	2.4×10^{-1}	5.4×10^{3}	9.0×10^{3}	1.8×10^{4}	3.0×10^{4}
Uranium-238	3.1×10^{-1}	1.3×10^{4}	2.2×10^{4}	3.2×10^{-1}	7.0×10^{3}	1.2×10^{4}	2.0×10^{4}	3.3×10^{4}
Neptunium-237	4.9×10^{-1}	2.0×10^{4}	3.4×10^{4}	3.7×10^{-1}	8.2×10^{3}	1.4×10^{4}	2.8×10^{4}	4.7×10^{4}
Plutonium-238	3.6×10^{3}	1.5×10^{8}	2.5×10^{8}	2.8×10^{3}	6.1×10^{7}	1.0×10^{8}	2.1×10^{8}	3.5×10^{8}
Plutonium-239	3.9×10^{2}	1.6×10^{7}	2.7×10^{7}	3.2×10^{2}	7.1×10^{6}	1.2×10^{7}	2.3×10^{7}	3.9×10^{7}
Plutonium-240	5.8×10^{2}	2.4×10^{7}	4.0×10^{7}	4.9×10^{2}	1.1×10^{7}	1.8×10^{7}	3.4×10^{7}	5.8×10^{7}
Plutonium-241	4.4×10^{4}	1.8×10^{9}	3.0×10^{9}	3.8×10^{4}	8.4×10^{8}	1.4×10^{9}	2.6×10^{9}	4.4×10^{9}
Plutonium-242	2.1	8.7×10^{4}	1.5×10^{5}	2.0	4.5×10^{4}	7.5×10^{4}	1.3×10^{5}	2.2×10^{5}
Americium-241	3.7×10^{3}	1.5×10^{8}	2.5×10^{8}	3.5×10^{3}	7.7×10^{7}	1.3×10^{8}	2.3×10^{8}	3.8×10^{8}
Americium-242/242m	2.3×10^{1}	9.3×10^{5}	1.6×10^{6}	2.3×10^{1}	5.2×10^{5}	8.7×10^{5}	1.4×10^{6}	2.4×10^{6}
Americium-243	2.7×10^{1}	1.1×10^{6}	1.9×10^{6}	2.5×10^{1}	5.5×10^{5}	9.2×10^{5}	1.7×10^{6}	2.8×10^{6}
Curium-242	1.9×10^{1}	7.7×10^{5}	1.3×10^{6}	1.9×10^{1}	4.3×10^{5}	7.1×10^{5}	1.2×10^{6}	2.0×10^{6}
Curium-243	1.8×10^{1}	7.3×10^{5}	1.2×10^{6}	1.6×10^{1}	3.5×10^{5}	5.8×10^{5}	1.1×10^{6}	1.8×10^{6}
Curium-244	1.5×10^{3}	6.2×10^{7}	1.0×10^{8}	1.3×10^{3}	2.8×10^{7}	4.7×10^{7}	9.0×10^{7}	1.5×10^{8}
Curium-245	3.9×10^{-1}	1.6×10^{4}	2.7×10^{4}	3.2×10^{-1}	7.1×10^{3}	1.2×10^{4}	2.3×10^{4}	3.8×10^{4}
Curium-246	8.2×10^{-2}	3.4×10^{3}	5.6×10^{3}	6.5×10^{-2}	1.4×10^{3}	2.4×10^{3}	4.8×10^{3}	8.0×10^{3}
Curium-247	2.9×10^{-7}	1.2×10^{-2}	2.0×10^{-2}	2.2×10^{-7}	4.8×10^{-3}	8.1×10^{-3}	1.6×10^{-2}	2.8×10^{-2}
Curium-248	8.3×10^{-7}	3.4×10^{-2}	5.7×10^{-2}	6.1×10^{-7}	1.4×10^{-2}	2.3×10^{-2}	4.8×10^{-2}	8.0×10^{-2}
Californium-252	6.7×10^{-8}	2.8×10^{-3}	4.6×10^{-3}	3.1×10^{-8}	6.8×10^{-4}	1.1×10^{-3}	3.4×10^{-3}	5.7×10^{-3}

a. Source: Compilation of Tables A-8 and A-9.

b. MTHM = metric tons of heavy metal.

Table A-11. Stainless-steel-clad spent nuclear fuel inventory.[a]

Discharging reactor	Storage location	Assemblies	MTHM[b]
Yankee-Rowe	Yankee-Rowe	76	21
San Onofre 1	San Onofre	395	144
San Onofre 1	Morris, Illinois	270	99
Indian Point 1	Indian Point	160	31
LaCrosse	LaCrosse	333	38
Haddam Neck	Haddam Neck	871	360
Haddam Neck	Morris, Illinois	82	34
Totals		**2,187**	**727**

a. Source: Cole (1998b, all).

b. MTHM = metric tons of heavy metal.

Table A-12. Elemental distribution of typical pressurized-water reactor fuel.[a]

Element	Grams per assembly[b]	Percent total[c]	Element	Grams per assembly[b]	Percent total[c]
Aluminum	47	0.01	Oxygen	62,000	9.35
Americium	600	0.09	Palladium	790	0.12
Barium	1,200	0.18	Phosphorus	85	0.01
Cadmium	77	0.01	Plutonium	4,600	0.69
Carbon	77	0.01	Praseodymium	610	0.09
Cerium	1,300	0.20	Rhodium	230	0.04
Cesium	1,100	0.17	Rubidium	200	0.03
Chromium	4,300	0.65	Ruthenium	1,200	0.18
Cobalt	38	0.01	Samarium	470	0.07
Europium	72	0.01	Silicon	170	0.03
Gadolinium	81	0.01	Silver	40	0.01
Iodine	130	0.02	Strontium	330	0.05
Iron	12,000	1.85	Technetium	420	0.06
Krypton	190	0.03	Tellurium	270	0.04
Lanthanum	670	0.10	Tin	1,900	0.29
Manganese	330	0.05	Titanium	51	0.01
Molybdenum	2,000	0.31	Uranium	440,000	65.78
Neodymium	2,200	0.33	Xenon	2,900	0.43
Neptunium	330	0.05	Yttrium	250	0.04
Nickel	5,000	0.75	Zirconium	120,000	17.77
Niobium	330	0.05			
Nitrogen	49	0.01	**Totals**	**668,637**	**99.99**

a. Source: DOE (1992, page 1.1-1).

b. To convert grams to ounces, multiply by 0.035274.

c. Table only includes elements that constitute at least 0.01 percent of the total; therefore, the total of the percentage column is slightly less than 100 percent.

A.2.1.5.4 *Thermal Output*

Heat generation rates are available as a function of spent fuel type, enrichment, burnup, and decay time in the Light-Water Reactor Radiological Database, which is an integral part of the *Characteristics Potential Repository Wastes* (DOE 1992, page 1.1-1). Table A-14 lists the thermal profiles for the typical pressurized-water reactor and boiling-water reactor assemblies from the Light-Water Reactor Radiological Database. For the EIS analysis, the typical thermal profile, applied across the proposed inventory, yields a good approximation of the expected thermal load in the repository. Figure A-6 shows these profiles as a function of time.

Table A-13. Elemental distribution of typical boiling-water reactor fuel.[a]

Element	Grams per assembly[b]	Percent total[c]	Element	Grams per assembly[b]	Percent total[c]
Aluminum	31	0.01	Nitrogen	25	0.01
Americium	220	0.07	Oxygen	25,000	7.82
Barium	390	0.12	Palladium	270	0.09
Cadmium	27	0.01	Plutonium	1,500	0.48
Carbon	36	0.01	Praseodymium	200	0.06
Cerium	430	0.14	Rhodium	79	0.03
Cesium	390	0.12	Rubidium	64	0.02
Chromium	1,900	0.60	Ruthenium	410	0.13
Cobalt	26	0.01	Samarium	160	0.05
Europium	24	0.01	Silicon	80	0.03
Gadolinium	310	0.10	Strontium	110	0.03
Iodine	43	0.01	Technetium	140	0.04
Iron	5,100	1.63	Tellurium	91	0.03
Krypton	62	0.02	Tin	1,600	0.50
Lanthanum	220	0.07	Titanium	83	0.03
Manganese	160	0.05	Uranium	170,000	55.35
Molybdenum	630	0.20	Xenon	950	0.30
Neodymium	730	0.23	Yttrium	81	0.03
Neptunium	97	0.03	Zirconium	96,000	30.52
Nickel	3,000	0.94			
Niobium	29	0.01	**Totals**	**310,698**	**99.94**

a. Source: DOE (1992, page 1.1-1).

b. To convert grams to ounces, multiply by 0.035274.

c. Table only includes elements that contribute at least 0.01 percent of the total; therefore, the total of the percentage column is slightly less than 100 percent.

Table A-14. Typical assembly thermal profiles.[a]

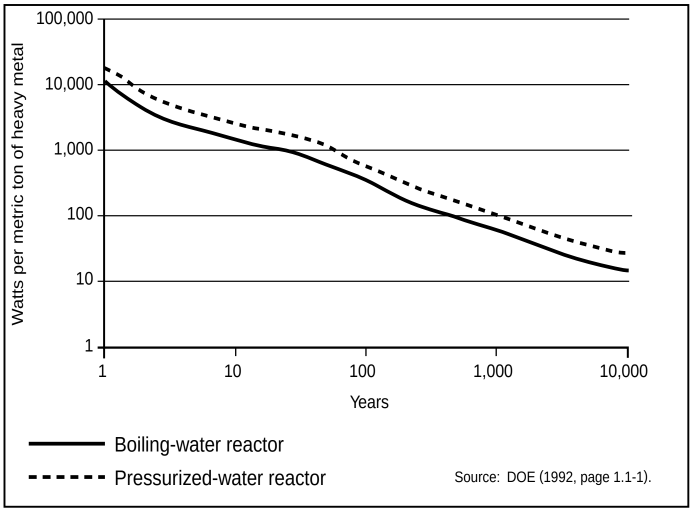
Years after discharge	Pressurized-water reactor		Boiling-water reactor	
	W/MTHM[b]	W/assembly[c]	W/MTHM	W/assembly[d]
1	10,500	4,800	8,400	1,500
3	3,700	1,700	3,000	550
5	2,200	1,000	1,800	340
10	1,500	670	1,200	220
26	990	450	820	150
30	920	420	770	140
50	670	310	570	100
100	370	170	320	58
300	160	73	140	26
500	120	53	100	19
1,000	66	31	58	11
2,000	35	16	30	5
5,000	22	10	19	3
10,000	16	8	13	3

a. Source: DOE (1992, page 1.1-1).

b. W/MTHM = watts per metric ton of heavy metal; to convert metric tons to tons, multiply by 1.1023.

c. W/assembly = watts per assembly; assumes 0.46 MTHM per assembly.

d. Assumes 0.18 MTHM per assembly.



Source: DOE (1992, page 1.1-1).

Figure A-6. Typical thermal profiles over time.

A.2.1.5.5 *Physical Parameters*

Table A-15 lists reference characteristics of typical pressurized-water and boiling-water reactor fuel assemblies. These data are from the *Integrated Data Base Report* (DOE 1997b, page 1-8) and reflect characteristics of unirradiated assemblies.

Table A-15. Reference characteristics for unirradiated typical fuel assemblies.[a]

Characteristics[b]	Boiling-water reactor	Pressurized-water reactor
Overall assembly length (meters)	4.5	4.1
Cross section (centimeters)	14 × 14	21 × 21
Fuel rod length (meters)	4.1	3.9
Active fuel height (meters)	3.8	3.7
Fuel rod outer diameter (centimeters)	1.3	0.95
Fuel rod array	8 × 8	17 × 17
Fuel rods per assembly	63	264
Assembly total weight (kilograms)	320	660
Uranium per assembly (kilograms)	180	460
Uranium oxide per assembly (kilograms)	210	520
Zirconium alloy per assembly (kilograms)	100[c]	110[d]
Hardware per assembly (kilograms)	8.6[e]	26[f]
Nominal volume per assembly (cubic meters)	0.086[g]	0.19[g]

a. Source: DOE (1997b, page 1-8).
b. To convert meters to feet, multiply by 3.2808; to convert centimeters to inches, multiply by 0.3937; to convert kilograms to pounds, multiply by 2.2046; to convert cubic meters to cubic feet, multiply by 35.314.
c. Includes zirconium alloy fuel rod spacers and fuel channels.
d. Includes zirconium alloy control rod guide thimbles.
e. Includes stainless-steel tie plates, Inconel springs, and plenum springs.
f. Includes stainless-steel nozzles and Inconel-718 grids.
g. Based on overall outside dimension; includes spacing between the stacked fuel rods of the assembly.

For additional details, the Light-Water Reactor Assembly Database contains individual physical descriptions of the fuel assemblies and fuel pins. The Light-Water Reactor Nonfuel Assembly Hardware Database contains physical and radiological descriptions of nonfuel assembly hardware. These databases are integral parts of the *Characteristics of Potential Repository Wastes* (DOE 1992, Section 2.8).

A.2.2 DOE SPENT NUCLEAR FUEL

A.2.2.1 Background

At present, DOE stores most of its spent nuclear fuel at three primary locations: the Hanford Site in Washington State, the Idaho National Engineering and Environmental Laboratory in Idaho, and the Savannah River Site in South Carolina. Some DOE spent nuclear fuel is stored at the Fort St. Vrain dry storage facility in Colorado. Much smaller quantities remain at other locations (LMIT 1997, all). DOE issued the *Record of Decision – Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement* on June 1, 1995 (DOE 1995b, all) and amended it in March 1996 (DOE 1996, all). The Record of Decision and its amendment specify three primary locations as storage sites for DOE spent nuclear fuel. With the exception of Fort St. Vrain, which will retain its spent nuclear fuel in dry storage, DOE will ship all its spent nuclear fuel from other sites to one of the three primary sites for storage and preparation for ultimate disposition.

During the last four decades, DOE and its predecessor agencies have generated more than 200 varieties of spent nuclear fuel from weapons production, nuclear propulsion, and research missions. A method described by Fillmore (1998, all) allows grouping of these many varieties of spent nuclear fuel into 16 categories for the repository Total System Performance Assessment. The grouping method uses regulatory requirements to identify the parameters that would affect the performance of DOE spent nuclear fuel in the repository and meet analysis needs for the repository License Application. Three fuel parameters (fuel matrix, fuel compound, and cladding condition) would influence repository performance behavior. The grouping methodology presents the characteristics of a select number of fuel types in a category that either bound or represent a particular characteristic of the whole category. Table A-16 lists these spent nuclear fuel categories.

Table A-16 includes sodium-bonded fuel (Category 14); however, DOE is considering a proposal to treat and manage sodium-bonded spent nuclear fuel for disposal. Alternatives being considered include processing and converting some or all of its sodium-bonded fuel to a high-level radioactive waste form before shipment. Section A.2.3, which covers data associated with high-level radioactive waste, includes data on waste produced from potential future treatment of Category 14 spent nuclear fuel (Dirkmaat 1997b, page 7).

A.2.2.2 Sources

The DOE National Spent Fuel Program maintains a spent nuclear fuel data base (LMIT 1997, all). Table A-16 provides a brief description of each of the fuel categories and a typical fuel. Section A.2.2.5.3 provides more detail on the chemical makeup of each category.

A.2.2.3 Present Storage and Generation Status

Table A-17 lists storage locations and inventory information on DOE spent nuclear fuels. During the preparation of the *Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement* (DOE 1995c, all), DOE evaluated and categorized all the materials listed in the table as spent nuclear fuel, in accordance with the definition in the Nuclear Waste Policy Act, as amended.

Table A-16. DOE spent nuclear fuel categories.[a,b]

	DOE SNF category	Typically from	Description of fuel
1.	Uranium metal	N-Reactor	Uranium metal fuel compounds with aluminum or zirconium alloy cladding
2.	Uranium-zirconium	HWCTR	Uranium alloy fuel compounds with zirconium alloy cladding
3.	Uranium-molybdenum	Fermi	Uranium-molybdenum alloy fuel compounds with zirconium alloy cladding
4.	Uranium oxide, intact	Commercial PWR	Uranium oxide fuel compounds with zirconium alloy or stainless-steel cladding in fair to good condition
5.	Uranium oxide, failed/ declad/aluminum clad	TMI core debris	Uranium oxide fuel compounds: (1) without cladding; (2) clad with zirconium alloy, Hastelloy, nickel-chromium, or stainless steel in poor or unknown condition; or (3) nondegraded aluminum clad
6.	Uranium-aluminide	ATR	Uranium-aluminum alloy fuel compounds with aluminum cladding
7.	Uranium-silicide	FRR MTR	Uranium silicide fuel compounds with aluminum cladding
8.	Thorium/uranium carbide, high-integrity	Fort St. Vrain	Thorium/uranium carbide fuel compounds with graphite cladding in good condition
9.	Thorium/uranium carbide, low-integrity	Peach Bottom	Thorium/uranium carbide fuel compounds with graphite cladding in unknown condition
10.	Plutonium/uranium carbide, nongraphite	FFTF carbide	Uranium carbide or plutonium-uranium carbide fuel compounds with or without stainless-steel cladding
11.	Mixed oxide	FFTF oxide	Plutonium/uranium oxide fuel compounds in zirconium alloy, stainless-steel, or unknown cladding
12.	Uranium/thorium oxide	Shippingport LWBR	Uranium/thorium oxide fuel compounds with zirconium alloy or stainless-steel cladding
13.	Uranium-zirconium hydride	TRIGA	Uranium-zirconium hydride fuel compounds with or without Incalloy, stainless-steel, or aluminum cladding
14.	Sodium-bonded	EBR-II driver and blanket, Fermi-I blanket	Uranium and uranium-plutonium metallic alloy with predominantly stainless-steel cladding
15.	Naval fuel	Surface ship/ submarine	Uranium-based with zirconium alloy cladding
16.	Miscellaneous	Not specified	Various fuel compounds with or without zirconium alloy, aluminum, Hastelloy, tantalum, niobium, stainless-steel or unknown cladding

a. Source: Fillmore (1998, all).

b. Abbreviations: SNF = spent nuclear fuel; HWCTR = heavy-water cooled test reactor; PWR = pressurized-water reactor; TMI = Three Mile Island; ATR = Advanced Test Reactor; FRR MTR = foreign research reactor – material test reactor; FFTF = Fast Flux Test Facility; LWBR = light-water breeder reactor; TRIGA = Training Research Isotopes – General Atomic; EBR-II = Experimental Breeder Reactor II.

A.2.2.4 Final Spent Nuclear Fuel Form

For all spent nuclear fuel categories except 14, the expected final spent nuclear fuel form does not differ from the current or planned storage form. Before its disposal in the repository, candidate material would be in compliance with approved acceptance criteria.

DOE has prepared an EIS at the Savannah River Site (DOE 1998d, all) to evaluate potential treatment alternatives for spent nuclear fuel and its ultimate disposal in the repository. The products of any proposed treatment of the Savannah River Site aluminum-based fuels are adequately represented by the

Table A-17. National Spent Nuclear Fuel Database projection of DOE spent nuclear fuel locations and inventories to 2035.[a,b]

	Fuel category and name	Storage Site	No. of units[c]	Mass (kilograms)[d]	Volume (cubic meters)[e]	Fissile mass (kilograms)	Equivalent uranium mass (kilograms)	MTHM
1.	Uranium metal[f]	INEEL	85	4,500	0.7	13	1,700	1.7
		Hanford	100,000	2,160,000	200	25,000	2,100,000	2100
		SRS	350	120,000	18	110	17,000	17
		Totals	*100,435*	*2,284,500*	*218.7*	*25,123*	*2,118,700*	*2119*
2.	Uranium-zirconium	INEEL	69	120	0.7	34	40	0.04
3.	Uranium-molybdenum	INEEL	29,000	4,600	0.3	970	3,800	3.8
4.	Uranium oxide, intact	INEEL	14,000	150,000	41	2,200	80,000	80
		Hanford	87	44,000	11	240	18,000	18
		Totals	*14,087*	*194,000*	*52*	*2,440*	*98,000*	*99*
5.	Uranium oxide, failed/declad/aluminum clad	INEEL	2,000	340,000	140	2,200	83,000	84
		Hanford	13	270	4.2	4	160	0.2
		SRS	7,600	58,000	96	2,600	3,200	3.2
		Totals	*9,613*	*398,270*	*240.2*	*4,804*	*86,360*	*87*
6.	Uranium-aluminide	SRS	18,000	130,000	150	6,000	8,800	8.7
7.	Uranium-silicide	SRS	7,400	47,000	53	1,200	12,000	12
8.	Thorium/uranium carbide, high-integrity	FSV	1,500	190,000	130	640	820	15
		INEEL	1,600	130,000	82	350	440	9.9
		Totals	*3,100*	*320,000*	*212*	*990*	*1,260*	*25*
9.	Thorium/uranium carbide, low-integrity	INEEL	810	55,000	17	180	210	1.7
10.	Plutonium/uranium carbide, nongraphite	INEEL	130	140	0	10	73	0.08
		Hanford	2	330	0.1	11	64	0.07
		Totals	*132*	*470*	*0.1*	*21*	*137*	*0.2*
11.	Mixed oxide	INEEL	2,000	6,100	2.4	240	2,000	2.1
		Hanford	620	110,000	33	2,400	8,000	10
		Totals	*2,620*	*116,100*	*35.1*	*2,640*	*10,000*	*12*
12.	Uranium/thorium oxide	INEEL	260	120,000	18	810	810	50
13.	Uranium-zirconium hydride	INEEL	9,800	33,000	8.1	460	2,000	2
		Hanford	190	660	33	7	36	0.04
		Totals	*9,990*	*33,660*	*8.3*	*467*	*2,036*	*2*
15.	Naval fuel[g,h]	INEEL	300	4,400,000	888	64,000	65,000	65
16.	Miscellaneous	INEEL	1,500	33,000	11	360	5,500	7.7
		Hanford	73	1,700	0.2	30	130	0.2
		SRS	8,800	9,200	8.2	550	2,900	2.9
		Totals	*10,373*	*43,900*	*19.4*	*940*	*8,530*	*11*
Grand totals			**210,000**	**8,150,000**	**1,900**	**110,000**	**2,420,000**	**2,500**

a. Source: Dirkmaat (1998a, all); individual values and totals rounded to two significant figures.
b. Abbreviations: SNF = spent nuclear fuel; INEEL = Idaho National Engineering and Environmental Laboratory; SRS = Savannah River Site; FSV = Fort St. Vrain.
c. Unit is defined as an assembly, bundle of elements, can of material, etc., depending on the particular spent nuclear fuel category.
d. To convert kilograms to pounds, multiply by 2.2046; to convert metric tons to tons, multiply by 1.1023.
e. To convert cubic meters to cubic yards, multiply by 1.3079.
f. N-Reactor fuel is stored in aluminum or stainless-steel cans at the K-East and K-West Basins. The mass listed in this table does not include the storage cans.
g. Information supplied by the Navy (Dirkmaat 1997a, Attachment, page 2).
h. A naval fuel unit consists of a naval dual-purpose canister that contains multiple assemblies.

properties of the present aluminum-based fuel (Categories 6, 7, and part of 5) for this Yucca Mountain EIS. They are bounded by the same total radionuclide inventory, heat generation rates, dissolution rates, and number of canisters. No additional data about the products will be required to ensure that they are represented in the EIS inventory.

A.2.2.5 Spent Nuclear Fuel Characteristics

A.2.2.5.1 *Mass and Volume*

Table A-17 lists total volume, mass, and MTHM for each DOE spent nuclear fuel category from the National Spent Nuclear Fuel Database (LMIT 1997, all).

A.2.2.5.2 *Amount and Nature of Radioactivity*

ORIGEN2 (Oak Ridge Isotope Generation), an accepted computer code for calculating spent nuclear fuel radionuclide inventories, was used to generate activity data for radionuclides in the DOE spent nuclear fuel inventory. The inventory came from the 1997 version of the National Spent Nuclear Fuel Database (LMIT 1997, all).

Table A-18 lists the activities expressed in terms of curies per handling unit for the radionuclides of interest (uranium, fission products and actinides). The table lists activity estimates decayed to 2030 for all categories except 15. A handling unit for DOE is a spent nuclear fuel canister, while for Category 15 naval fuels, it is a naval dual-purpose canister.

The activity for naval spent nuclear fuel is provided for typical submarine (15a) or surface ship (15b) spent nuclear fuels. Dirkmaat (1997a, Attachment, pages 3 to 5) provided these activities for 5 years after shutdown, which would be the minimum cooling time before naval fuel would reach the repository. The power history assumed operations at power for a full core life. The assumptions about the power history and minimum cooling time conservatively bound the activity for naval fuel that would be emplaced in a monitored geologic repository. In addition, ORIGEN2 was used to calculate the activity associated with activation products in the cladding, which are listed in Table A-18. For completeness, the data also include the activity that would be present in the activated corrosion products deposited on the fuel.

A.2.2.5.3 *Chemical Composition*

This section discusses the chemical compositions of each of the 16 categories of DOE spent nuclear fuel (Dirkmaat 1998a, all).

- *Category 1: Uranium metal.* The fuel in this category consists primarily of uranium metal. N-reactor fuel represents the category because its mass is so large that the performance of the rest of the fuel in the category, even if greatly different from N-Reactor fuel, would not change the overall category performance. The fuel is composed of uranium metal about 1.25 percent enriched in uranium-235, and is clad with a zirconium alloy. Approximately 50 percent of the fuel elements are believed to have failed cladding. This fuel typically has low burnup. Other contributors to this category include the Single Pass Reactor fuel at Hanford and declad Experimental Breeder Reactor-II blanket material at the Savannah River Site.

- *Category 2: Uranium-zirconium.* The fuel in this category consists primarily of a uranium- (91-percent) zirconium alloy. The Heavy Water Components Test Reactor fuel is the representative fuel because it is the largest part of the inventory. This fuel is approximately 85-percent enriched in uranium-235 and is clad with a zirconium alloy.

- *Category 3: Uranium molybdenum.* The fuel in this category consists of uranium- (10 percent)-molybdenum alloy and 25-percent enriched in uranium-235, and is clad with a zirconium alloy. Fermi driver core 1 and 2 are the only fuels in the category. The fuel is currently in an aluminum container. The proposed disposition would include the aluminum container.

Table A-18. Radionuclide activity by DOE spent nuclear fuel category[a] (page 1 of 2).

	Category[c]															
Storage site[b]	1	2	3	4	5	6	7	8	9	10	11	12	13	15a[d]	15b	16
	Number of handling units															
Hanford	440	0	0	34	1	0	0	0	0	2	324	0	3	0	0	5
INEEL	6	8	70	195	406	0	0	503[e]	60	3	43	71	97	200	100	39
SRS	9	0	0	0	425	750	225	0	0	0	0	0	0	0	0	2
Totals	**455**	**8**	**70**	**229**	**832**	**750**	**225**	**503**	**60**	**5**	**367**	**71**	**100**	**200**	**100**	**46**
Radio-nuclide[f]	Curies per handling unit															
Ac-227	2.2×10^{-5}	4.8×10^{-9}	6.9×10^{-6}	1.7×10^{-4}	1.4×10^{-5}	3.4×10^{-7}	2.3×10^{-7}	0	2.8×10^{-3}	8.9×10^{-9}	1.5×10^{-9}	4.3×10^{-1}	5.6×10^{-8}	1.3×10^{-4}	1.6×10^{-4}	6.8×10^{-7}
Am-241	1.1×10^{3}	3.9×10^{-1}	4.6×10^{-5}	1.6×10^{3}	7.3	3.3	3.6×10^{1}	3.7	2.7	2.4×10^{2}	4.3×10^{2}	8.3×10^{-1}	2.0×10^{-1}	4.9×10^{1}	6.7×10^{1}	1.2×10^{2}
Am-242m	6.6×10^{-2}	1.2×10^{-3}	0	2.6	1.4×10^{-2}	2.3×10^{-3}	1.3×10^{-2}	1.0×10^{-3}	1.4×10^{-3}	4.1×10^{-1}	7.5×10^{-1}	8.7×10^{-3}	2.3×10^{-3}	6.6×10^{-1}	8.5×10^{-1}	1.5×10^{-1}
Am-243	2.8×10^{-1}	3.8×10^{-3}	7.3×10^{-13}	8.3	2.2×10^{-2}	2.5×10^{-3}	3.6×10^{-2}	2.7×10^{-2}	1.3×10^{-3}	6.7×10^{-3}	1.8×10^{-1}	1.7×10^{-3}	2.5×10^{-4}	6.2×10^{-1}	1.1	4.9×10^{-1}
C-14	1.5	8.2×10^{-6}	2.2×10^{-3}	1.0×10^{-1}	1.1×10^{-3}	9.9×10^{-7}	1.8×10^{-5}	2.2×10^{-1}	3.7×10^{-2}	1.5×10^{-5}	9.9×10^{-4}	6.7×10^{-1}	8.5×10^{-2}	2.7×10^{1}	4.6×10^{1}	1.7×10^{-3}
Cf-252	--[f]	--	--	--	--	--	--	--	--	--	--	--	--	2.8×10^{-8}	1.4×10^{-7}	--
Cl-36	0	0	5.6×10^{-6}	3.5×10^{-4}	1.7×10^{-5}	0	0	2.7×10^{-3}	1.1×10^{-3}	0	1.1×10^{-5}	1.5×10^{-2}	2.6×10^{-3}	1.0	1.8	4.2×10^{-6}
Cm-242	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	0	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.3\times10^{1}$	$< 7.4\times10^{1}$	1.5	2.2	$< 7.4\times10^{1}$
Cm-243	--	--	--	--	--	--	--	--	--	--	--	--	--	7.4×10^{-1}	2.8×10^{-2}	
Cm-244	8.5	1.6×10^{-1}	6.8×10^{-14}	3.5×10^{2}	9.3×10^{-1}	2.1×10^{-2}	3.0×10^{-1}	8.3×10^{-1}	3.5×10^{-2}	2.8×10^{-1}	7.6	1.6×10^{-1}	6.8×10^{-3}	4.6×10^{1}	9.9×10^{1}	1.9×10^{1}
Cm-245	3.6×10^{-3}	8.0×10^{-6}	1.9×10^{-19}	1.4×10^{-1}	3.8×10^{-4}	1.8×10^{-6}	2.0×10^{-5}	1.4×10^{-4}	4.0×10^{-6}	1.4×10^{-5}	3.1×10^{-3}	3.3×10^{-5}	1.4×10^{-7}	3.8×10^{-3}	9.1×10^{-3}	7.1×10^{-3}
Cm-246	5.3×10^{-4}	5.5×10^{-7}	6.1×10^{-23}	2.4×10^{-2}	6.4×10^{-5}	8.6×10^{-8}	1.5×10^{-6}	6.9×10^{-5}	1.3×10^{-7}	9.7×10^{-7}	5.3×10^{-4}	2.2×10^{-6}	3.9×10^{-9}	6.6×10^{-4}	1.9×10^{-3}	1.2×10^{-3}
Cm-247	--	--	--	--	--	--	--	--	--	--	--	--	--	1.6×10^{-9}	5.1×10^{-9}	--
Cm-248	--	--	--	--	--	--	--	--	--	--	--	--	--	3.1×10^{-9}	1.1×10^{-8}	--
Co-60	1.4×10^{-1}	0	1.1×10^{-2}	1.8×10^{1}	1.6×10^{-12}	1.2×10^{-11}	2.0×10^{-10}	0	2.5×10^{-2}	1.8	1.4	4.3	1.8×10^{-1}	9.0×10^{2}	1.6×10^{3}	7.6×10^{-4}
Cs-134	2.7×10^{-1}	4.6×10^{-2}	1.9×10^{-8}	9.6×10^{-2}	8.3×10^{-3}	1.7×10^{-1}	3.7×10^{-1}	7.6×10^{-3}	3.6×10^{-7}	3.4×10^{-2}	7.5×10^{-3}	6.0×10^{-3}	3.3×10^{-4}	3.1×10^{1}	5.5×10^{1}	5.7×10^{-1}
Cs-135	1.8×10^{-1}	7.7×10^{-3}	4.5×10^{-3}	1.8×10^{-1}	2.9×10^{-2}	2.8×10^{-2}	1.9×10^{-2}	1.7×10^{-2}	2.6×10^{-2}	1.4×10^{-2}	3.2×10^{-3}	2.0×10^{-1}	3.2×10^{-2}	3.9	4.7	1.4×10^{-1}
Cs-137	2.0×10^{4}	7.4×10^{3}	0	2.9×10^{4}	3.6×10^{3}	3.8×10^{3}	8.1×10^{3}	2.4×10^{3}	1.9×10^{3}	1.5×10^{4}	4.0×10^{3}	2.5×10^{3}	3.1×10^{3}	4.4×10^{5}	5.5×10^{5}	8.7×10^{4}
H-3	2.3×10^{1}	4.4	8.6×10^{-2}	3.6×10^{1}	1.3	5.9×10^{-1}	1.3×10^{1}	2.0	1.5	7.3	2.8	2.3×10^{1}	9.6×10^{-1}	1.5×10^{3}	1.8×10^{3}	1.3×10^{1}
I-129	1.6×10^{-2}	1.6×10^{-3}	1.2×10^{-4}	1.8×10^{-2}	7.5×10^{-4}	1.8×10^{-3}	3.8×10^{-3}	2.1×10^{-3}	7.3×10^{-4}	2.9×10^{-3}	3.6×10^{-4}	1.1×10^{-2}	7.2×10^{-4}	1.1×10^{-1}	1.4×10^{-1}	2.3×10^{-2}
Kr-85	3.6×10^{2}	9.3×10^{1}	7.7×10^{-1}	3.1×10^{2}	2.7×10^{1}	1.3×10^{2}	2.6×10^{2}	6.0×10^{1}	7.2	4.8×10^{1}	2.4×10^{1}	6.2×10^{2}	1.7×10^{1}	3.8×10^{4}	4.7×10^{4}	4.2×10^{2}
Nb-93m	8.0×10^{-1}	8.7×10^{-3}	4.6×10^{-3}	6.7×10^{-1}	1.1×10^{-2}	1.6×10^{-2}	3.1×10^{-2}	9.2×10^{-3}	4.6×10^{-2}	1.5×10^{-2}	1.3×10^{-2}	3.1×10^{-1}	7.1×10^{-3}	8.5	1.3×10^{1}	1.7×10^{-1}
Nb-94	5.7×10^{-6}	1.6×10^{-6}	8.4×10^{-4}	7.3×10^{-3}	4.2×10^{-5}	3.1×10^{-6}	7.4×10^{-6}	1.3×10^{-4}	4.9×10^{-4}	2.9×10^{-6}	1.9×10^{-5}	1.6×10^{-2}	4.6×10^{-3}	2.1×10^{2}	3.7×10^{2}	3.5×10^{-5}
Ni-59	8.2×10^{-2}	0	6.9×10^{-3}	9.4×10^{-2}	2.3×10^{-4}	0	0	1.7×10^{-2}	1.5×10^{-3}	0	2.1×10^{-3}	5.1×10^{-2}	5.0×10^{-1}	1.2	2.0	8.2×10^{-4}
Ni-63	7.7	0	1.4×10^{-1}	3.0×10^{2}	2.5×10^{-2}	2.3×10^{-22}	0	4.1×10^{-1}	1.5×10^{-1}	5.0	8.7	6.2	6.2×10^{1}	1.3×10^{2}	2.3×10^{2}	1.0×10^{-1}
Np-237	1.7×10^{-1}	2.0×10^{-2}	3.3×10^{-4}	1.8×10^{-1}	3.1×10^{-3}	1.2×10^{-2}	1.8×10^{-2}	1.6×10^{-2}	7.4×10^{-3}	3.7×10^{-2}	6.5×10^{-3}	7.1×10^{-4}	1.9×10^{-3}	2.9	4.0	2.4×10^{-1}
Pa-231	5.8×10^{-5}	2.3×10^{-7}	2.0×10^{-5}	3.0×10^{-4}	2.6×10^{-5}	4.2×10^{-6}	2.8×10^{-6}	1.9×10^{-2}	4.8×10^{-3}	4.1×10^{-7}	1.2×10^{-7}	1.1	9.0×10^{-7}	6.4×10^{-4}	7.9×10^{-4}	1.0×10^{-5}
Pb-210	3.2×10^{-10}	8.6×10^{-13}	1.4×10^{-10}	9.0×10^{-8}	5.2×10^{-9}	2.1×10^{-11}	1.2×10^{-11}	4.6×10^{-6}	2.6×10^{-7}	1.5×10^{-12}	3.1×10^{-10}	7.8×10^{-5}	1.4×10^{-12}	7.6×10^{-7}	9×10^{-7}	7.510^{-10}

Table A-18. Radionuclide activity by DOE spent nuclear fuel category[a] (page 2 of 2).

Radio-nuclide[f]	Category[b]															
	1	2	3	4	5	6	7	8	9	10	11	12	13	15a[c]	15b	16
	Curies per handling unit															
Pd-107	3.3×10^{-2}	1.1×10^{-3}	1.3×10^{-4}	4.8×10^{-2}	8.3×10^{-4}	9.3×10^{-4}	3.5×10^{-3}	8.7×10^{-4}	4.8×10^{-4}	2.0×10^{-3}	1.0×10^{-3}	2.4×10^{-3}	6.0×10^{-4}	7.9×10^{-2}	9.9×10^{-2}	1.8×10^{-2}
Pu-238	2.5×10^{2}	4.3×10^{1}	1.7×10^{-2}	1.2×10^{3}	5.8	1.7×10^{1}	2.8×10^{1}	8.1×10^{1}	1.8×10^{1}	1.1×10^{2}	7.9×10^{1}	2.8	2.1	1.4×10^{4}	2.3×10^{4}	5.3×10^{2}
Pu-239	5.1×10^{2}	1.1	2.0	1.5×10^{2}	1.3×10^{1}	2.4	2.2×10^{1}	2.3×10^{-1}	4.1×10^{-1}	1.9×10^{2}	3.2×10^{2}	1.8×10^{-1}	4.5	1.3×10^{1}	1.8×10^{1}	5.2×10^{1}
Pu-240	3.0×10^{2}	6.1×10^{-1}	6.1×10^{-3}	2.4×10^{2}	4.4	1.2	1.6×10^{1}	3.8×10^{-1}	3.2×10^{-1}	1.6×10^{2}	2.8×10^{2}	1.0×10-1	1.8	9.9	1.4×10^{1}	3.7×10^{1}
Pu-241	3.8×10^{3}	2.1×10^{2}	6.0×10^{-4}	1.4×10^{4}	2.9×10^{2}	6.3×10^{1}	7.0×10^{2}	0	3.0×10^{1}	1.7×10^{3}	2.6×10^{3}	2.4×10^{1}	1.3×10^{2}	4.2×10^{3}	5.9×10^{3}	3.5×10^{3}
Pu-242	1.6×10^{-1}	9.2×10^{-4}	3.8×10^{-11}	9.1×10^{-1}	3.0×10^{-3}	9.9×10^{-4}	1.6×10^{-2}	0	4.2×10^{-4}	1.6×10^{-3}	2.0×10^{-2}	2.3×10^{-4}	2.5×10^{-4}	5.7×10^{-2}	9.0×10^{-2}	7.0×10^{-2}
Ra-226	4.6×10^{-6}	2.2×10^{-12}	6.5×10^{-10}	2.6×10^{-7}	2.0×10^{-8}	3.8×10^{-10}	2.3×10^{-10}	4.9×10^{-6}	9.3×10^{-7}	2.3×10^{-9}	5.3×10^{-9}	4.5×10^{-5}	2.3×10^{-12}	5.6×10^{-6}	6.3×10^{-6}	4.1×10^{-9}
Ra-228	3.7×10^{-10}	1.2×10^{-13}	4.0×10^{-9}	1.3×10^{-4}	1.1×10^{-5}	7.3×10^{-13}	1.1×10^{-12}	6.5×10^{-3}	2.4×10^{-3}	6.9×10^{-13}	2.0×10^{-11}	7.1×10^{-2}	3.5×10^{-9}	3.0×10^{-7}	5.3×10^{-7}	1.5×10^{-11}
Rh-102	--	--	--	--	--	--	--	--	--	--	--	--	--	1.1	1.5	--
Ru-106	3.1×10^{-5}	6.3×10^{-7}	3.1×10^{-15}	3.9×10^{-7}	1.2×10^{-6}	1.3×10^{-5}	4.2×10^{-5}	3.2×10^{-9}	3.0×10^{-15}	2.6×10^{-6}	3.1×10^{-8}	2.2×10^{-10}	1.5×10^{-9}	4.2	7.1	5.7×10^{-5}
Se-79	2.6×10^{-1}	3.0×10^{-2}	1.7×10^{-3}	1.9×10^{-1}	1.6×10^{-2}	5.0×10^{-2}	1.0×10^{-1}	2.9×10^{-2}	1.4×10^{-2}	5.2×10^{-2}	3.6×10^{-3}	2.5×10^{-1}	1.3×10^{-2}	2.2	2.7	4.7×10^{-1}
Sm-151	3.3×10^{2}	2.7×10^{1}	6.9	5.3×10^{2}	2.5×10^{1}	4.2×10^{1}	3.4×10^{1}	4.5×10^{1}	2.6×10^{1}	1.8×10^{2}	2.4×10^{2}	9.1×10^{1}	2.4×10^{1}	1.2×10^{3}	1.3×10^{3}	3.8×10^{2}
Sn-126	3.5×10^{-1}	2.6×10^{-2}	3.8×10^{-3}	2.4×10^{-1}	1.2×10^{-2}	1.7×10^{-2}	4.1×10^{-2}	1.4×10^{-2}	1.2×10^{-2}	4.7×10^{-2}	4.8×10^{-3}	2.8×10^{-1}	1.2×10^{-2}	1.9	2.4	3.3×10^{-1}
Sr-90	1.6×10^{4}	7.1×10^{3}	0	2.1×10^{4}	3.2×10^{3}	3.7×10^{3}	7.6×10^{3}	2.3×10^{3}	1.8×10^{3}	1.3×10^{4}	1.6×10^{3}	2.6×10^{3}	2.9×10^{3}	4.2×10^{5}	5.2×10^{5}	8.3×10^{4}
Tc-99	7.7	9.9×10^{-1}	4.5×10^{-2}	6.6	4.2×10^{-1}	1.0	2.2	7.4×10^{-1}	4.1×10^{-1}	1.8	1.3×10^{-1}	2.3	4.3×10^{-1}	6.7×10^{1}	8.2×10^{1}	1.4×10^{1}
Th-229	3.9×10^{-8}	1.1×10^{-10}	2.4×10^{-9}	4.0×10^{-4}	3.2×10^{-5}	2.2×10^{-9}	1.2×10^{-9}	2.8×10^{-2}	6.8×10^{-3}	2.5×10^{-10}	1.7×10^{-9}	1.8×10^{-1}	1.2×10^{-9}	6.1×10^{-6}	9.9×10^{-6}	8.7×10^{-9}
Th-230	4.4×10^{-6}	8.6×10^{-9}	1.2×10^{-7}	3.7×10^{-5}	2.9×10^{-6}	1.8×10^{-7}	1.2×10^{-7}	1.9×10^{-3}	1.3×10^{-4}	5.1×10^{-7}	1.2×10^{-6}	6.9×10^{-3}	3.9×10^{-9}	1.9×10^{-3}	2.1×10^{-3}	1.2×10^{-6}
Th-232	5.1×10^{-10}	2.0×10^{-12}	4.3×10^{-9}	1.4×10^{-4}	1.2×10^{-5}	1.9×10^{-11}	3.0×10^{-11}	5.1×10^{-3}	2.5×10^{-3}	4.4×10^{-12}	5.5×10^{-11}	8.4×10^{-2}	1.0×10^{-8}	3.8×10^{-7}	6.6×10^{-7}	9.8×10^{-11}
U-232	9.9×10^{-5}	3.5×10^{-5}	1.9×10^{-6}	0	2.2×10^{-5}	1.7×10^{-4}	1.4×10^{-4}	2.3	2.4×10^{-1}	0	0	7.1×10^{2}	2.4×10^{-5}	3.2×10^{-1}	4.9×10^{-1}	3.5×10^{-4}
U-233	2.5×10^{-5}	9.1×10^{-7}	9.9×10^{-7}	1.6×10^{-1}	1.2×10^{-2}	2.6×10^{-6}	1.8×10^{-6}	6.9	2.6	1.7×10^{-6}	9.3×10^{-7}	1.2×10^{2}	5.6×10^{-6}	1.8×10^{-3}	3.0×10^{-3}	1.6×10^{-5}
U-234	2.0	8.6×10^{-4}	5.0×10^{-4}	1.7×10^{-1}	1.1×10^{-2}	2.2×10^{-3}	1.8×10^{-3}	5.6×10^{-1}	4.4×10^{-1}	4.9×10^{-3}	8.0×10^{-3}	5.9	2.1×10^{-4}	1.7×10^{1}	1.8×10^{1}	1.8×10^{-2}
U-235	8.4×10^{-2}	8.2×10^{-3}	3.2×10^{-2}	1.7×10^{-2}	1.2×10^{-2}	1.8×10^{-2}	1.3×10^{-2}	2.2×10^{-3}	6.8×10^{-3}	1.5×10^{-2}	2.2×10^{-4}	4.0×10^{-4}	9.9×10^{-3}	2.6×10^{-1}	2.5×10^{-1}	1.2×10^{-1}
U-236	3.3×10^{-1}	3.4×10^{-2}	1.7	1.4×10^{-1}	1.2×10^{-2}	3.7×10^{-2}	5.9×10^{-2}	2.1×10^{-2}	1.7×10^{-2}	6.0×10^{-2}	4.1×10^{-3}	8.1×10^{-4}	1.3×10^{-2}	3.3	4.0	4.4×10^{-1}
U-238	1.6	1.5×10^{-4}	1.4×10^{-2}	1.3×10^{-1}	3.4×10^{-2}	8.9×10^{-4}	1.6×10^{-2}	5.4×10^{-5}	7.1×10^{-5}	2.7×10^{-4}	2.7×10^{-3}	1.3×10^{-5}	5.8×10^{-3}	1.1×10^{-3}	1.2×10^{-3}	2.4×10^{-2}
Zr-93	1.0	1.5×10^{-1}	6.7×10^{-3}	9.1×10^{-1}	5.0×10^{-2}	1.0×10^{-1}	2.1×10^{-1}	1.1	6.4×10^{-2}	2.7×10^{-1}	1.7×10^{-2}	5.7×10^{-1}	7.8×10^{-2}	1.8×10^{1}	2.7×10^{1}	1.9

a. Source: Dirkmaat (1998b, all); values are rounded to two significant figures.
b. INEEL = Idaho National Engineering and Environmental Laboratory; SRS = Savannah River Site.
c. Categories 1-13 and 16 decayed to 2030. Category 15 cooled for 5 years.
d. 15a = naval submarine fuel; 15b = naval surface ship fuel.
e. Includes 334 canisters from Fort St. Vrain.
f. -- = not found in appreciable quantities.

- *Category 4: Uranium oxide, intact.* The fuel in this category consists of uranium oxide that has been formed into pellets or plates and clad with a corrosion-resistant material. Commercial fuel is the representative fuel for this category because it is a large part of the inventory. The fuel is made of uranium oxide, some of which is highly enriched in uranium-235 and some of which is low enriched in uranium-235. The fuel elements are clad with a zirconium alloy.

- *Category 5: Uranium oxide, failed/declad/aluminum clad.* The fuel in this category is chemically similar to the fuels in Category 4, except accident or destructive examination has disrupted it. The failed fuel from Three Mile Island Reactor 2 represents this category because it comprises 96 percent of the total MTHM of the category. The Three Mile Island Reactor 2 fuel is melted uranium oxide. The accident greatly disrupted the cladding. Other fuel in this category is declad or has a large amount of cladding damage. Approximately 4 percent consists of intact aluminum clad fuel included in this category because the aluminum cladding is less corrosion resistant than Category 4 cladding material.

- *Category 6: Uranium-aluminide.* This category consists of fuel with a uranium-aluminum compound dispersed in a continuous aluminum metal phase. The fuel is clad with an aluminum alloy. The uranium-235 enrichment varies from 10 to 93 percent.

- *Category 7: Uranium-silicide.* The fuel in this category is a uranium-silicide compound dispersed in a continuous aluminum metal phase. The fuel is clad with an aluminum alloy. The uranium-235 enrichment varies from 8 to 93 percent, but most are less than 20 percent.

- *Category 8: Thorium/uranium carbide, high-integrity.* This category consists of fuels with thorium carbide or uranium carbide formed into particles with a high-integrity coating. Fort St. Vrain Reactor fuel represents the category because it makes up 95 percent of the mass of the category. This fuel is uranium carbide and thorium carbide formed into particles and coated with layers of pyrolytic carbon and silicon carbide. The particles are bonded in a carbonaceous matrix material and emplaced in a graphite block. The fuel was made with uranium enriched to 93 percent in uranium-235. The thorium was used to generate fissile uranium-233 during irradiation. Some fuel does not have a silicon carbide coating, but its effect on the category is very small. Less than 1 percent of the fuel particles are breached.

- *Category 9: Thorium/uranium carbide, low-integrity.* This category consists of fuels with uranium carbide or thorium carbide made into particles with a coating of an earlier design than that described for Category 8. Peach Bottom Unit 1, Core 1 is the only fuel in this category. This fuel is chemically similar to Category 8 fuel except 60 percent of the particle coating is breached. Peach Bottom Unit 1, Core 2 is included in Category 8 because its fuel particles are basically intact and are more rugged than the Peach Bottom Unit 1, Core 1 particles.

- *Category 10: Plutonium/uranium carbide, nongraphite.* This category consists of fuel that contains uranium carbide. Much of it also contains plutonium carbide. Fast Flux Test Facility carbide assemblies represent this category because they make up 70 percent of the category and contain both uranium and plutonium. The Fast Flux Test Facility carbide fuel was constructed from uncoated uranium and plutonium carbide spheres that were loaded directly into the fuel pins, or pressed into pellets that were loaded into the pins. The pins are clad with stainless steel.

- *Category 11: Mixed oxide.* This category consists of fuels constructed of both uranium oxide and plutonium oxide. The Fast Flux Test Facility mixed-oxide test assembly is the representative fuel because it comprises more than 80 percent of the category. The fuels are a combination of uranium oxide and plutonium oxide pressed into pellets and clad with stainless steel or a zirconium alloy. The uranium-235 enrichment is low, but the fissile contribution of the plutonium raises the effective enrichment to 15 percent.

- *Category 12: Uranium/thorium oxide.* This category consists of fuels constructed of uranium oxide and thorium oxide. Shippingport light-water breeder reactor fuel is the representative fuel because it comprises more than 75 percent of the inventory. The Shippingport light-water breeder reactor fuel is made of uranium-233, and the irradiation of the thorium produces more uranium-233. The mixture is pressed into pellets and clad with a zirconium alloy.

- *Category 13: Uranium-zirconium hydride.* This category consists of fuels made of uranium-zirconium hydride. Training Research Isotopes-General Atomic fuels comprise more than 90 percent of the mass of this category. The fuel is made of uranium-zirconium hydride formed into rods and clad primarily with stainless steel or aluminum. The uranium is enriched as high as 90 percent in uranium-235, but most is less than 20 percent enriched.

- *Category 14: Sodium-bonded.* For purposes of analysis in this EIS, it is assumed that all Category 14 fuels would be treated during the proposed electrometallurgical treatment that would result in high-level radioactive waste. The chemical composition of the resulting high-level radioactive waste is described in Section A.2.3. Category 14 is included here for completeness.

- *Category 15: Naval fuel.* Naval nuclear fuel is highly robust and designed to operate in a high-temperature, high-pressure environment for many years. This fuel is highly enriched (93 to 97 percent) in uranium-235. In addition, to ensure that the design will be capable of withstanding battle shock loads, the naval fuel material is surrounded by large amounts of zirconium alloy (Beckett 1998, Attachment 2).

  DOE plans to emplace approximately 300 canisters of naval spent nuclear fuel in the Yucca Mountain repository. There are several different designs for naval nuclear fuel, but all designs employ similar materials and mechanical arrangements. The total weight of the fuel assemblies in a canister of a typical submarine spent reactor fuel, which is representative of the chemical composition of naval spent nuclear fuel, would be 11,000 to 13,000 kilograms (24,000 to 29,000 pounds). Of this total, less than 500 kilograms (1,100 pounds) would be uranium. Approximately 1,000 to 2,000 kilograms (2,200 to 4,400 pounds) of the total weight of these fuel assemblies is from hafnium in the poison devices (primarily control rods) permanently affixed to the fuel assemblies (Beckett 1998, Attachment 2).

  There would be approximately 9,000 to 12,000 kilograms (20,000 to 26,500 pounds) of zirconium alloy in the fuel structure in the typical canister. The typical chemical composition of zirconium alloy is approximately 98 percent zirconium, 1.5 percent tin, 0.2 percent iron, and 0.1 percent chromium (Beckett 1998, Attachment 2).

  The small remainder of the fuel mass in a typical canister of naval submarine spent nuclear fuel [less than 500 kilograms (1,100 pounds)] would consist of small amounts of such metals and nonmetals as fission products and oxides (Beckett 1998, Attachment 2).

- *Category 16: Miscellaneous.* This category consists of the fuels that do not fit into the previous 15 categories. The largest amount of this fuel, as measured in MTHM, is uranium metal or alloy. The other two primary contributors are uranium alloy and uranium-thorium alloy. These three fuel types make up more than 80 percent of the MTHM in the category. It is conservative to treat the total category as uranium metal. Other chemical compounds included in this category include uranium oxide, uranium nitride, uranium alloys, plutonium oxide, plutonium nitride, plutonium alloys, and thorium oxide.

Table A-19 lists the primary materials of construction and chemical composition for each category.

A.2.2.5.4 *Thermal Output*

Table A-20 lists the maximum heat generation per handling unit for each spent nuclear fuel category (Dirkmaat 1997a, Attachment, pages 74 to 77; Dirkmaat 1998b, all). The category 15 (naval fuel) thermal data used the best estimate radionuclide content from Dirkmaat (1997a, Attachment, pages 74 to 77) at a minimum cooling time of 5 years.

A.2.2.5.5 *Quantity of Spent Nuclear Fuel Per Canister*

Table A-21 lists the projected number of canisters required for each site and category. The amount of fuel per canister would vary widely among categories and would depend on a variety of parameters. The average mass of submarine spent nuclear fuel in a short naval dual-purpose canister would be approximately 13 metric tons (14 tons) with an associated volume of 2.7 cubic meters (95 cubic feet). Surface ship spent nuclear fuel in a long naval dual-purpose canister would have an average mass of approximately 18 metric tons (20 tons) and a volume of 3.5 cubic meters (124 cubic feet) (Dirkmaat 1997a, Attachment, pages 86 to 88).

A.2.2.5.6 *Spent Nuclear Fuel Canister Parameters*

The Idaho National Engineering and Environmental Laboratory would use a combination of 46- and 61-centimeter (18- and 24-inch)-diameter stainless-steel canisters for spent nuclear fuel disposition. The Savannah River Site would use 18-inch canisters, and Hanford would use 64-centimeter (25.3-inch) multicanister overpacks and 18-inch canisters. Table A-21 lists the specific number of canisters per site. Detailed canister design specifications for the standard 18- and 24-inch canisters are contained in DOE (1998c, all). Specifications for the Hanford multicanister overpacks are in Parsons (1999, all).

There are two conceptual dual-purpose canister designs for naval fuel: one with a length of 539 centimeters (212 inches) and one with a length of 475 centimeters (187 inches). Both canisters would have a maximum diameter of 169 centimeters (67 inches) (Dirkmaat 1997a, Attachment, pages 86 to 88). Table A-22 summarizes the preliminary design information.

For both designs, the shield plug, shear ring, and outer seal plate would be welded to the canister shell after the fuel baskets were loaded in the canister. The shield plug, shear ring, and welds, along with the canister shell and bottom plug, would form the containment boundary for the disposable container. The shell, inner cover, and outer cover material for the two canisters would be low-carbon austenitic stainless steel or stabilized austenitic stainless steel. Shield plug material for either canister would be stainless steel or another high-density material sheathed in stainless steel (Dirkmaat 1997a, Attachment, pages 86 to 88).

A.2.3 HIGH-LEVEL RADIOACTIVE WASTE

High-level radioactive waste is the highly radioactive material resulting from the reprocessing of spent nuclear fuel. DOE stores high-level radioactive waste at the Hanford Site, the Savannah River Site, and the Idaho National Engineering and Environmental Laboratory. Between 1966 and 1972, commercial chemical reprocessing operations at the Nuclear Fuel Services plant near West Valley, New York, generated a small amount of high-level radioactive waste at a site presently owned by the New York State

Table A-19. Chemical composition of DOE spent nuclear fuel by category (kilograms).[a,b]

	Category														
Fuel	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16
Components															
Uranium	2,120,000	40	3,800	98,000	87,000	8,800	12,000	1,300	210	140	9,900	810	2,000	65,000	8,500
Aluminum	1,700	(c)				18,000	4,200								
Molybdenum			380										9		
Zirconium	140	440		7,500									23,000		
Thorium								27,000	1,500			48,000			2,200
Plutonium										16	2,400				8
Silicon	260						880								
Silicon carbide								53,000							
Carbon	1,200			30				220,000	53,000				1,700		
Cladding and structure															
Aluminum	100		640		18,000	64,000	52,000						11,000		500
Stainless steel				11,000	3,000				8,000	320	2,400	31,000	17,000		20,000
Zirconium alloy	160,000	70	280	64,000	58,000						500	12,000	100	3,600,000	100
Inconel				1,000	1,700										
Container															
Stainless steel	2,640,000	5,600	50,000	165,000	750,000	900,000	270,000	500,000	42,000	3,500	260,000	50,000	70,000	9,900,000	31,000
Aluminum			660		10,000										
Other															
Concrete					30,000[d]										
Boron									29						
Silver					1,100										
Cadmium					34										
Indium					280										
Magnesium									430						
Nickel	210														
Rhodium									30						
Ruthenium									30						
Samarium													67		
Gadolinium					530	950	23								
Hafnium														600,000	

a. Source: Dirkmaat (1998a, all); values are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Blanks indicate none or less than reportable quantities.
d. Low density converters were added to canisters of Three Mile Island Unit 2 fuel and would remain when shipped to the repository.

Table A-20. Maximum heat generation for DOE spent nuclear fuel (watts per handling unit).[a,b]

Category and fuel type	Maximum heat generation
1. Uranium metal	18
2. Uranium zirconium	90
3. Uranium molybdenum	4
4. Intact uranium oxide	1,000
5. Failed/declad/aluminum clad uranium oxide	800
6. Uranium aluminide	480
7. Uranium silicide	1,400
8. High-integrity thorium/uranium carbide	250
9. Low-integrity thorium/uranium carbide	37
10. Nongraphite plutonium/uranium carbide	1,800
11. Mixed oxide	1,800
12. Thorium/uranium oxide	120
13. Uranium zirconium hydride	100
14. Sodium-bonded	N/A[c]
15. Naval fuel	4,250
16. Miscellaneous	1,000

a. Sources: Dirkmaat (1997a, Attachment, pages 74 to 77; Dirkmaat 1998b, all).
b. Handling unit is a canister or naval dual purpose canister.
c. N/A = not applicable. Assumed to be treated and therefore part of high-level radioactive waste inventory (see Section A.2.2.1).

Table A-21. Required number of canisters for disposal of DOE spent nuclear fuel.[a,b]

	Hanford		INEEL		SRS	Naval	
Category	18-inch	25.3-inch	18-inch	24-inch	18-inch	Short DPC[c]	Long DPC
1		440	6		9		
2			8				
3			70				
4	14	20	179	16			
5	1		406		425		
6					750		
7					225		
8			503[d]				
9			60				
10	2		3				
11	324		43				
12			24	47			
13	3		97				
14[e]							
15						200	100
16	5		39		2		
Totals	**349**	**460**	**1,438**	**63**	**1,411**	**200**	**100**

a. Sources: Dirkmaat (1997b, Attachment, page 2); Dirkmaat (1998a, all).
b. INEEL = Idaho National Engineering and Environmental Laboratory; SRS = Savannah River Site.
c. Naval dual-purpose canister.
d. Includes 334 canisters from Fort St. Vrain.
e. Assumed to be treated and therefore part of high-level radioactive waste inventory (see Section A.2.2.1).

Energy Research and Development Authority. These operations ceased after 1972. In 1980, Congress passed the West Valley Demonstration Project Act, which authorizes DOE to conduct, with the Research and Development Authority, a demonstration of solidification of high-level radioactive waste for disposal and the decontamination and decommissioning of demonstration facilities(DOE 1992, Chapter 3). This

Table A-22. Preliminary naval dual-purpose canister design parameters.[a]

Parameter	Short canister	Long canister
Maximum outside diameter (centimeters)[b,c]	169	169
Maximum outer length (centimeters)	475	539
Minimum loaded weight (metric tons)[d]	27	27
Maximum loaded weight (metric tons)	45	45

a. Source: Dirkmaat (1997a, Attachment, pages 86 to 88).
b. To convert centimeters to inches, multiply by 0.3937.
c. Right circular cylinder.
d. To convert metric tons to tons, multiply by 1.1023.

section addresses defense high-level radioactive waste generated at the DOE sites (Hanford Site, Idaho National Engineering and Environmental Laboratory, and Savannah River Site) and commercial high-level radioactive waste generated at the West Valley Demonstration Project.

A.2.3.1 Background

In 1985, DOE published a report in response to Section 8 of the Nuclear Waste Policy Act (of 1982) that required the Secretary of Energy to recommend to the President whether defense high-level radioactive waste should be disposed of in a geologic repository along with commercial spent nuclear fuel. That report, *An Evaluation of Commercial Repository Capacity for the Disposal of Defense High-Level Waste* (DOE 1985, all), provided the basis, in part, for the President's determination that defense high-level radioactive waste should be disposed of in a geologic repository. Given that determination, DOE decided to allocate 10 percent of the capacity of the first repository for the disposal of DOE spent nuclear fuel (2,333 MTHM) and high-level radioactive waste (4,667 MTHM) (Dreyfuss 1995, all; Lytle 1995, all).

Calculating the MTHM quantity for spent nuclear fuel is straightforward. It is determined by the actual heavy metal content of the spent fuel. However, an equivalence method for determining the MTHM in defense high-level radioactive waste is necessary because almost all of its heavy metal has been removed. A number of alternative methods for determining MTHM equivalence for high-level radioactive waste have been considered over the years. Four of those methods are described in the following paragraphs.

Historical Method. Table 1-1 of the 1985 DOE report provided a method to estimate the MTHM equivalence for high-level radioactive waste based on comparing the radioactive (curie) equivalence of commercial high-level radioactive waste and defense high-level radioactive waste. The method relies on the relative curie content of a hypothetical (in the early 1980s) canister of defense high-level radioactive waste from the Savannah River, Hanford, or Idaho site, and a hypothetical canister of vitrified waste from reprocessing of high-burnup commercial spent nuclear fuel. Based on commercial high-level radioactive waste containing 2.3 MTHM per canister (heavy metal has not been removed from commercial waste) and defense high-level radioactive waste estimated to contain approximately 22 percent of the radioactivity of a canister of commercial high-level radioactive waste, defense high-level radioactive waste was estimated to contain the equivalent of 0.5 MTHM per canister. Since 1985, DOE has used this 0.5 MTHM equivalence per canister of defense high-level radioactive waste in its consideration of the potential impacts of the disposal of defense high-level radioactive waste, including the analysis presented in this EIS. With this method, less than 50 percent of the total inventory of high-level radioactive waste could be disposed of in the repository within the 4,667 MTHM allocation for high-level radioactive waste. There has been no determination of which waste would be shipped to the repository, or the order of shipments.

Spent Nuclear Fuel Reprocessed Method. Another method of determining MTHM equivalence, based on the quantity of spent nuclear fuel reprocessed, would be to consider the MTHM in the high-level radioactive waste to be the same as the MTHM in the spent nuclear fuel before it was reprocessed. Using this method, less than 5 percent of the total inventory of high-level radioactive waste could be disposed of in the repository within the 4,667 MTHM allocation for high-level radioactive waste.

Total Radioactivity Method. Another method, the total radioactivity method, would establish equivalence based on a comparison of radioactivity inventory (curies) of defense high-level radioactive waste to that of a standard MTHM of commercial spent nuclear fuel. For this equivalence method the standard spent nuclear fuel characteristics are based on pressurized-water reactor fuel with uranium-235 enrichment of 3.11 percent and 39.65 gigawatt-days per MTHM burnup. Using this method, 100 percent of the total inventory of high-level radioactive waste inventory could be disposed of in the repository within the 4,667 MTHM allocation for high-level radioactive waste.

Radiotoxicity Method. Yet another method, the radiotoxicity method, uses a comparison of the relative radiotoxicity of defense high-level radioactive waste to that of a standard MTHM of commercial spent nuclear fuel, and is thus considered an extension of the total radioactivity method. Radiotoxicity compares the inventory of specific radionuclides to a regulatory release limit for that radionuclide, and uses these relationships to develop an overall radiotoxicity index. For this equivalence, the standard spent nuclear fuel characteristics are based on pressurized-water reactor fuel with uranium-235 enrichment of 3.11 percent, 39.65 gigawatt-days per MTHM burnup. Using this method, 100 percent of the total inventory of high-level radioactive waste could be disposed of in the repository within the 4,667 MTHM allocation for high-level radioactive waste.

A recent report (Knecht et al. 1999, all) describes four equivalence calculation methods and notes that, under the Total Radioactivity Method or the Radiotoxicity Method, all DOE high-level radioactive waste could be disposed of under the Proposed Action. Using different equivalence methods would shift the proportion of high-level radioactive waste that could be disposed of between the Proposed Action and Inventory Module 1 analyzed in Chapter 8, but would not change the cumulative impacts analyzed in this EIS. Regardless of the equivalence method used, the EIS analyzes the impacts from disposal of the entire inventory of high-level radioactive waste in inventory Module 1.

A.2.3.2 Sources

A.2.3.2.1 *Hanford Site*

The Hanford high-level radioactive waste materials discussed in this EIS are those in the Tank Waste Remediation System Disposal Program and include tank waste, strontium capsules, and cesium capsules (Picha 1997, Table RL-1). DOE has not declared other miscellaneous materials or waste at Hanford, either existing or forecasted, to be candidate high-level radioactive waste streams. Before shipment to the repository, DOE would vitrify the high-level radioactive waste into a borosilicate glass matrix and pour it into stainless-steel canisters.

A.2.3.2.2 *Idaho National Engineering and Environmental Laboratory*

The Idaho National Engineering and Environmental Laboratory has proposed three different high-level radioactive waste stream matrices for disposal at the proposed Yucca Mountain Repository—glass, ceramic, and metal. The glass matrix waste stream would come from the Idaho Nuclear Technology and Engineering Center and would consist of wastes generated from the treatment of irradiated nuclear fuels. The Argonne National Laboratory-West proposed electrometallurgical treatment of DOE sodium-bonded fuels would generate both ceramic and metallic high-level radioactive waste matrices. DOE is preparing an EIS [DOE/EIS-0287 (Notice of Intent, 62 *FR* 49209, September 19, 1997)] to support decisions on managing the high-level radioactive waste at the Idaho Nuclear Technology and Engineering Center. DOE is preparing a separate EIS on managing sodium-bonded spent nuclear fuel at Argonne National

Laboratory-West and elsewhere, under which electrometallurgical treatment as well as alternative terminologies are being considered [DOE/EIS-0306 (Notice of Intent, 64 *FR* 8553, February 22, 1999)].

A.2.3.2.3 *Savannah River Site*

Savannah River Site high-level radioactive waste consists of wastes generated from the treatment of irradiated nuclear fuels. These wastes include various chemicals, radionuclides, and fission products that DOE maintains in liquid, sludge, and saltcake forms. The Defense Waste Processing Facility at the Savannah River Site mixes the high-level radioactive waste with glass-forming materials, converts it to a durable borosilicate glass waste form, pours it into stainless-steel canisters, and seals the canisters with welded closure plugs (Picha 1997, Attachment 4, page 2).

Another source of high-level radioactive waste at the Savannah River Site is the immobilized plutonium addressed in Section A.2.4.

A.2.3.2.4 *West Valley Demonstration Project*

The West Valley Demonstration Project is responsible for solidifying high-level radioactive waste that remains from the commercial spent nuclear fuel reprocessing plant operated by Nuclear Fuel Services. The Project mixes the high-level radioactive waste with glass-forming materials, converts it to a durable borosilicate glass waste form, pours it into stainless-steel canisters, and seals the canisters with welded closure plugs.

A.2.3.3 Present Status

A.2.3.3.1 *Hanford Site*

The Hanford Site stores high-level radioactive waste in underground carbon-steel tanks. This analysis assumed that before vitrification, strontium and cesium capsules currently stored in water basins at Hanford would be blended with the liquid high-level radioactive waste. To date, Hanford has immobilized no high-level radioactive waste. Before shipping waste to a repository, DOE would vitrify it into an acceptable glass form. DOE has scheduled vitrification to begin in 2007 with an estimated completion in 2028.

A.2.3.3.2 *Idaho National Engineering and Environmental Laboratory*

Most of the high-level radioactive waste at the Idaho Nuclear Technology and Engineering Center (formerly the Idaho Chemical Processing Plant) is in calcined solids (calcine) stored at the Idaho National Engineering and Environmental Laboratory. The calcine, an interim waste form, is in stainless-steel bins in concrete vaults. Before shipment to a repository, DOE proposes to immobilize the high-level radioactive waste in a vitrified (glass) waste form. The Idaho Nuclear Technology and Engineering Center proposes to implement its vitrification program in 2020 and complete it in 2035 (LMIT 1998, pages A-39 to A-42).

As discussed in Section A.2.2.1, DOE is evaluating treatment of sodium-bonded fuels at Argonne National Laboratory-West. If electrometallurgical treatment were to be chosen, DOE would stabilize the high-level radioactive waste generated from the treatment of its sodium-bonded fuel in the Fuel Conditioning Facility and Hot Fuel Examination Facility into ceramic and metal waste forms in the same facilities. The Radioactive Scrap and Waste Facility at Argonne National Laboratory-West would provide interim storage for these waste forms. There are several technologies being considered for waste treatment (for example, electrometallurgical treatment, melt and dilute, Purex). If a decision was made to implement this proposal, DOE would begin stabilization in 2000.

A.2.3.3.3 *Savannah River Site*

DOE stores high-level radioactive waste in underground tanks in the F- and H-Areas at the Savannah River Site. High-level radioactive waste that has been converted to a borosilicate glass form is stored in the Glass Waste Storage Building in the S-Area. DOE projects completion of the vitrification of the stored high-level radioactive waste by 2022 (Davis and Wells 1997, all).

A.2.3.3.4 *West Valley Demonstration Project*

High-level radioactive waste is stored in underground tanks at the West Valley site. High-level radioactive waste that has been converted into a borosilicate glass waste form is stored in the converted Chemical Process Cell in the Process Building, referred to as the Interim High-Level Radioactive Waste Storage Facility. West Valley plans to complete its vitrification program by the Fall of 2002 (DOE 1992, Chapter 3).

A.2.3.4 Final Waste Form

The final waste form for high-level radioactive waste from the Hanford Site, Savannah River Site, Idaho Nuclear Technology and Engineering Center, and West Valley Demonstration Project would be a vitrified glass matrix in a stainless-steel canister.

The waste forms from Argonne National Laboratory-West could be ceramic and metallic waste matrices depending on decisions to be based on an ongoing EIS. These could be in stainless-steel canisters similar to those used for Savannah River Site and Idaho Nuclear Technology and Engineering Center glass wastes.

A.2.3.5 Waste Characteristics

A.2.3.5.1 *Mass and Volume*

Hanford Site. The estimated volume of borosilicate glass generated by high-level radioactive waste disposal actions at Hanford will be 15,700 cubic meters (554,000 cubic feet); the estimated mass of the glass is 44,000 metric tons (48,500 tons) (Picha 1998a, Attachment 1). The volume calculation assumes that strontium and cesium compounds from capsules currently stored in water basins would be blended with tank wastes before vitrification with no increase in product volume. This volume of glass would require 14,500 canisters, nominally 4.5 meters (15 feet) long with a 0.61-meter (2-foot) diameter (Picha 1998a, Attachment 1).

Idaho National Engineering and Environmental Laboratory. Table A-23 lists the volumes, masses, densities, and estimated number of canisters for the three proposed waste streams.

Savannah River Site. Based on Revision 8 of the High-Level Waste System Plan (Davis and Wells 1997, all), the Savannah River Site would generate an estimated 5,978 canisters of high-level radioactive waste (Picha 1997, Attachment 1). The canisters have a nominal outside diameter of 0.61 meter (2 feet) and a nominal height of 3 meters (10 feet). They would contain a total of approximately 4,240 cubic meters (150,000 cubic feet) of glass. The estimated total mass of high-level radioactive waste for repository disposal would be 11,600 metric tons (12,800 tons) (Picha 1997, Attachment 1). Section A.2.4.5.2.1 addresses the additional high-level radioactive waste canisters that DOE would generate at the

Table A-23. Physical characteristics of high-level radioactive waste at the Idaho National Engineering and Environmental Laboratory.[a,b]

Physical quantities	INTEC glass matrix	ANL-W ceramic matrix	ANL-W metal matrix
Volume (cubic meters)[c]	743	60.0	1.2
Mass (kilograms)[d]	1,860,000	144,000	9,000
Density (kilograms per cubic meter)	2,500	2,400	7,750
Number of canisters [range][e]	1,190	96 [80 - 125]	6 [2 - 10]

a. Sources: Picha (1997, Attachment 1); Goff (1998a, all); Goff (1998b, all).
b. INTEC = Idaho Nuclear Technology and Engineering Center; ANL-W = Argonne National Laboratory-West.
c. To convert cubic meters to cubic yards, multiply by 1.3079.
d. To convert kilograms to pounds, multiply by 2.2046.
e. Canister would be nominally 3 meters (10 feet) by 0.6 meter (2 feet). Canisters would be filled to approximately 0.625 cubic meter (22 cubic feet).

Savannah River Site as a result of immobilizing surplus plutonium. As discussed in that section, 77 additional canisters would be required if the assumed 18 metric tons (20 tons) of plutonium is immobilized. If the entire 50 metric tons (55 tons) of surplus plutonium was immobilized, 210 additional high-level radioactive waste canisters would be required.

West Valley Demonstration Project. The West Valley Demonstration Project will generate between 260 and 300 canisters of high-level radioactive waste. The canisters have a nominal outside diameter of 0.61 meter (2 feet) and a nominal height of 3 meters (10 feet) (Picha 1997, Attachment 1). They will contain approximately 200 cubic meters (7,060 cubic feet) of glass. The estimated total mass of this high-level radioactive waste will be between 540 and 630 metric tons (595 and 694 tons) (Picha 1998c, page 3).

Summary. Table A-24 summarizes the information in the previous paragraphs to provide the total mass and volume projected to be disposed of at the repository.

Table A-24. High-level radioactive waste mass and volume summary.

Parameter	Total[a,b]
Mass	58,000 metric tons
Volume	21,000 cubic meters
Number of canisters	22,147 - 22,280[c]

a. Sources: Picha (1997, Attachment 1); Picha (1998a, Attachment 1).
b. To convert metric tons to tons, multiply by 1.1023; to convert cubic meters to cubic yards, multiply by 1.3079.
c. The number of canisters depends on the amount of surplus weapons-usable plutonium immobilized (see Section A.2.4.5.2.1).

A.2.3.5.2 *Amount and Nature of Radioactivity*

The following paragraphs present radionuclide inventory information for the individual sites. They present the best available data at varying dates; however, in most cases, the data are conservative because the inventories are for dates earlier than the date of disposal, and additional radioactive decay would occur before disposal. Any differences due to varying amounts of radioactive decay are small.

Hanford Site. Table A-25 lists the estimated radionuclide inventory for Hanford high-level radioactive glass waste, including strontium-90 and cesium-137 currently stored in capsules (Picha 1997, Table RL-1). With the exception of hydrogen-3 and carbon-14, this table makes the conservative assumption that 100 percent of a radionuclide in Hanford's 177 tanks and existing capsules is vitrified. Consistent with Hanford modeling for the Integrated Data Base (DOE 1997b, page 2-24), pretreatment and vitrification would separate hydrogen-3 and carbon-14 from the high-level radioactive waste stream such

Table A-25. Radionuclide distribution for Hanford Site high-level radioactive waste.[a,b]

Radionuclide	Total curies	Curies per canister	Radionuclide	Total curies	Curies per canister
Hydrogen-3	--[c]	--	Thorium-229	1.8	1.3×10^{-4}
Carbon-14	9.6×10^{-2}	6.6×10^{-6}	Thorium-230	--	--
Chlorine-36	--	--	Thorium-232	2.1	1.5×10^{-4}
Nickel-59	9.3×10^{2}	6.4×10^{-2}	Protactinium-231	1.6×10^{2}	1.1×10^{-2}
Nickel-63	9.2×10^{4}	6.3	Uranium-232	1.2×10^{2}	8.5×10^{-3}
Cobalt-60	1.2×10^{4}	8.5×10^{-1}	Uranium-233	4.8×10^{2}	3.3×10^{-2}
Selenium-79	7.7×10^{2}	5.3×10^{-2}	Uranium-234	3.5×10^{2}	2.4×10^{-2}
Krypton-85	--	--	Uranium-235	1.5×10^{1}	1.0×10^{-3}
Strontium-90	9.7×10^{7}	6.7×10^{3}	Uranium-236	9.6	6.6×10^{-4}
Niobium-93m	2.7×10^{3}	1.9×10^{-1}	Uranium-238	3.2×10^{2}	2.2×10^{-2}
Niobium-94	--	--	Neptunium-237	1.4×10^{2}	9.7×10^{-3}
Zirconium-93	3.6×10^{3}	2.5×10^{1}	Plutonium-238	2.8×10^{3}	1.9×10^{-1}
Technetium-99	3.3×10^{4}	2.3	Plutonium-239	3.9×10^{4}	2.7
Rhodium-101	--	--	Plutonium-240	8.9×10^{3}	6.2×10^{-1}
Rhodium-102	--	--	Plutonium-241	2.3×10^{5}	1.6×10^{1}
Ruthenium-106	1.0×10^{5}	7.2	Plutonium-242	1.2	8.0×10^{-5}
Palladium-107	--	--	Americium-241	7.0×10^{4}	4.8
Tin-126	1.2×10^{3}	8.2×10^{-2}	Americium-242m	--	--
Iodine-129	3.2×10^{1}	2.2×10^{-3}	Americium-243	9.3	6.4×10^{-4}
Cesium-134	8.9×10^{4}	6.1	Curium-242	7.7×10^{1}	5.3×10^{-3}
Cesium-135	--	--	Curium-243	1.0×10^{1}	6.9×10^{-4}
Cesium-137	1.1×10^{8}	7.7×10^{3}	Curium-244	2.4×10^{2}	1.7×10^{-2}
Samarium-151	2.8×10^{6}	1.9×10^{2}	Curium-245	--	--
Lead-210	--	--	Curium-246	--	--
Radium-226	6.3×10^{-2}	4.4×10^{-6}	Curium-247	--	--
Radium-228	7.7×10^{1}	5.3×10^{-3}	Curium-248	--	--
Actinium-227	8.8×10^{1}	6.0×10^{-3}	Californium-252	--	--

a. Sources: Picha (1997, Table RL-1); Picha (1998a, Attachment 1).
b. Decayed to January 1, 1994.
c. -- = not found in appreciable quantities.

that essentially 0.0 percent and 0.002 percent of each, respectively, would be present in the glass. A large portion of iodine-129 could also be separated, but the analysis assumed a conservative 50-percent retention (Picha 1998a, Attachment 1). Table A-25 uses the estimated number of canisters (14,500) to develop the curies-per-canister value.

Idaho National Engineering and Environmental Laboratory. Table A-26 contains a baseline radionuclide distribution for the three Idaho National Engineering and Environmental Laboratory high-level radioactive waste streams. For each waste stream, the total radionuclide inventory is provided, as is the worst-case value for curies per canister. For Idaho Nuclear Technology and Engineering Center glass, the calculated inventories are decayed to 2035. For Argonne National Laboratory-West waste matrices, the calculated inventories are decayed to 2000.

Savannah River Site. The Waste Qualification Report details the projected radionuclide distribution in the high-level radioactive waste from the Savannah River Site (Plodinec and Marra 1994, page 10). Table A-27 lists the quantities of individual radionuclides in 2015, the expected time of shipment (Pearson 1998, all). The curie-per-canister values were obtained by dividing the total radionuclide projection by the expected number of canisters (5,978).

West Valley Demonstration Project. DOE used the ORIGEN2 computer code to estimate the radionuclide inventory for the West Valley Demonstration Project, simulating each Nuclear Fuel Services

Table A-26. Radionuclide distribution for Idaho National Engineering and Environmental Laboratory high-level radioactive waste.[a,b]

	INTEC glass		ANL-W ceramic[c]		ANL-W metal[c]	
Radionuclides	Total curies for 2035	Curies per canister[d]	Total curies for 2000	Curies per canister[d]	Total curies for 2000	Curies per canister[d]
Hydrogen-3	3.6×10^{3}	4.3	--[e]	--	--	--
Carbon-14	2.8×10^{-2}	8.3×10^{-5}	--	--	4.3	4.3
Chlorine-36	--	--	--	--	--	--
Cobalt-60	3.2×10^{1}	3.6×10^{-2}	--	--	3.2×10^{3}	3.2×10^{3}
Nickel-59	--	--	--	--	1.1×10^{1}	1.1×10^{1}
Nickel-63	--	--	--	--	4.1×10^{2}	3.9×10^{2}
Selenium-79	--	--	--	--	--	--
Krypton-85	--	--	--	--	--	--
Strontium-90	7.0×10^{6}	1.2×10^{4}	7.1×10^{5}	4.7×10^{4}	--	--
Niobium-93	4.7×10^{2}	1.4	--	--	2.9×10^{1}	2.9×10^{1}
Niobium-94	5.4×10^{-3}	1.6×10^{-5}	--	--	2.7	2.7
Zirconium-93	--	--	--	--	--	--
Technetium-99	3.4×10^{3}	9.9	--	--	1.3×10^{2}	1.3×10^{2}
Rhodium-101	--	--	--	--	--	--
Rhodium-102	2.0×10^{-5}	2.2×10^{-8}	--	--	--	--
Ruthenium-106	1.0×10^{-9}	8.7×10^{-13}	--	--	2.1×10^{4}	2.1×10^{4}
Palladium-107	--	--	--	--	--	--
Tin-126	8.9×10^{1}	2.6×10^{-1}	--	--	2.8	2.1
Iodine-129	5.6	1.7×10^{-2}	3.4×10^{-1}	1.8×10^{-2}	--	--
Cesium-134	3.3×10^{-2}	3.6×10^{-5}	7.9×10^{3}	5.1×10^{2}	--	--
Cesium-135	1.6×10^{2}	2.5×10^{-1}	1.6×10^{1}	8.8×10^{-1}	--	--
Cesium-137	6.0×10^{6}	1.2×10^{4}	8.5×10^{5}	5.3×104	--	--
Samarium-151	--	--	--	--	--	--
Lead-210	--	--	--	--	--	--
Radium-226	9.7×10^{-3}	7.2×10^{-5}	3.0×10^{-5}	2.1×10^{-6}	--	--
Radium-228	--	--	--	--	--	--
Actinium-227	--	--	--	--	--	--
Thorium-229	--	--	--	--	--	--
Thorium-230	4.0×10^{-1}	2.8×10^{-3}	4.7×10^{-3}	8.9×10^{-4}	--	--
Thorium-232	9.9×10^{-8}	5.0×10^{-10}	2.3×10^{-9}	1.3×10^{-10}	--	--
Protactinium-231	--	--	--	--	--	--
Uranium-232	4.6×10^{-3}	5.2×10^{-6}	2.6×10^{-3}	1.8×10^{-4}	1.2×10^{-4}	1.2×10^{-4}
Uranium-233	1.3×10^{-3}	6.1×10^{-6}	2.0×10^{-4}	1.4×10^{-5}	5.8×10^{-5}	5.8×10^{-5}
Uranium-234	1.0×10^{2}	1.1×10^{-1}	2.8	1.9×10^{-1}	7.7×10^{-1}	7.7×10^{-1}
Uranium-235	5.9×10^{-1}	6.6×10^{-4}	8.8×10^{-2}	5.9×10^{-3}	2.5×10^{-2}	2.5×10^{-2}
Uranium-236	1.5	1.7×10^{-3}	6.3×10^{-2}	4.2×10^{-3}	1.8×10^{-2}	1.8×10^{-2}
Uranium-238	2.9×10^{-2}	3.3×10^{-5}	2.8×10^{-1}	4.9×10^{-3}	9.7×10^{-2}	8.8×10^{-2}
Neptunium-237	6.3	2.8×10^{-2}	1.3	5.8×10^{-2}	2.4×10^{-5}	2.3×10^{-5}
Plutonium-238	9.0×10^{4}	1.0×10^{2}	3.6×10^{2}	2.9×10^{1}	6.6×10^{-3}	6.6×10^{-3}
Plutonium-239	1.8×10^{3}	2.0	1.7×10^{4}	8.1×10^{2}	3.3×10^{-1}	3.3×10^{-1}
Plutonium-240	1.6×10^{3}	1.8	1.5×10^{3}	6.9×10^{1}	2.9×10^{-2}	2.9×10^{-2}
Plutonium-241	1.9×10^{4}	2.2×10^{1}	1.1×10^{4}	1.3×10^{3}	1.9×10^{-1}	1.9×10^{-1}
Plutonium-242	3.4	3.8×10^{-3}	1.2×10^{-1}	2.3×10^{-2}	2.0×10^{-6}	2.0×10^{-6}
Americium-241	1.3×10^{4}	1.4×10^{1}	1.6×10^{3}	3.4×10^{1}	3.1×10^{-2}	2.1×10^{-2}
Americium-242/242m	1.5×10^{-2}	9.4×10^{-5}	1.4×10^{1}	2.1×10^{-1}	2.7×10^{-4}	2.1×10^{-4}
Americium-243	1.4×10^{-2}	1.1×10^{-4}	2.8×10^{-1}	1.9×10^{-2}	4.8×10^{-6}	4.8×10^{-6}
Curium-242	1.2×10^{-2}	7.7×10^{-5}	1.2×10^{1}	1.8×10^{-1}	2.3×10^{-4}	1.8×10^{-4}
Curium-243	4.7×10^{-4}	3.4×10^{-6}	1.6×10^{-1}	3.1×10^{-3}	3.0×10^{-6}	2.1×10^{-6}
Curium-244	1.0×10^{-2}	7.7×10^{-5}	1.9	1.3×10^{-1}	3.1×10^{-5}	3.1×10^{-5}
Curium-245	3.7×10^{-6}	2.8×10^{-8}	6.8×10^{-5}	4.7×10^{-6}	1.1×10^{-9}	1.1×10^{-9}
Curium-246	8.7×10^{-8}	6.6×10^{-10}	4.2×10^{-7}	2.9×10^{-8}	7.1×10^{-12}	7.1×10^{-12}
Curium-247	3.1×10^{-14}	2.4×10^{-16}	2.4×10^{-13}	1.6×10^{-14}	4.0×10^{-18}	4.0×10^{-18}
Curium-248	9.4×10^{-15}	7.2×10^{-17}	2.6×10^{-14}	1.8×10^{-15}	4.4×10^{-19}	4.4×10^{-19}
Californium-252	--	--	6.5×10^{-19}	1.6×10^{-19}	--	--

a. Sources: Picha (1997, Table ID-2); Goff (1998a, all).

b. INTEC = Idaho Nuclear Technology and Engineering Center; ANL-W = Argonne National Laboratory-West.

c. Matrices based on treating all sodium-bonded fuels. Waste input streams and associated radioactivity for 2000 averaged for total number of canisters produced. Curie values based on calculated data from stored material.

d. Curie per canister values were provided as worst case rather than a homogenous mixture.

e. -- = not found in appreciable quantities.

Table A-27. Radionuclide distribution for Savannah River Site high-level radioactive waste (2015).[a]

Radionuclide	Total (curies)	Curies per canister	Radionuclide	Total (curies)	Curies per canister
Hydrogen-3	--[b]	--	Thorium-229	--	--
Carbon-14	--	--	Thorium-230	2.4×10^{-2}	4.0×10^{-6}
Chlorine-36	--	--	Thorium-232	--	--
Nickel-59	1.1×10^{2}	1.8×10^{-2}	Protactinium-231	--	--
Nickel-63	1.2×10^{4}	2.1	Uranium-232	--	--
Cobalt-60[c]	--	4.5×10^{1}	Uranium-233	--	--
Selenium-79	1.1×10^{3}	1.8×10^{-1}	Uranium-234	1.6×10^{2}	2.7×10^{-2}
Krypton-85	--	--	Uranium-235	--	--
Strontium-90	1.7×10^{8}	2.9×10^{4}	Uranium-236	--	--
Niobium-93m	1.3×10^{4}	2.2	Uranium-238	5.0×10^{1}	8.3×10^{-3}
Niobium-94	--	--	Neptunium-237	4.1×10^{2}	6.8×10^{-2}
Zirconium-93	3.0×10^{4}	5.0	Plutonium-238	3.0×10^{6}	5.0×10^{2}
Technetium-99	1.5×10^{4}	2.5	Plutonium-239	3.7×10^{4}	6.2
Rhodium-101	--	--	Plutonium-240	2.5×10^{4}	4.1
Rhodium-102	--	--	Plutonium-241	3.3×10^{6}	5.4×10^{2}
Ruthenium-106[c]	--	2.4	Plutonium-242	3.5×10^{1}	5.8×10^{-3}
Palladium-107	7.3×10^{1}	1.2×10^{-2}	Americium-241	1.6×10^{5}	2.6×10^{1}
Tin-126	2.6×10^{3}	4.3×10^{-1}	Americium-242m	--	--
Iodine-129	--	--	Americium-243	1.1×10^{3}	1.8×10^{-1}
Cesium-134[c]	--	1.2×10^{1}	Curium-242	--	--
Cesium-135	4.0×10^{2}	6.7×10^{-2}	Curium-243	--	--
Cesium-137	1.5×10^{8}	2.4×10^{4}	Curium-244	4.9×10^{5}	8.3×10^{1}
Samarium-151	3.3×10^{6}	5.5×10^{2}	Curium-245	--	--
Lead-210	--	--	Curium-246	--	--
Radium-226	--	--	Curium-247	--	--
Radium-228	--	--	Curium-248	--	--
Actinium-227	--	--	Californium-252	--	--

a. Sources: Plodinec and Marra (1994, page 10); Pearson (1998, all).
b. -- = not found in appreciable quantities.
c. Total curie content not provided for these nuclides; curie per canister values provided for 10 years after production.

irradiated fuel campaign. A detailed description of the development of these estimates is in the West Valley Demonstration Project Waste Qualification Report (WVNS 1996, WQR-1.2, Appendix 1). Table A-28 lists the estimated activity by nuclide and provides the total curies, as well as the curies per canister, based on 260 canisters.

A.2.3.5.3 *Chemical Composition*

Hanford Site. The Integrated Data Base (DOE 1997b, page 2-29) provides the best available information for the proposed representative chemical composition of future high-level radioactive waste glass from Hanford. Table A-29 combines the percentages by weight of chemical constituents obtained from the Integrated Data Base with the estimated mass to present the expected chemical composition of the glass in terms of mass per chemical compound.

Idaho National Engineering and Environmental Laboratory

Idaho Nuclear Technology and Engineering Center Glass Matrix. This waste stream is composed of three primary sources—zirconium calcine, aluminum calcine, and sodium-bearing waste.

The distribution of these sources is 55 percent, 15 percent, and 30 percent, respectively (Heiser 1998, all). Table A-30 lists the chemical composition of the total waste stream.

Table A-28. Radionuclide distribution for West Valley Demonstration Project high-level radioactive waste (2015).[a]

Radionuclide	Total curies	Curies per canister	Radionuclide	Total curies	Curies per canister
Hydrogen-3	2.0×10^{1}	7.8×10^{-2}	Thorium-229	2.3×10^{-1}	8.9×10^{-4}
Carbon-14	1.4×10^{2}	5.3×10^{-1}	Thorium-230	6.0×10^{-2}	2.3×10^{-4}
Chlorine-36	--[b]	--	Thorium-232	1.6	6.3×10^{-3}
Nickel-59	1.1×10^{2}	4.1×10^{-1}	Protactinium-231	1.5×10^{1}	5.9×10^{-2}
Nickel-63	7.1×10^{3}	2.7×10^{1}	Uranium-232	5.9	2.3×10^{-2}
Cobalt-60	2.9×10^{1}	1.1×10^{-1}	Uranium-233	9.5	3.7×10^{-2}
Selenium-79	6.0×10^{1}	2.3×10^{-1}	Uranium-234	5.0	1.9×10^{-2}
Krypton-85	--	--	Uranium-235	1.0×10^{-1}	3.9×10^{-4}
Strontium-90	3.7×10^{6}	1.4×10^{4}	Uranium-236	3.0×10^{-1}	1.1×10^{-3}
Niobium-93m	2.5×10^{2}	9.5×10^{-1}	Uranium-238	8.5×10^{-1}	3.3×10^{-3}
Niobium-94	--	--	Neptunium-237	2.4×10^{1}	9.2×10^{-2}
Zirconium-93	2.7×10^{2}	1.1	Plutonium-238	7.0×10^{3}	2.7×10^{1}
Technetium-99	1.7×10^{3}	6.5	Plutonium-239	1.7×10^{3}	6.4
Rhodium-101	--	--	Plutonium-240	1.2×10^{3}	4.7
Rhodium-102	--	--	Plutonium-241	2.5×10^{4}	9.5×10^{1}
Ruthenium-106	5.0×10^{-7}	1.9×10^{-9}	Plutonium-242	1.7	6.4×10^{-3}
Palladium-107	1.1×10^{1}	4.2×10^{-2}	Americium-241	5.3×10^{4}	2.0×10^{2}
Tin-126	1.0×10^{2}	4.0×10^{-1}	Americium-242m	2.7×10^{2}	1.0
Iodine-129	2.1×10^{-1}	8.1×10^{-4}	Americium-243	3.5×10^{2}	1.3
Cesium-134	1.2	4.4×10^{-3}	Curium-242	2.2×10^{2}	8.4×10^{-1}
Cesium-135	1.6×10^{2}	6.2×10^{-1}	Curium-243	7.3×10^{1}	2.8×10^{-1}
Cesium-137	4.1×10^{6}	1.6×10^{4}	Curium-244	2.9×10^{3}	1.1×10^{1}
Samarium-151	7.0×10^{4}	2.7×10^{2}	Curium-245	8.8×10^{-1}	3.4×10^{-3}
Lead-210	--	--	Curium-246	1.0×10^{-1}	3.9×10^{-4}
Radium-226	--	--	Curium-247	--	--
Radium-228	1.6	6.3×10^{-3}	Curium-248	--	--
Actinium-227	1.2×10^{1}	4.6×10^{-2}	Californium-252	--	--

a. Source: WVNS (1996, WQR-1.2, Appendix 1).

b. -- = not found in appreciable quantities.

Table A-29. Expected chemical composition of Hanford high-level radioactive waste glass (kilograms).[a,b]

Compound	Mass	Compound	Mass
Aluminum oxide	4,100,000	Sodium oxide	5,190,000
Boron oxide	3,090,000	Sodium sulfate	44,000
Bismuth trioxide	510,000	Nickel monoxide	480,000
Calcium oxide	370,000	Phosphorous pentaoxide	690,000
Ceric oxide	500,000	Lead monoxide	62,000
Chromic oxide	160,000	Silicon oxide	20,300,000
Ferric oxide	1,980,000	Strontium oxide	79,000
Potassium oxide	75,000	Thorium dioxide	4,400
Lanthanum oxide	48,000	Uranium oxide	2,940,000
Lithium oxide	880,000	Zirconium dioxide	1,630,000
Manganese dioxide	510,000	Other	75,000
Sodium fluoride	280,000	**Total**	**44,000,000**

a. Sources: DOE (1997b, page 2-29); Picha (1998a, Attachment 1).

b. To convert kilograms to pounds, multiply by 2.2046.

Argonne National Laboratory-West Ceramic and Metal Matrices. Electrometallurgical processing of DOE spent nuclear fuel containing thermal-bond sodium would result in two high-level radioactive waste forms for repository disposal, depending on decisions to be based on an going EIS [DOE/EIS-0306

Table A-30. Expected glass matrix chemical composition at Idaho Nuclear Technology and Engineering Center (kilograms).[a,b]

Compound or element	Mass	Compound or element	Mass
Aluminum oxide	130,000	Silicon oxide	1,020,000
Ammoniummolybdophosphate	26,000	Zirconium dioxide	18,000
Boron oxide	200,000	Arsenic	100
Calcium fluoride	140,000	Cadmium	42,000
Calcium oxide	4,100	Chromium	14,000
Ceric oxide	300	Mercury[c]	200
Ferric oxide	800	Nickel	1,400
Sodium oxide	250,000	Lead	1,800
Phosphorous pentaoxide	1,000	**Total[d]**	**1,860,000**

a. Sources: Picha (1997, Table ID-3); Heiser (1998, all).
b. Masses are rounded to the nearest 100 kilograms; to convert kilograms to pounds, multiply by 2.2046.
c. Assumes only 0.1 percent capture of original mercury in the feed materials.
d. Trace amounts of antimony, beryllium, barium, selenium, silver, and thallium were also reported.

(Notice of Intent, 64 *FR* 8553, February 22, 1999)]. The first form would be a glass-bonded ceramic composite.

It would stabilize the alkali, alkaline earth, lanthanide, halide, and transuranic materials in processed spent nuclear fuel. These elements would be present as halides after fuel treatment. For disposal, these compounds would be stabilized in a zeolite-based material (Goff 1998a, all).

The chemical formula for zeolite-4A, the typical starting material, is $Na_{12}[(AlO_2)_{12}(SiO_2)_{12}]$. In the waste form, zeolite would contain approximately 10 to 12 percent of the halide compounds by weight. The zeolite mixture typically would be combined with 25-percent glass frit by weight, placed in a stainless-steel container, and processed into a solid monolith using a hot isostatic press. The zeolite would convert to the mineral sodalite in the process (Goff 1998a, all). Table A-31 lists the composition of the waste form.

Table A-31. Expected ceramic waste matrix chemical composition at Argonne National Laboratory-West (kilograms).[a,b]

Component	Mass	Component	Mass
Zeolite-4A	92,000	Potassium iodide	10
Silicon oxide	24,000	Cesium chloride	160
Boron oxide	6,800	Barium chloride	70
Aluminum oxide	2,500	Lanthium chloride	90
Sodium oxide	2,700	Ceric chloride	140
Potassium oxide	140	Praseodymium chloride	70
Lithium-potassium chloride	13,000	Neodymium chloride	240
Sodium chloride	980	Samarium chloride	40
Rubidium chloride	20	Yttrium chloride	60
Strontium chloride	70	**Total[c]**	**144,000**

a. Source: Goff (1998a, all).
b. To convert kilograms to pounds, multiply by 2.2046.
c. Includes trace amounts of potassium bromide and europium chloride.

The halide composition would depend on the fuel processed. The final bulk composition of the ceramic waste form by weight percentages would be 25 percent glass, 63 to 65 percent zeolite-4A, and 10 to 12 percent halide salts.

Table A-32 lists the estimated composition of the second high-level radioactive waste form, which is a metal matrix waste form. The table combines percentage weight distribution with the total expected mass of the metal waste form to achieve a distributed mass by element (Goff 1998a, all).

Savannah River Site. Fowler et al. (1995, page 4) describes the chemical composition of the Defense Waste Processing Facility glass in detail. Table A-33 lists the distributed mass of the chemical constituents that comprise the current design-basis glass for the Savannah River Site. These values are based on a total mass of the glass of 11,600 metric tons (12,800 tons) (Picha 1997, Attachment 1).

West Valley Demonstration Project. The West Valley Demonstration Project will produce a single type of vitrified high-level radioactive waste. WVNS (1996, WQR-1.1, page 7) provides a target composition for all chemical constituents in the high-level radioactive waste. Table A-34 lists the expected chemical composition based on this target composition and the upper range of the projected total glass mass, 630 metric tons (694 tons).

Table A-32. Expected metal waste matrix chemical composition at Argonne National Laboratory-West (kilograms).[a]

Component	Mass
Iron	4,200
Chromium	1,500
Nickel	1,100
Manganese	180
Molybdenum	220
Silicon	90
Zirconium	1,400
NMFPs[b]	360
Others[c]	20
Total	**9,000**

a. Source: Goff (1998a, all); to convert kilograms to pounds, multiply by 2.2046.

b. NMFPs = Noble metal fission products; includes silver, niobium, palladium, rhodium, ruthenium, antimony, tin, tantalum, technetium, and cobalt in small amounts.

c. Others include trace amounts of carbon, phosphorus, and sulfur.

A.2.3.5.4 *Thermal Output*

Hanford Site. The estimated total thermal power from radioactive decay in the 14,500 reference canisters would be 1,190 kilowatts (as of January 1, 1994). This total heat load equates to an average power of 82 watts per canister. These values represent the hypothetical situation in which washed sludges from 177 tanks, cesium concentrates from the decontamination of low-level supernates, and strontium and cesium materials from capsules would be uniformly blended before vitrification. Realistically, uniform blending would not be likely. Current planning calls for merging all capsule materials with tank wastes from 2013 through 2016, which would create much hotter canisters during these years. In the extreme, the nonuniform blending of cesium concentrates and capsule materials into a relatively small volume of sludge waste could produce a few canisters with specific powers as high as 2,540 watts, which is the limit for the nominally 4.5-meter (15-foot) Hanford canisters in the Civilian Radioactive Waste Management System Baseline (Picha 1997, Attachment 1, page 2; Taylor 1997, all).

Table A-33. Expected Savannah River Site high-level radioactive waste chemical composition (kilograms).[a,b]

Glass component	Mass	Glass component	Mass
Aluminum oxide	460,000	Sodium chloride	22,000
Barium sulfate	31,000	Neodymium	13,000
Calcium oxide	110,000	Nickel monoxide	100,000
Calcium sulfate	9,300	Neptunium	100
Cadmium	140	Promethium	210
Cerium	6,800	Praseodymium	3,300
Chromic oxide	14,000	Rubidium	120
Cesium oxide	14,000	Selenium	270
Copper oxide	51,000	Silicon oxide	5,800,000
Europium	200	Samarium	2,200
Ferric oxide	1,200,000	Tin	120
Potassium oxide	450,000	Tellurium	2,200
Lanthanum	3,500	Thorium dioxide	22,000
Lithium oxide	510,000	Titanium dioxide	100,000
Magnesium oxide	160,000	Uranium oxide	250,000
Manganese oxide	230,000	Zirconium	13,000
Molybdenum	14,000	Other[c]	58,000
Sodium oxide	1,000,000		
Sodium sulfate	12,000	**Total**	**11,600,000**

a. Sources: Fowler et al. (1995, page 4); Picha (1997, Attachment 1).
b. To convert kilograms to pounds, multiply by 2.2046.
c. Includes trace amounts of silver, americium, cobalt, and antimony.

Table A-34. Expected West Valley Demonstration Project chemical composition (kilograms).[a,b]

Compound	Mass	Compound	Mass
Aluminum oxide	38,000	Nickel monoxide	1,600
Boron oxide	82,000	Phosphorous pentaoxide	7,600
Barium oxide	1,000	Rubidium oxide	500
Calcium oxide	3,000	Silicon oxide	260,000
Ceric oxide	2,000	Strontium oxide	100
Chromic oxide	900	Thorium dioxide	23,000
Ferric oxide	76,000	Titanium dioxide	4,300
Potassium oxide	32,000	Uranium oxide	3,000
Lithium oxide	24,000	Zinc oxide	100
Magnesium oxide	5,600	Zirconium dioxide	7,100
Manganese oxide	5,200	Others	3,900
Sodium oxide	51,000		
Neodymium oxide	900	**Total**	**630,000**

a. Sources: WVNS (1996, WQR-1.1, page 7); Picha (1998c, page 3).
b. To convert kilograms to pounds, multiply by 2.2046.

Idaho National Engineering and Environmental Laboratory. The Laboratory has three proposed high-level radioactive waste streams. Table A-35 lists the thermal output of these waste streams per waste canister.

Savannah River Site. The radionuclide inventories reported for the Savannah River Site high-level radioactive waste in Section A.2.3.5.2 were used to calculate projected heat generation rates for single canisters.

For the design-basis waste form, the heat generation rates 10 and 20 years after production are 465 and 302 watts per canister, respectively (Plodinec, Moore, and Marra 1993, pages 8 and 9).

Table A-35. Idaho National Engineering and Environmental Laboratory waste stream thermal output (watts).[a,b]

Output per waste canister	INTEC glass matrix	ANL-W ceramic matrix	ANL-W metal matrix
Average[c]	7.1	160	170
Worst case [d]	180	620	410

a. Source: Picha (1997, Attachment 1, page 2).

b. INTEC = Idaho Nuclear Technology and Engineering Center; ANL-W = Argonne National Laboratory-West.

c. Based on average case; 2035 used as base year for Idaho Nuclear Technology and Engineering Center glass and 2000 for ANL-W matrices.

d. Based on worst case; 2020 used as base year for Idaho Nuclear Technology and Engineering Center glass and 2000 for ANL-W matrices.

West Valley Demonstration Project. West Valley has calculated heat generation rates for a nominal West Valley canister after several different decay times (WVNS 1996, WQR-3.8, page 2). In the nominal case, the ORIGEN2-computed heat generation rate was 324 watts at the calculational base time in 1988. The heat generation rate would decrease continuously from 324 watts to about 100 watts after 50 years of additional decay.

A.2.3.5.5 *Quantity of Waste Per Canister*

Table A-36 lists the estimated mass of glass per waste canister for each high-level radioactive waste stream.

Table A-36. Mass of high-level radioactive waste glass per canister (kilograms).[a]

Waste stream[b]	Mass per canister	Source
Hanford	3,040	Picha (1997, Attachment 1, page 2)
INEEL		
INTEC	1,560	Picha (1997, Attachment 1, page 2)
ANL-W ceramic[c]	960 - 1,500	Goff (1998a, all)
ANL-W metal[c]	1,500 - 4,850	Goff (1998a, all)
Savannah River Site	2,000	Pearson (1998, all)
WVDP	2,000	Picha (1997, Attachment 1, page 2)

a. To convert kilograms to pounds, multiply by 2.2046.

b. INEEL = Idaho National Engineering and Environmental Laboratory; INTEC = Idaho Nuclear Technology and Engineering Center; ANL-W = Argonne National Laboratory-West; WVDP = West Valley Demonstration Project.

c. These values are estimates. ANL-W is evaluating waste package configurations compatible with existing storage and remote hot cell facilities. The geometries would be compatible with the Defense Waste Processing Facility high-level radioactive waste canister.

A.2.3.5.6 *High-Level Radioactive Waste Canister Parameters*

Hanford Site. Table A-37 lists preliminary physical parameters for a Hanford Tank Waste Remediation System standard canister (Picha 1997, Table RL-3).

Idaho National Engineering and Environmental Laboratory. The Idaho Nuclear Technology and Engineering Center would use stainless-steel canisters identical in design to those used at the Savannah River Site in the Defense Waste Processing Facility. A similar canister would also be used to contain the ceramic and metal waste matrices resulting from the proposed high-level radioactive waste processing at Argonne National Laboratory-West (Picha 1997, Table ID-1).

Table A-37. Parameters of proposed Tank Waste Remediation System standard canister for Hanford high-level radioactive waste disposal.[a]

Parameter	Value[b]	Comments[c]
Length	4.50 meters	1.5 meters longer than DWPF and WVDP canisters - nominal 4.5-meter length
Outer diameter	0.61 meter	Same as DWPF and WVDP canisters
Material	304 stainless steel	Same as DWPF and WVDP canisters
Wall thickness	0.95 centimeter	Same as DWPF
Canister weight	720 kilograms	
Flange opening	0.41 meters	Same as WVDP canister; large opening
Dished bottom	Yes	Same as DWPF and WVDP
Available volume	1.2 cubic meters	
Nominal percent fill	90 percent	Provides approximately same void volume as WVDP canister
Glass volume	1.1 cubic meters	

a. Source: Picha (1997, Table RL-3).

b. To convert meters to feet, multiply by 3.2808; to convert centimeters to inches, multiply by 0.3937; to convert kilograms to tons, multiply by 0.0011023; to convert cubic meters to cubic feet, multiply by 35.314.

c. DWPF = Defense Waste Processing Facility; WVDP = West Valley Demonstration Project.

Savannah River Site. The fabrication specifications of the Defense Waste Processing Facility high-level radioactive waste canisters are described in detail in Marra, Harbour, and Plodinec (1995, all). The canisters are fabricated from four basic pieces of A240 304L austenitic stainless steel—the main cylinder, the bottom head, the top head, and a nozzle. The nominal wall thickness of the canister is 0.95 centimeter (0.37 inch).

West Valley Demonstration Project. The West Valley canister is designed, fabricated, and handled in accordance with the specifications in the West Valley Demonstration Project Waste Qualification Report (WVNS 1996, WQR-2.2, all). The West Valley canisters are fabricated from four principal 304L austenitic stainless-steel components. The nominal wall thickness of the canister is 0.34 centimeter (0.13 inch).

A.2.3.5.7 *Nonstandard Packages*

Each site that would ship high-level radioactive waste to the repository has provided additional data on an estimate of nonstandard packages for possible inclusion in the candidate waste material. The mass, volume, and radioactivity of potential nonstandard packages would be dominated by failed melters from the vitrification facilities. Final disposition plans for these melters are in development and vary from site to site. The EIS used the following assumptions to estimate the potential inventory.

Hanford Site. DOE could need to ship such nonstandard high-level radioactive waste packages as failed melters and failed contaminated high-level radioactive waste processing equipment to the repository. For this EIS, the estimated volume of nonstandard packages available for shipment to the repository from the Hanford Site would be equivalent to that described below for the Savannah River Site.

Idaho National Engineering and Environmental Laboratory. DOE proposes to treat and dispose of nonstandard packages under existing regulations. However, to bound the number of failed melters the Idaho National Engineering and Environmental Laboratory could ship to the repository, this EIS uses the same ratio of failed melters to the number of canisters produced as the Savannah River Site (Palmer 1997, page 2). The Idaho National Engineering and Environmental Laboratory would produce approximately 20 percent of the number of canisters produced at the Savannah River Site, which assumes 10 failed melters. Therefore, the Idaho National Engineering and Environmental Laboratory assumes two failed melters. The volumes and other parameters would then be twice the values listed in Table A-38 for an individual melter.

Table A-38. Parameters of nonstandard packages from Savannah River Site.[a]

Parameter	Value
Volume	10 melters based on current planning to 2021
Activity	4.5 equivalent DWPF[b] canisters for each melter
Mass	1,000 metric tons[c] for 10 melters (filled melter: 100 metric tons)
Chemical composition	Glass (see Section A.2.3.5.3) Melter – Refractory brick Aluminum Stainless steel Inconel
Quantity per disposal package	1 melter per disposal package
Thermal generation	4.5 times the heat generation of a single canister for each melter

a. Source: Pearson (1997, Attachment 1, pages 3 and 4).
b. DWPF = Defense Waste Processing Facility.
c. To convert metric tons to tons, multiply by 1.1023.

Savannah River Site. Table A-38 lists the estimated parameters of nonstandard packages for repository shipment from the Savannah River Site.

West Valley Demonstration Project. The West Valley Demonstration Project anticipates that it would send only one melter to the repository at the end of the waste solidification campaign. It would be treated as a nonstandard waste package. Table A-39 lists the estimated parameters of nonstandard packages from the West Valley Demonstration Project.

Table A-39. Parameters of nonstandard packages from West Valley Demonstration Project.[a]

Parameter	Value[b]
Volume	1 melter (24 cubic meters)
Activity	1.1 equivalent West Valley canisters
Mass	52 metric tons
Chemical composition	Melter refractories (38 metric tons) Inconel (11 metric tons) Stainless steel (1.6 metric tons) Glass (see Table A-34)
Quantity per disposal package	1 melter per package
Thermal generator	1.1 times the heat generation of a single canister (A.2.3.5.4)

a. Source: Rowland (1997, all).
b. To convert cubic meters to cubic feet, multiply by 35.314; to convert metric tons to tons, multiply by 1.1023.

A.2.4 SURPLUS WEAPONS-USABLE PLUTONIUM

A.2.4.1 Background

The President has declared approximately 50 metric tons (55 tons) of weapons-usable plutonium to be surplus to national security needs (DOE 1998a, page 1-1). This material includes the following:

- Purified plutonium in various forms (metal, oxide, etc.)
- Nuclear weapons components (pits)

- High-purity materials that DOE could process in the future to produce purified plutonium
- Plutonium residues that DOE previously saved for future recovery of purified plutonium

These materials are currently stored at the Pantex Plant, the Rocky Flats Environmental Technology Site, the Savannah River Site, the Hanford Site, the Idaho National Engineering and Environmental Laboratory (Argonne National Laboratory-West), and the Oak Ridge, Los Alamos, and Lawrence Livermore National Laboratories. DOE would draw the specific surplus weapons-usable plutonium it ultimately disposed of from the larger inventory primarily stored at these sites.

DOE could process the surplus weapons-usable plutonium as two material streams. One stream would be an immobilized plutonium ceramic form that DOE would dispose of using a can-in-canister technique with high-level radioactive waste. The second stream would be mixed uranium and plutonium oxide fuel assemblies that would be used for power production in light-water reactors and disposed of as commercial spent nuclear fuel. The Surplus Plutonium Disposition Environmental Impact Statement (DOE 1998a, page 1-1) evaluates the quantity of plutonium processed in each stream. This EIS assumes that approximately 18 metric tons (20 tons) of surplus weapons-usable plutonium would be immobilized and approximately 32 metric tons (35 tons) would be made into mixed-oxide commercial nuclear fuel. The actual split could include the immobilization of between 18 and 50 metric tons (55 tons).

A.2.4.2 Sources

DOE would produce the immobilized plutonium and/or mixed-oxide fuel at sites determined in a Record of Decision for the Surplus Plutonium Disposition Environmental Impact Statement (DOE 1998a, page 1-9). The Department has selected for further environmental review six alternative commercial light-water reactors in which it proposes to irradiate the mixed-oxide fuel: both units at Catawba in York, South Carolina; both units at McGuire in Huntersville, North Carolina; and both units at North Anna Power Station in Mineral Springs, Virginia (DOE 1999, all).

A.2.4.3 Present Storage and Generation Status

DOE would begin production of the immobilized plutonium in 2006 with an estimated completion by 2016. The immobilization of 18 metric tons (20 tons) of plutonium would produce an estimated 77 additional canisters of high-level radioactive waste, which the production location would store until shipment to the repository. The immobilization of 50 metric tons (55 tons) of plutonium would produce an estimated 210 additional canisters of high-level radioactive waste. This EIS assumes that the production location would be the Savannah River Site and, therefore, used the physical dimensions of the Defense Waste Processing Facility canisters to calculate these values (DOE 1998a, pages 2-26 and 2-27).

Commercial light-water reactors would use mixed-oxide fuel assemblies for power production starting as early as 2007. This fuel would replace the low-enriched uranium fuel that normally would be in the reactors. After the fuel assemblies were discharged from the reactors as spent mixed-oxide fuel, the reactor sites would store them until shipment to the repository. Mixed-oxide fuel use would produce an insignificant number of additional spent nuclear fuel assemblies (less than 0.1 percent) (DOE 1998a, page 4-378).

A.2.4.4 Final Waste Form

The final waste form would be immobilized plutonium or spent mixed-oxide fuel. Section A.2.4.5 discusses the characteristics of these materials. The spent mixed-oxide fuel discussed here has different characteristics than the mixed-oxide fuel included in the National Spent Fuel Program (LMIT 1997, all) and described in Section A.2.2.

A.2.4.5 Material Characteristics

A.2.4.5.1 *Mixed-Oxide Fuel*

A.2.4.5.1.1 Mass and Volume. The EIS on surplus weapons-usable plutonium disposition (DOE 1998a, page 1-9) evaluates the disposal of approximately 32 metric tons (35 tons) of plutonium as mixed-oxide fuel. The amount of plutonium and uranium measured in metric tons of heavy metal going to a repository would depend on the average percentage of plutonium in the fuel. The percentage of plutonium would be influenced by the fuel design. DOE has chosen pressurized-water reactors for the proposed irradiation of these assemblies. For pressurized-water reactors, the expected average plutonium percentages would be approximately 4.6 percent; however, they could range between 3.5 and 6 percent (Stevenson 1997, pages 5 and 6). Table A-40 lists estimates and ranges for the total metric tons of heavy metal (uranium and plutonium) that would result from disposing of 32 metric tons (35 tons) of plutonium in mixed-oxide fuel. The table also lists a corresponding estimate for the number of assemblies required, based on using the typical assemblies described in Section A.2.1.4. The ranges of metric tons of heavy metal account for the proposed range in potential plutonium percentage.

Table A-40. Estimated spent nuclear fuel quantities for disposition of 32 metric tons of plutonium in mixed-oxide fuel.[a,b]

Reactor and fuel type	Plutonium percentage	Best estimate (MTHM)	Assemblies required	Range (MTHM)
Pressurized-water reactor	4.56	700	1,500	500-900

a. Source: Stevenson (1997, pages 5 and 6).

b. MTHM = metric tons of heavy metal; to convert metric tons to tons, multiply by 1.1023.

DOE assumed that each spent mixed-oxide assembly irradiated and disposed of would replace an energy-equivalent, low-enriched uranium assembly originally intended for the repository. The mixed-oxide assemblies would be part of the 63,000 metric tons (69,000 tons) that comprise the commercial spent nuclear fuel disposal amount in the Proposed Action (Person 1998, all). DOE also assumes that the average burnup levels for the pressurized-water reactor would be the same as that for the energy-equivalent, low-enriched uranium fuel. Table A-41 lists the assumed burnup levels and the amount of heavy metal in an assembly.

Table A-41. Assumed design parameters for typical mixed-oxide assembly.[a]

Parameter	Pressurized-water reactor
Mixed-oxide and low-enriched uranium burnup (MWd/MTHM)[b]	45,000
Mixed-oxide assembly mass (kilograms[c] of heavy metal)	450
Mixed-oxide assembly percentage of plutonium	4.56

a. Source: Stevenson (1997, page 7).

b. MWd/MTHM = megawatt days per metric ton of heavy metal; to convert metric tons to tons, multiply by 1.1023.

c. To convert kilograms to pounds, multiply by 2.2046.

The analysis assumed that the mixed-oxide spent nuclear fuel would replace the low-enriched uranium fuel. Because of the similarities in the two fuel types, impacts to the repository would be small. Nuclear criticality, radionuclide release rates, and heat generation comparisons are evaluated in Stevenson (1997, pages 35 to 37).

A.2.4.5.1.2 Amount and Nature of Radioactivity. Tables A-42 and A-43 list isotopic composition data for spent mixed-oxide fuel assemblies. The tables reflect SCALE data files from an Oak Ridge National Laboratory report used with computer simulation to project the characteristics of spent mixed-oxide fuel in pressurized-water reactors (Ryman, Hermann, and Murphy 1998, Volume 3, Appendix B). The tables summarize data for two different potential fuel assemblies: a typical pressurized-water reactor,

Table A-42. Radionuclide activity for typical pressurized-water reactor spent mixed-oxide assembly.[a]

Isotope	Curies per assembly	Isotope	Curies per assembly
Hydrogen-3	2.0×10^{2}	Samarium-151	5.3×10^{2}
Carbon-14	3.4×10^{-1}	Uranium-234	4.9×10^{-2}
Cobalt-60	1.7×10^{3}	Uranium-235	1.0×10^{-3}
Nickel-59	1.1	Uranium-236	6.4×10^{-3}
Nickel-63	1.4×10^{2}	Uranium-238	1.4×10^{-1}
Krypton-85	1.9×10^{3}	Plutonium-238	1.2×10^{3}
Strontium-90	1.7×10^{4}	Plutonium-239	6.6×10^{2}
Zirconium-93	6.5×10^{-2}	Plutonium-240	8.6×10^{2}
Niobium-93m	2.8×10^{1}	Plutonium-241	2.0×10^{5}
Niobium-94	6.8×10^{-1}	Americium-241	2.2×10^{3}
Technetium-99	6.3	Americium-242/242m	3.4×10^{1}
Ruthenium-106	1.6×10^{4}	Americium-243	2.4×10^{1}
Iodine-129	2.1×10^{-2}	Curium-242	6.0×10^{1}
Cesium-134	1.4×10^{4}	Curium-243	3.2×10^{1}
Cesium-137	4.7×10^{4}	Curium-244	2.6×10^{3}

a. Source: Ryman, Hermann, and Murphy (1998, Volume 3, Appendix B).

Table A-43. Radionuclide activity for high-burnup pressurized-water reactor spent mixed-oxide assembly.[a]

Isotope	Curies per assembly	Isotope	Curies per assembly
Hydrogen-3	2.9×10^{2}	Uranium-234	6.8×10^{-2}
Carbon-14	5.4×10^{-1}	Uranium-235	6.7×10^{-4}
Cobalt-60	2.4×10^{3}	Uranium-236	7.7×10^{-3}
Nickel-59	1.7	Uranium-238	1.5×10^{-1}
Nickel-63	2.3×10^{2}	Plutonium-238	2.7×10^{3}
Krypton-85	2.6×10^{3}	Plutonium-239	4.6×10^{2}
Strontium-90	2.4×10^{4}	Plutonium-240	8.8×10^{2}
Niobium-93m	3.9×10^{1}	Plutonium-241	2.2×10^{5}
Niobium-94	9.8×10^{-1}	Americium-241	2.5×10^{3}
Technetium-99	9.0	Americium-242/242m	4.9×10^{1}
Ruthenium-106	1.8×10^{4}	Americium-243	5.6×10^{1}
Iodine-129	3.0×10^{-2}	Curium-242	1.0×10^{2}
Cesium-134	2.5×10^{4}	Curium-243	8.5×10^{1}
Cesium-137	7.0×10^{4}	Curium-244	8.9×10^{3}
Samarium-151	5.4×10^{2}		

a. Sources: Ryman, Hermann, and Murphy (1998, Volume 3, Appendix B).

and a high-burnup pressurized-water reactor. A high burnup pressurized-water assembly would be irradiated for three cycles in comparison to the two cycles for the typical assemblies. For each of these assemblies, the tables provide radioactivity data for the common set of nuclides used in this EIS for the assumed 5-year minimum cooling time.

A.2.4.5.1.3 Chemical Composition. Tables A-44 and A-45 list the elemental distributions for the typical and high-burnup pressurized-water reactor spent mixed-oxide fuel assemblies.

A.2.4.5.1.4 Thermal Output. Table A-46 lists the decay heat from the representative mixed-oxide spent fuel assemblies at a range of times after discharge.

A.2.4.5.1.5 Physical Parameters. Because the mixed-oxide fuel would replace low-enriched uranium fuel in existing reactors, Section A.2.1.5.5 describes the physical parameters, with the exception of uranium and plutonium content, which are listed in Table A-41.

Table A-44. Elemental distribution of typical burn-up pressurized-water reactor spent mixed-oxide assembly.[a]

Element	Grams per assembly[b]	Percent[c]	Element	Grams per assembly	Percent
Americium	770	0.12	Palladium	1,200	0.19
Barium	750	0.12	Phosphorus	140	0.02
Carbon	67	0.01	Plutonium	17,000	2.59
Cerium	1,100	0.16	Praseodymium	500	0.08
Cesium	1,500	0.23	Rhodium	360	0.05
Chromium	2,300	0.36	Rubidium	91	0.01
Europium	90	0.01	Ruthenium	1,300	0.20
Iodine	150	0.02	Samarium	440	0.07
Iron	4,600	0.71	Silicon	66	0.01
Krypton	100	0.02	Strontium	210	0.03
Lanthanum	540	0.08	Technetium	370	0.06
Manganese	110	0.02	Tellurium	260	0.04
Molybdenum	1,700	0.27	Tin	1900	0.28
Neodymium	1,700	0.26	Uranium	428,000	65.92
Neptunium	72	0.01	Xenon	2500	0.38
Nickel	4,400	0.68	Yttrium	110	0.02
Niobium	330	0.05	Zirconium	111,000	17.10
Oxygen	62,000	9.56	**Totals**	**648,000**	**99.73**

a. Source: Murphy (1998, all).

b. To convert grams to ounces, multiply by 0.035274.

c. Table includes only elements that constitute at least 0.01 percent of the total; therefore, total is slightly less than 100 percent.

Table A-45. Elemental distribution of high burn-up pressurized-water reactor spent mixed-oxide assembly.[a]

Element	Grams per assembly[b]	Percent[c]	Element	Grams per assembly	Percent
Americium	1,000	0.16	Palladium	2,000	0.30
Barium	1,200	0.18	Phosphorus	140	0.02
Carbon	70	0.01	Plutonium	14,000	2.22
Cerium	1,600	0.24	Praseodymium	750	0.11
Cesium	2,100	0.33	Rhodium	460	0.07
Chromium	2,300	0.36	Rubidium	140	0.02
Europium	140	0.02	Ruthenium	2,000	0.31
Iodine	220	0.03	Samarium	630	0.10
Iron	4,600	0.71	Silicon	66	0.01
Krypton	150	0.02	Strontium	300	0.05
Lanthanum	810	0.12	Technetium	520	0.08
Manganese	100	0.02	Tellurium	390	0.06
Molybdenum	2,500	0.39	Tin	1,900	0.29
Neodymium	2,500	0.39	Uranium	421,000	64.84
Neptunium	93	0.01	Xenon	3,700	0.57
Nickel	4,400	0.68	Yttrium	170	0.03
Niobium	330	0.05	Zirconium	111,000	17.10
Oxygen	62,000	9.56	**Totals**	**646,000**	**99.46**

a. Source: Murphy (1998, all).

b. To convert grams to ounces, multiply by 0.035274.

c. Table includes only elements that constitute at least 0.01 percent of the total; therefore, total is slightly less than 100 percent.

Table A-46. Mixed-oxide spent nuclear fuel thermal profile (watts per assembly).[a]

Years	Typical PWR[b]	High-burnup PWR
1	6,100	8,000
5	1,000	1,600
10	670	1,100
15	610	970
30	540	780
100	370	430
300	240	260
1,000	110	110
3,000	42	38
10,000	25	22
30,000	10	7.9
100,000	1.5	1.3
250,000	0.5	0.6

a. Source: Ryman, Hermann, and Murphy (1998, Volume 3, Appendix B).

b. PWR = pressurized-water reactor.

A.2.4.5.2 *Immobilized Plutonium*

At present, approximately 50 metric tons (55 tons) of weapons-usable plutonium have been declared to be surplus to national needs. DOE has not yet determined the total quantity of plutonium for immobilization. The Department assumes that approximately 32 metric tons (35 tons) is “clean” metal suitable for use in mixed-oxide fuel, and that it could dispose of this material by burning it in reactors (DOE 1998a, page 1-1). The remaining surplus plutonium would require considerable additional chemical processing to make it suitable for reactor use. This EIS evaluates two cases, one in which DOE immobilizes only the “impure” materials (base case) and a second in which it immobilizes the entire 50-metric-ton surplus inventory. The base case is evaluated for the Proposed Action because it is DOE’s preferred alternative (DOE 1998a, page 1-1). The EIS evaluates the second case for potential cumulative impacts (Modules 1 and 2) because it would conservatively predict the largest number of required high-level radioactive waste canisters.

A.2.4.5.2.1 Mass and Volume. In DOE’s preferred disposition alternative, immobilized plutonium would arrive at the repository in canisters of vitrified high-level radioactive waste that would be externally identical to standard canisters from the Defense Waste Processing Facility at the Savannah River Site. Smaller cans containing immobilized plutonium in ceramic disks would be embedded in each canister of high-level radioactive waste glass. This is the *can-in-canister* concept. Because the design of the can-in-canister is not final, DOE has not determined final waste loadings per canister, volume displaced by the cans, or other specifications. The current baseline concept calls for cylindrical cans that are 53 centimeters (21 inches) high with a 7.6-centimeter (3-inch) diameter. The gross volume of each can would be 2.4 liters (150 cubic inches). DOE estimates that each canister would contain 28 cans, but has not yet finalized the actual number. One of the limitations on the number of cans is determined by the ability to ensure that the high-level radioactive waste glass would fill completely around the cans; increasing the volume that the cans would occupy in a canister could increase the difficulty of achieving this. Final confirmation of the design will be confirmed by actual test pours at scale (Stevenson 1997, page 41).

Marra, Harbour, and Plodinec (1995, page 2) describes the volume of a high-level radioactive waste canister. Each canister has a design capacity of 2,000 kilograms (4,400 pounds) of high-level radioactive waste glass. A nominal glass density of 2.7 grams per cubic centimeter (0.10 pound per cubic inch) yields a design glass volume of 620 liters (22 cubic feet). The 28 cans containing plutonium would displace 68 liters (2.4 cubic feet), or about 11 percent of the available volume. The rack holding the cans would displace about an additional 1 percent of the available volume, yielding a total displacement of about 12 percent.

Each plutonium can would contain 20 cylindrical pellets, 6.7 centimeters (2.6 inches) in diameter and 2.5 centimeters (1 inch) in height. The pellets would have an average density of 5.5 grams per cubic centimeter (0.20 pound per cubic inch) and would contain 10.5 percent of plutonium by weight. Each can, therefore, would contain about 1 kilogram (2.2 pounds) of plutonium, yielding a total of about 28 kilograms (62 pounds) per canister (1 kilogram of plutonium per can multiplied by 28 cans per canister).

Table A-47 lists the number of high-level radioactive waste canisters required to dispose of immobilized surplus plutonium using the loading and volumetric assumptions given above for both the base and 50-metric-ton (55-ton) cases. It also lists the number of additional canisters DOE would have to produce (in addition to those the high-level radioactive waste producer would already have produced) due to the displacement of high-level radioactive waste glass by the plutonium-containing canisters. The total number of required canisters would be a function of both the number of cans in each canister and the plutonium loading of the immobilization form. The number of additional canisters would depend only on the plutonium loading of the immobilization form.

Table A-47. Number of canisters required for immobilized plutonium disposition.[a,b]

Canisters	Base case	50-metric-ton case
Containing plutonium	635	1,744
In excess of those required for DWPF[c] (12% of total canisters)	77	210
Additional[d]	1.3%	3.5%

a. Source: DOE (1998a, pages 2-26 and 2-27).

b. Assumes 28 kilograms (62 pounds) of plutonium per canister and displacement of 12 percent of the high-level radioactive waste glass by plutonium cans and rack.

c. DWPF = Defense Waste Processing Facility.

d. As percentage of total planned DWPF canisters (about 6,000).

A.2.4.5.2.2 Amount and Nature of Radioactivity. Assuming the current 10.5-percent plutonium loading in the ceramic (Stevenson 1997, page 49), the expected isotopic composition of the various materials in the feedstream for ceramic production, and the nominal quantity of ceramic in each canister, Stevenson (1997, page 49) calculated the activity of the immobilized material in each high-level radioactive waste canister. The figures do not include the radioactivity of the vitrified high-level radioactive waste that would surround the cans of immobilized plutonium. Calculation of the total radioactivity of a canister requires the subtraction of approximately 12 percent from the radioactivity of a full high-level radioactive waste canister to account for the displacement of the immobilized plutonium and its rack. Those reduced numbers, added to the appropriate figures in Table A-48, produce the total activity of a plutonium-containing high-level radioactive waste canister.

Values for the base case and the 50-metric-ton case are different because the plutonium in the base case contains more transuranic radionuclides, other than plutonium-239, than does the remainder of the plutonium [32 metric tons (35 tons)]. Thus, the “other” transuranic radionuclides are diluted in the 50-metric-ton case. From a thermal output and radiological impact standpoint, the base case is a more severe condition and, therefore, DOE has used it for the Proposed Action analysis.

Section A.2.3.5.2 contains information on the radioactivity contained in a standard Defense Waste Processing Facility high-level radioactive waste canister.

Table A-48. Average total radioactivity of immobilized plutonium ceramic in a single canister in 2010 (curies).[a,b]

Nuclide	Base case	50-metric-ton case
Plutonium-238	120	60
Plutonium-239	1,600	1,700
Plutonium-240	550	430
Plutonium-241	4,700	2,800
Plutonium-242	0.098	0.046
Americium-241	720	430
Uranium-234	< 0.000015[c]	< 0.000005
Uranium-235	0.0024	< 0.0011
Uranium-238	0.019	0.019
Thorium-232	< 0.00003	< 0.00003
Totals	**7,700**	**5,400**

a. Source: Stevenson (1997, page 49).

b. Assumes 10.5 percent of plutonium by weight in ceramic form, 1:2 molar ratio of plutonium to uranium, and 28 kilograms (62 pounds) of plutonium per canister. These values account only for the radioactivity in the immobilized form; they do not include that in the surrounding high-level radioactive waste glass.

c. < = less than.

A.2.4.5.2.3 Chemical Composition. The current design for a ceramic immobilization form is a multiphase titanate ceramic, with a target bulk composition listed in Table A-49. The neutron absorbers, hafnium and gadolinium, are each present at a 1-to-1 atomic ratio to plutonium, and the atomic ratio of uranium to plutonium is approximately 2-to-1. For the base case, the presence of impurities in some categories of surplus weapons-usable plutonium would result in the presence of a few weight percent of other nonradioactive oxides in some of the actual ceramic; Table A-49 does not list these impurities (Stevenson 1997, page 51).

Table A-49. Chemical composition of baseline ceramic immobilization form.[a]

Oxide	Approximate percent by weight
Titanium oxide	36
Hafnium oxide	10
Calcium oxide	10
Gadolinium oxide	8
Plutonium oxide	12
Uranium oxide	24

a. Source: Stevenson (1997, page 51).

The ceramic phase assemblage is mostly Hf-pyrochlore [(CaGd)(Gd,Pu,U,Hf)Ti_2O_7], with subsidiary Hf-zirconolite [(CaGd)(Gd,Pu,U,Hf)Ti_2O_7)], and minor amounts of brannerite [(U,Pu,Gd)Ti_2O_6] and rutile [(Ti,Hf)O_2]. Pyrochlore and zirconolite differ in their crystalline structures. The presence of silicon as an impurity in the plutonium could lead to the formation of a minor amount of a silicate glass phase in the ceramic. This phase could contain a trace amount of the immobilized plutonium. Some residual plutonium oxide (less than 0.5 percent of the total quantity of plutonium) could also be present. The residual plutonium oxide contains uranium with smaller amounts of gadolinium and hafnium as a result of partial reaction with the other constituents of the ceramic (Stevenson 1997, page 51). Section A.2.3.5.3 describes the chemical composition of the high-level radioactive waste glass surrounding the plutonium-containing cans.

A.2.4.5.2.4 Thermal Output. Stevenson (1997, page 49) has presented the heat generation of the immobilized ceramic. These figures represent only the heat from the ceramic; they do not account for the heat from the surrounding high-level radioactive waste glass. The total heat from a Defense Waste Processing Facility canister containing high-level radioactive waste and immobilized plutonium would be the value listed in Table A-50 combined with 88 percent of the value listed in Section A.2.3.5.4 for the heat from a Defense Waste Processing Facility canister.

Table A-50. Thermal generation from immobilized plutonium ceramic in a single canister in 2010 (watts per canister).[a]

Case	Thermal production
Base case	8.6
50-metric-ton[b] case	7.0

a. Source: Stevenson (1997, page 49).

b. To convert metric tons to tons, multiply by 1.1023.

A.2.4.5.2.5 Quantity of Material Per Canister. As discussed in Section A.2.4.5.2.1, DOE has yet to determine the actual configuration of the can-in-canister disposal package. Although the final configuration could use either the Savannah River Site or Hanford canisters, this EIS assumes the use of the Savannah River Site canister. The current baseline concept (described above) would result in a per-canister loading of 28 kilograms (62 pounds) of plutonium. Table A-48 lists the radioactivities of these materials. Section A.2.3.5.5 discusses the quantity of high-level radioactive waste associated with each Defense Waste Processing Facility canister. The quantity of high-level radioactive waste in each plutonium-containing canister would be less than the nominal content of a standard Defense Waste Processing Facility canister because the displacement of the plutonium cans and the support rack would amount to an estimated 12 percent of the net canister volume.

The canisters would differ internally from normal Defense Waste Processing Facility canisters due to the presence of the stainless-steel cans of immobilized plutonium and a stainless-steel rack holding the cans in place during pouring of molten high-level radioactive waste glass into the canister.

A.2.5 COMMERCIAL GREATER-THAN-CLASS-C LOW-LEVEL WASTE

A.2.5.1 Background

Title 10 of the Code of Federal Regulations, Part 61 (10 CFR Part 61), establishes disposal requirements for three classes of waste—A, B, and C—suitable for near-surface disposal. Class C has the highest level of radioactivity and therefore the most rigorous disposal specifications. Wastes with concentrations above Class C limits (listed in 10 CFR 61.55 Tables 1 and 2 for long and short half-life radionuclides, respectively) are called Greater-Than-Class-C low-level waste, and are not generally suitable for near-surface disposal (DOE 1994, all).

Commercial nuclear powerplants, research reactors, radioisotope manufacturers, and other manufacturing and research institutions generate waste that exceeds the Nuclear Regulatory Commission Class C shallow-land-burial disposal limits. Public Law 99-240 assigns the Federal Government, specifically DOE, the responsibility for disposing of this Greater-Than-Class-C waste. DOE could use a number of techniques for the disposal of these wastes, including engineered near-surface disposal, deep borehole disposal, intermediate-depth burial, and disposal in a deep geologic repository (DOE 1994, all).

The activities of nuclear electric utilities and other radioactive waste generators to date have produced relatively small quantities of Greater-Than-Class-C waste. As the utilities take their reactors out of service and decommission them, they could generate more waste of this type (DOE 1994, all).

Greater-Than-Class-C waste could include the following materials:

- Nuclear powerplant operating wastes
- Nuclear powerplant decommissioning wastes
- Sealed radioisotope sources that exceed Class C limits for waste classification
- DOE-held Greater-Than-Class-C waste (addressed in Section A.2.6)
- Greater-Than-Class-C waste from other generators

This section describes the quantities and characteristics of these waste types.

A.2.5.2 Sources

Sources or categories of Greater-Than-Class-C waste include:

- DOE facilities (addressed in Section A.2.6)
- Nuclear utilities
- Sealed sources
- Other generators

Nuclear utility waste includes activated metals and process wastes from commercial nuclear powerplants. Sealed sources are radioactive materials in small metallic capsules used in measurement and calibration devices. Other generator wastes consist of sludge, activated metals, and other wastes from radionuclide manufacturers, commercial research, sealed-source manufacturers, and similar operations. The decommissioning of light-water reactors probably will generate additional Greater-Than-Class-C waste. Some internal reactor components will exceed Class C disposal limits.

A.2.5.3 Present Status

Nuclear utilities store their Greater-Than-Class-C waste at the generator site, where it will remain until a disposal option becomes available.

Sealed sources are held by a Nuclear Regulatory Commission or Agreement State licensee. Current DOE sealed-source management plans call for the licensees to store their sealed-source wastes until a disposal option becomes available. If storage by a licensee became physically or financially impossible and a threat to public health and safety, the Nuclear Regulatory Commission would determine if the source was a candidate for DOE storage. At that time, the Commission could request that DOE accept the source for storage, reuse, or recycling. The inventory projections do not include such a transfer of material.

In 1993, there were 13 identified “other generators” of Greater-Than-Class-C waste (DOE 1994, Appendix D), which were categorized into seven business types:

- Carbon-14 user
- Industrial research and development
- Irradiation laboratory
- Fuel fabricator
- University reactor
- Sealed-source manufacturer
- Nonmedical academic institution

These generators store their wastes at their sites and will continue to do so until a disposal site becomes operational.

A.2.5.4 Final Waste Form

The final disposition method for Greater-Than-Class-C waste is not known. If DOE was to place such waste in a repository, it is assumed that it would be placed in a disposal package before shipment. The EIS assumes the use of a package similar to the naval dual-purpose canister, which is described in Section A.2.2.5.6, for all shipments by rail and a package similar to the high-level radioactive waste canisters for all shipments by truck.

A.2.5.5 Waste Characteristics

Table A-51 lists existing and projected volumes for the three Greater-Than-Class-C waste generator sources. DOE conservatively projects the volume of nuclear utility wastes to 2055 because that date would include the majority of this waste from the decontamination and decommissioning of commercial nuclear reactors. The projected volumes conservatively reflect the highest potential volume and activity based on inventories, surveys, and industry production rates. DOE projects the other two generator sources (sealed sources and other generators) to 2035 (DOE 1994, all).

Table A-51. Greater-Than-Class-C waste volume by generator source (cubic meters).[a,b]

Source	1993 volume	Projected volume
Nuclear electric utility	26	1,300
Sealed sources	39	240
Other generators	74	470
Totals	**139**	**2,010**

a. Source: DOE (1994, all).

b. To convert cubic meters to cubic feet, multiply by 35.314.

The data concerning the volumes and projections are from Greater-Than-Class-C Waste Characterization: Estimated Volumes, Radionuclide Activities, and Other Characteristics (DOE 1994), Appendix A-1, which provides detailed radioactivity reports for such waste currently stored at nuclear utilities. Table A-52 summarizes the radioactivity data for the primary radionuclides in the waste, projected to 2055.

Table A-52. Commercial light-water reactor Greater-Than-Class-C waste radioactivity (curies) by nuclide (projected to 2055).[a]

Nuclide	Radioactivity
Carbon-14	6.8×10^{4}
Cobalt-60	3.3×10^{7}
Iron-55	1.8×10^{7}
Hydrogen-3	1.2×10^{4}
Manganese-54	3.2×10^{4}
Niobium-94	9.8×10^{2}
Nickel-59	2.5×10^{5}
Nickel-63	3.7×10^{7}
Transuranics	2.0×10^{3}
Total	$\mathbf{8.8\times10^{7}}$

a. Source: DOE (1994, Appendix A-1).

Appendix B of DOE (1994) provides detailed radioactivity reports for the sealed sources, which could be candidate wastes for the repository. Table A-53 summarizes the radioactivity data for the radionuclides in these sources, projected to 2035.

Table A-53. Sealed-source Greater-Than-Class-C waste radioactivity (curies) by nuclide (projected to 2035).[a]

Nuclide	Radioactivity
Americium-241	8.0×10^4
Curium-244	1.6×10^2
Cesium-137	4.0×10^7
Plutonium-238	1.6×10^4
Plutonium-239	1.1×10^5
Plutonium-241	2.8×10^1
Technetium-99	5.8×10^3
Uranium-238	5.7×10^1
Total	$\mathbf{4.2\times10^7}$

a. Source: DOE (1994, Appendix B).

DOE (1994, Section 5) also identifies the 13 other generators and the current and projected volumes and total radioactivity of Greater-Than-Class-C waste held by each. It does not provide specific radionuclide activity by nuclide. DOE used the data to derive a distribution, by user business type, of the specific nuclides that comprise the total radioactivity. Table A-54 lists this distributed radioactivity for other generators.

Table A-54. Other generator Greater-Than-Class-C waste radioactivity (in curies) by nuclide (projected to 2035).[a]

Nuclide	Radioactivity
Carbon-14	7.7×10^3
Transuranic	2.2×10^3
Cobalt-60	1.5×10^2
Nickel-63	1.5×10^2
Americium-241	2.4×10^3
Cesium-137	6.6×10^1
Technetium-99	5.1×10^{-2}
Total[b]	$\mathbf{1.3\times10^4}$

a. Source: Derived from DOE (1994, Appendix D).

b. Total differs from sum of values due to rounding.

A detailed chemical composition by weight percentage for current Greater-Than-Class-C waste is not available. However, Table A-55 lists the typical composition of such wastes by generator.

Table A-55. Typical chemical composition of Greater-Than-Class-C wastes.[a]

Source	Typical composition
Nuclear electric utility	Stainless steel-304, and zirconium alloys
Sealed sources	Stainless steel-304 (source material has very small mass contribution)
Other generators	Various materials

a. Source: DOE (1994, all).

The heat generation rates or thermal profiles for this waste type are not included in the source documentation. However, the contribution to the total thermal load at the repository from the Greater-Than-Class-C radioactive waste would be very small in comparison to commercial spent nuclear fuel or high-level radioactive waste.

A.2.6 SPECIAL-PERFORMANCE-ASSESSMENT-REQUIRED LOW-LEVEL WASTE

A.2.6.1 Background

DOE production reactors, research reactors, reprocessing facilities, and research and development activities generate wastes that exceed the Nuclear Regulatory Commission Class C shallow-land-burial disposal limits. The Department is responsible for the safe disposal of such waste, and could use a number of techniques such as engineered near-surface disposal, deep borehole disposal, intermediate-depth burial, or disposal in a deep geologic repository. These wastes have been designated as Special-Performance-Assessment Required wastes.

DOE Special-Performance-Assessment-Required waste could include the following materials:

- Production reactor operating wastes
- Production and research reactor decommissioning wastes
- Non-fuel-bearing components of naval reactors
- Sealed radioisotope sources that exceed Class C limits for waste classification
- DOE isotope production-related wastes
- Research reactor fuel assembly hardware

A.2.6.2 Sources

DOE has identified Special-Performance-Assessment-Required waste inventories at several locations. Table A-56 lists the generators and amounts of these wastes. These amounts include current and projected inventory. The Department will generate additional waste as it decommissions its nuclear facilities.

Table A-56. Estimated Special-Performance-Assessment-Required low-level waste volume and mass by generator source.[a]

Source[b]	Volume (cubic meters)[c]	Mass (kilograms)[d]
Hanford	20	360,000
INEEL[e]	20	280,000
ORNL	2,900	4,700,000
WVDP	550	5,200,000
ANL-E	1	230
Naval Reactors Facility	500	2,500,000
Totals	**4,000**	**13,040,230**

a. Source: Picha (1998b, all).

b. INEEL = Idaho National Engineering and Environmental Laboratory (including Argonne National Laboratory-West); ORNL = Oak Ridge National Laboratory; WVDP = West Valley Demonstration Project; ANL-E = Argonne National Laboratory-East.

c. To convert cubic meters to cubic yards, multiply by 1.3079.

d. To convert kilograms to pounds, multiply by 2.2046.

e. Includes Argonne National Laboratory-West.

A.2.6.3 Present Status

DOE stores its Special-Performance-Assessment-Required waste at the generator sites listed in Table A-56. Tables A-57 through A-60 list the waste inventories at the individual sites. For radionuclides, these tables include only the reported isotopes with inventories greater than 1×10^{-5} curies. Table A-61 lists the chemical composition of this material at each site.

Table A-57. Hanford Special-Performance-Assessment-Required low-level waste radioactivity by nuclide (curies).[a]

Nuclide	Radioactivity
Cesium-137	6.0×10^{4}
Strontium-90	6.0×10^{4}

a. Source: Picha (1998b, all).

Table A-58. Idaho National Engineering and Environmental Laboratory (including Argonne National Laboratory-West) Special-Performance-Assessment-Required low-level waste radioactivity by nuclide (curies).[a]

Nuclide	Radioactivity
Hydrogen-3	5.9×10^{6}
Carbon-14	8.3×10^{2}
Cobalt-60	1.1×10^{6}
Nickel-59	9.0×10^{1}
Nickel-63	1.3×10^{4}
Strontium-90	7.4×10^{3}
Niobium-94	1.4×10^{2}
Technetium-99	3.3
Cesium-137	3.1×10^{1}
Radium-226	3.0×10^{1}
Plutonium-239	2.0×10^{1}
Americium-241	2.4×10^{2}

a. Source: Picha (1998b, all).

Table A-59. Oak Ridge National Laboratory Special-Performance-Assessment-Required low-level waste radioactivity by nuclide (curies).[a]

Nuclide	Radioactivity
Hydrogen-3	1.9×10^{6}
Carbon-14	1.0×10^{1}
Cobalt-60	1.9×10^{6}
Nickel-59	7.6×10^{3}
Nickel-63	7.5×10^{5}
Strontium-90	8.3×10^{7}
Niobium-94	1.0×10^{4}
Technetium-99	8.0×10^{-1}
Iodine-129	7.5×10^{-5}
Cesium-137	1.7×10^{-4}

a. Source: Picha (1998b, all).

Table A-60. Radioactivity of naval Special-Performance-Assessment-Required waste (curies per package).[a]

Isotope	Short canister	Long canister	Isotope	Short canister	Long canister
Americium-241	5.4×10^{-2}	6.0×10^{-2}	Nickel-59	2.2×10^{2}	2.5×10^{2}
Americium-242m	5.8×10^{-4}	6.5×10^{-4}	Nickel-63	2.7×10^{4}	3.0×10^{4}
Americium-243	5.8×10^{-4}	6.5×10^{-4}	Plutonium-239	2.1×10^{-2}	2.4×10^{-2}
Carbon-14	3.2	3.6	Plutonium-240	5.4×10^{-3}	6.0×10^{-3}
Chlorine-36	5.3×10^{-2}	6.0×10^{-2}	Plutonium-241	4.1	4.6
Curium-242	1.4×10^{-3}	1.5×10^{-3}	Plutonium-242	4.5×10^{-5}	5.1×10^{-5}
Curium-243	6.6×10^{-4}	7.4×10^{-4}	Ruthenium-106	2.1×10^{-1}	2.3×10^{-1}
Curium-244	7.0×10^{-2}	7.9×10^{-2}	Selenium-79	1.2×10^{-5}	1.3×10^{-5}
Curium-245	1.3×10^{-5}	1.5×10^{-5}	Samarium-151	1.7×10^{-2}	1.9×10^{-2}
Cesium-134	1.6	1.8	Tin-126	1.2×10^{-5}	1.3×10^{-5}
Cesium-135	1.1×10^{-5}	1.2×10^{-5}	Strontium-90	4.2×10^{-1}	4.7×10^{-1}
Cesium-137	1.1	1.3	Technetium-99	5.3×10^{-4}	6.0×10^{-4}
Hydrogen-3	1.5	1.7	Uranium-232	1.2×10^{-4}	1.4×10^{-4}
Krypton-85	4.9×10^{-2}	5.6×10^{-2}	Uranium-233	7.8×10^{-5}	8.8×10^{-5}
Niobium-93m	3.6×10^{-1}	4.1×10^{-1}	Zirconium-93	3.8×10^{-1}	4.3×10^{-1}
Niobium-94	5.9×10^{-1}	6.7×10^{-1}			

a. Source: Beckett (1998, Attachment 1).

Table A-61. Typical chemical composition of Special-Performance-Assessment-Required low-level waste.[a]

Source[b]	Composition
Hanford	Vitrified fission products in glass waste form; hot cell waste
INEEL	Activated metal
ORNL	Activated metal; isotope production waste; hot cell waste
WVDP	Activated metal; vitrified transuranic waste
Naval Reactors	Activated metal (zirconium alloy, Inconel, stainless steel)
Other generators	Stainless-steel sealed sources

a. Source: Picha (1998b, all).

b. INEEL = Idaho National Engineering and Environmental Laboratory; ORNL = Oak Ridge National Laboratory; WVDP = West Valley Demonstration Project.

A.2.6.4 Final Waste Form

The final disposal method for DOE Special-Performance-Assessment-Required waste is not known. If the Department disposed of such waste in a repository, it is assumed that the material would be placed in a disposable package before shipment to the repository. The EIS assumes the use of a dual-purpose canister similar to those used for naval fuels for all rail shipments and packages similar to a high-level radioactive waste canister for all truck shipments.

A.2.6.5 Waste Characteristics

The low-level waste from West Valley consists of material in the Head End Cells (5 cubic meters [177 cubic feet]) and remote-handled and contact-handled transuranic waste (545 cubic meters [19,000 cubic feet]). The estimated radioactivity of the material in the Head End Cells is 6,750 curies, while the activity of the remote-handled and contact-handled transuranic waste is not available at present (Picha 1998b, all). The naval Special-Performance-Assessment-Required waste consists primarily of zirconium alloys, Inconel, and stainless steel (Beckett 1998, all); Table A-60 lists the specific radioactivity of the projected material 5 years after discharge.

The specific activity associated with the radium sources at Argonne National Laboratory-East has not been determined. However, in comparison to the other Special-Performance-Assessment-Required waste included in this section, its impact would be small.

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Appendix B

Federal Register Notices

August 10, 1995 in Vieques, PR to solicit public comment on the DEIS for ROTHR. In order to allow additional time for public review, the public hearings have been postponed and the public comment period has been extended to September 29, 1995. Notice of the revised hearing dates will be published in local newspapers at least 15 days prior to the hearings.

The DEIS has been distributed to various federal, Commonwealth, and local agencies, elected officials, special interest groups, and libraries. The DEIS is available for review at the following locations: Town Hall, Municipality of Vieques, Vieques Island, PR; Public Library, Municipality of Lajas, PR; and Mayor's Office, Lajas, PR. A limited number of copies of the DEIS are available by contacting Ms. Linda Blount, (804) 322–4892 or Sr. Jose Negron, Commander Fleet Air, Caribbean, (809) 965–4429.

Written statements and/or comments regarding the DEIS should be mailed to: Department of the Navy, Commander, Atlantic Division, Naval Facilities Engineering Command, 1510 Gilbert Street, Norfolk, VA 23511–2699 (Attn. Ms. Linda Blount, Code 2032LB). Questions may be directed to Ms. Linda Blount, (804) 322–4892 or Sr. Jose Negron, Commander Fleet Air, Caribbean, (809) 865–4429. All comments must be postmarked no later than September 29, 1995 to become part of the official record.

Dated: August 19, 1995.

L.R. McNees,

LCDR, JAGC, USN, Federal Register Liaison Officer.

[FR Doc. 95–19322 Filed 8–4–95; 8:45 am]

BILLING CODE 3810–FF–M

DEPARTMENT OF ENERGY

Preparation of an Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada

AGENCY: Department of Energy.

ACTION: Notice of intent.

SUMMARY: The U.S. Department of Energy (DOE) announces its intent to prepare an environmental impact statement (EIS) for a geologic repository at Yucca Mountain, Nye County, Nevada, for the disposal of spent nuclear fuel and high-level radioactive waste, in accordance with the Nuclear Waste Policy Act of 1982, as amended (NWPA) (42 U.S.C. § 10101 *et seq.*), the National Environmental Policy Act (NEPA) of 1969 (42 U.S.C. § 4321 *et seq.*), the Council on Environmental Quality regulations that implement the procedural provisions of NEPA (40 CFR Parts 1500–1508), and the DOE procedures for implementing NEPA (10 CFR Part 1021). DOE invites Federal, State, and local agencies, Native American tribal organizations, and other interested parties to participate in determining the scope and content of the EIS.

The NWPA directs DOE to evaluate the suitability of the Yucca Mountain site in southern Nevada as a potential site for a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste. If the Secretary of Energy determines that the Yucca Mountain site is suitable, the Secretary may then recommend that the President approve the site for development of a repository. Under the NWPA, any such recommendation shall be considered a major Federal action and must be accompanied by a final environmental impact statement. Accordingly, DOE is preparing this EIS in conjunction with any potential DOE recommendation regarding the development of a repository at Yucca Mountain.

The NWPA provides that the environmental impact statement need not consider the need for a repository, the alternatives to geologic disposal, or alternative sites to the Yucca Mountain site. Therefore, this environmental impact statement will evaluate a proposal to construct, operate, and eventually close a repository at Yucca Mountain. The EIS will evaluate reasonable alternatives for implementing such a proposal in accordance with the NWPA.

The NWPA also provides that the Nuclear Regulatory Commission shall, to the extent practicable, adopt DOE's EIS in connection with any subsequent construction authorization and license that the Commission issues to DOE for a repository. The EIS process is scheduled to be completed in September 2000 and is separate from the licensing process that would be initiated by any submission of a license application by DOE to the Commission in June 2001.

The EIS will be prepared over a five-year period in conjunction with DOE's separate but parallel site suitability evaluation and potential license application. DOE is beginning the EIS process early to ensure that the appropriate data gathering and tests are performed to adequately assess potential environmental impacts, and to allow the public sufficient time to consider this complex program and to provide input.

DATES: DOE invites and encourages comments and suggestions on the scope of the EIS to ensure that all relevant environmental issues and reasonable alternatives are addressed. Public scoping meetings are discussed below in the **SUPPLEMENTARY INFORMATION** section. DOE will carefully consider all comments and suggestions received during the 120-day public scoping period that ends on December 5, 1995. Comments and suggestions received after the close of the public scoping period will be considered to the extent practicable.

ADDRESSES: Written comments on the scope of this EIS, requests to pre-register to speak at any of the public scoping meetings, questions concerning the proposed action and EIS, or requests for additional information on the EIS, should be directed to: Wendy R. Dixon, EIS Project Manager, Yucca Mountain Site Characterization Office, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, 101 Convention Center Drive Suite P–110, MS 010, Las Vegas, NV 89109, Telephone: 1–800–967–3477, Facsimile: 1–800–967–0739.

FOR FURTHER INFORMATION CONTACT: For more information about this EIS, please contact Wendy R. Dixon at the address, above. For information on DOE's NEPA process, please contact: Carol M. Borgstrom, Director, Office of NEPA Policy and Assistance (EH–42), U.S. Department of Energy, 1000 Independence Avenue, S.W., Washington, D.C. 20585, Telephone: 1–202–586–4600 or leave a message at 1–800–472–2756.

SUPPLEMENTARY INFORMATION:

Public Participation

All interested persons, including Federal agencies, Native American tribal organizations, State and local government agencies, public interest groups, transportation interests, industry and utility organizations, regulators, and the general public are encouraged to take part in the EIS scoping process. Because of the anticipated public interest and national scope of the program, DOE will provide several methods for people to express their views and provide comments, request additional information and copies of the EIS, or pre-register to speak at the scoping meetings. Comments submitted by any of these means will become part of the official record for scoping.

Written Comments and Toll-Free Facsimile Number

Written comments and requests may be mailed or sent by facsimile to Wendy R. Dixon at the address or toll-free facsimile number listed above

Toll-Free Telephone Line

All interested parties are invited to record their comments or request information on the scope of the EIS by calling a toll-free telephone number, 1–800–967–3477. Throughout the public scoping period, this number will be staffed between the hours of 9 a.m. to 9 p.m. Eastern Standard Time, Monday through Friday. During other hours, calls will be forwarded to an answering machine.

Electronic Mail

Comments and information requests may be submitted by electronic mail to the following Internet electronic mail address: ymp—eisr@notes.ymp.gov.

Internet

The public may access the Notice of Intent, request information, and provide comments via the World Wide Web at the following Uniform Resource Locator address: http://www.ymp.gov, under the listing *Environmental Impact Statement (EIS)* on the Yucca Mountain Project Home Page. When available, the EIS and other selected technical documents may also be accessed at this Uniform Resource Locator address.

Scoping Meetings

DOE will hold 15 public scoping meetings in cities throughout the United States to provide and discuss information and to receive comments on the scope of this EIS. Table 1 at the end of this Notice lists the specific locations, dates, and times for each scoping meeting. Persons wishing to speak at any of these meetings can pre-register up to two days before the meeting by: (1) Calling the toll-free telephone number 1–800–967–3477, (2) writing to Wendy R. Dixon at the address listed above, or (3) sending their request to pre-register by facsimile or electronic mail, as identified above.

Persons wishing to speak who have not registered in advance can register at each meeting. These ‘‘walk-in registrants’’ will be accommodated to the extent practicable, following those persons who have pre-registered. Only one spokesperson per organization, group, or agency may present comments on its behalf. Oral statements will be limited to ten minutes; however, written comments can be of any length and submitted any time during the scoping period.

Each of the 15 public scoping meetings will have either a morning or afternoon session, and an evening session. Morning sessions will begin at 8:30 a.m. and end at 12:30 p.m., and afternoon sessions will begin at 12:00 p.m. and end at 4:00 p.m. Evening sessions will begin at 6:00 p.m. and end about 10:00 p.m. If additional time is required in order to accommodate all speakers wishing to present oral comments, the meeting facilitator will consult with the audience and DOE staff and determine whether to continue the meeting past the scheduled ending time. A court reporter will record all portions of the scoping meetings, and transcripts will be prepared and made a part of the official record of the scoping process.

Each session will have an introductory presentation, a question and answer period, and a public comment segment. A facilitator will begin the introductory presentation of each session by explaining the scoping meeting format. DOE staff will provide a brief description (lasting approximately 30–45 minutes) of the repository program, the EIS, and the scoping process. The question and answer period (lasting approximately 45 minutes) will provide members of the public an opportunity to ask questions and discuss various aspects of the repository and to obtain additional information that may be useful in formulating opinions and comments. Each member of the public will be allowed five minutes to ask questions. The meeting facilitator may allow extra time for additional questions depending on the number of people present who have indicated their desire to participate during the question and answer period. The meeting facilitator will begin the public comment portion of the scoping meeting after the question and answer period. At this time, members of the public will provide their comments on the scope of the EIS.

Each public scoping meeting also will have a separate information room containing exhibits and informational handouts about the repository program and the EIS. DOE and contractor staff will be available throughout the day to answer questions in an informal setting. A table with blank comment cards will also be available for people to privately prepare and submit written comments on the scope of the EIS. These comment cards will be included in the formal record of each scoping meeting.

Subsequent Document Preparation

Results of scoping, including the transcripts from the question and answer periods and public comment segments, and all other oral and written comments received by DOE, will be summarized in the EIS Implementation Plan. This Plan will guide the preparation of the EIS, and will describe the planned scope and content of the EIS, record the results of the scoping process, and contain EIS activity schedules. As a ‘‘living document,’’ the Implementation Plan may be amended as needed to incorporate changes in schedules, alternatives, or EIS content.

The Implementation Plan will be available to the public for information purposes as soon as possible after the close of the public scoping process, and before issuing the Draft EIS. The Implementation Plan and the transcripts from the public scoping meetings will be available for inspection at major DOE facilities and public reading rooms in Nevada and across the country, as identified at the end of this Notice. Copies of the Implementation Plan, as well as the Draft and Final EIS and related comments, will be provided to anyone requesting copies of these documents.

Availability of the Draft EIS for public review, and the locations and times of public hearings on the Draft EIS, will be announced in the **Federal Register** and through local media (approximately in the Fall of 1998). After considering all public comments received on the Draft EIS, DOE will prepare and issue a Final EIS, followed thereafter by a Record of Decision (approximately in the Fall of 2000).

Background

Spent nuclear fuel[1] has been and is being generated and stored in the United States as part of commercial power generation. The accumulation of spent nuclear fuel from commercial power reactor operations in the United States probably will continue for several decades. There are 109 operating commercial facilities at 75 sites in 34 States where spent nuclear fuel is stored. By the year 2035, total spent nuclear fuel from power reactors will amount to about 85,000 metric tons of heavy metal (i.e., metric tons of heavy metal, typically uranium, without materials such as cladding, alloy and structural materials) (MTHM).

Spent nuclear fuel and high-level radioactive waste[2], generated from

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[1] Spent nuclear fuel is fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

[2] High-level radioactive waste is the highly radioactive material resulting from reprocessing of spent nuclear fuel. It includes liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient

Continued

DOE's national atomic energy defense and research activities, are primarily located at DOE's Hanford Reservation, the Savannah River Site, and the Idaho National Engineering Laboratory. Other spent nuclear fuel, either currently in DOE possession or which may come under DOE possession, includes material from foreign research reactors, approximately 29 domestic university reactors, 5 non-DOE research reactors, and 4 ''special case'' reactors at non-DOE locations.

In 1982, in response to the continued accumulation of spent nuclear fuel and high-level radioactive waste, Congress passed the NWPA. The purpose of the NWPA was to establish geologic repositories that would provide reasonable assurance that the public and the environment would be adequately protected from the hazards posed by these materials. In 1987, Congress amended the NWPA and directed DOE to evaluate the suitability of only the Yucca Mountain site in southern Nevada as a potential site for the first repository. If, based on this evaluation, the Secretary of Energy determines that the Yucca Mountain site is suitable, the Secretary may then recommend that the President approve the site for development of a repository.

Under the NWPA, DOE is prohibited from emplacing more than 70,000 MTHM of spent nuclear fuel and high-level radioactive waste in the first repository until such time as a second repository is in operation. The current planning basis calls for 63,000 MTHM of commercial spent nuclear fuel to be disposed of in the first repository, proposed to be located at the Yucca Mountain site. The planning basis also calls for the disposal of 7,000 MTHM equivalent of DOE-owned spent nuclear fuel and high-level radioactive waste in this first repository.

Proposed Action

If the site were found to be suitable, the proposed action would be to construct, operate, and eventually close a repository at Yucca Mountain for the geologic disposal of up to 70,000 MTHM of commercial and DOE-owned spent nuclear fuel and high-level radioactive waste. Spent nuclear fuel and high-level radioactive waste would be disposed of in the repository in a subsurface configuration that would ensure its long-term isolation from the human environment. Repository construction, operation, and closure would be governed by the Nuclear Regulatory Commission's licensing process.

Construction would begin if the Nuclear Regulatory Commission authorizes construction of the repository. Surface facilities would be designed and constructed to receive, and prepare for disposal, spent nuclear fuel and high-level radioactive waste that would arrive in transportation casks by highway and by rail. Capability to treat or package the secondary wastes generated during disposal operations would also be provided. Subsurface facilities would be designed and constructed for emplacement of spent nuclear fuel and high-level radioactive waste in disposal drifts. Subsurface facilities would primarily include access ramps, ventilation systems, disposal drifts, and equipment alcoves.

Disposal operations would begin once the Nuclear Regulatory Commission issues a license allowing receipt of spent nuclear fuel and high-level radioactive waste. Disposal operations would be expected to last up to 40 years, depending on shipment schedules. Disposal drifts would continue to be constructed during this time period as necessary. Spent nuclear fuel assemblies,[3] and canisters containing assemblies[4] or vitrified (i.e., solidified) high-level radioactive waste[5] would be shipped to the repository in transportation casks that meet the Nuclear Regulatory Commission and U.S. Department of Transportation requirements for shipping by truck or rail[6]. The assemblies would be removed from the transportation casks, which would be placed back into service after decontamination and maintenance or after necessary repairs were completed. Canisters and assemblies would be transferred to a ''hot'' cell—a room where remotely-controlled equipment would be used to place the material in disposal containers. These ''waste packages'' (i.e., assemblies and canisters in disposal containers) would be transported underground in a transportation vehicle having radiation shielding for worker protection. Monitoring equipment, which would either be placed in selected drifts or would be mobile remote-sensing devices, would monitor performance of waste packages and aspects of the local repository geology.

The closure/post-closure period would begin after the Nuclear Regulatory Commission amends the license to authorize permanent closure. Underground equipment would be removed, repository openings would be backfilled and sealed, and the surface facilities would be decontaminated, decommissioned, and dismantled or converted to other uses. Institutional controls, such as permanent markers and monuments, would be designed and constructed to last thousands of years and discourage human activities that could compromise the waste isolation capabilities of the repository.

The disposal and closure/post-closure activities would be designed and implemented so that the combination of engineered (i.e., waste package and any backfill) and natural (geologic system) barriers would isolate the spent nuclear fuel and high-level radioactive waste. The combination of barriers would meet a standard to be specified by the Environmental Protection Agency, which has been entrusted to develop a radiation release standard pursuant to Section 801 of the Energy Policy Act of 1992 (42 U.S.C. § 10141 note); individual barriers would perform according to Nuclear Regulatory Commission requirements, including its performance objectives at 10 CFR 60.113. The engineered barrier must provide substantially complete containment of spent nuclear fuel and high-level radioactive waste for between 300 and 1,000 years by using corrosion resistant materials in the waste package.

Beyond 1,000 years, continued isolation would be assisted by features that would limit the rate at which radioactive components of the waste would be released. The rate of release would be substantially affected by natural conditions, the heat generation rate of spent nuclear fuel and high-level radioactive waste (i.e., thermal load), and its rate of heat dissipation. First, different thermal loads would affect directly the internal and external waste package temperatures, thereby affecting the corrosion rate and integrity of the waste package. Second, the heat would affect the geochemistry, hydrology, and mechanical stability of the disposal drifts, which in turn would influence the flow of groundwater and the

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concentrations and other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation.

[3] A fuel assembly is made up of fuel elements held together by plates and separated by spacers attached to the fuel cladding.

[4] Under one scenario, spent nuclear fuel assemblies would be sealed in a multi-purpose canister that would then be inserted into separate casks/containers for storage, transportation, and disposal. Other canisters are available and include single-purpose systems, which require transferring of individual assemblies from one cask/container to another for storage, transport, and disposal. Another alternative would be dual-purpose systems which require storing and transporting individual assemblies in one cask and disposing of them in another container.

[5] Vitrified high-level radioactive waste would be sealed in canisters suitable for transport in a truck or train cask.

[6] Barges may also be used for intermodal shipments of spent nuclear fuel and high-level radioactive waste from generator sites to nearby locations for transfer to truck and rail.

transport of radionuclides from the engineered and natural barrier systems to the environment. Therefore, the long-term performance of the repository would be managed by appropriately spacing the waste packages within disposal drifts and the distances between disposal drifts, and by selectively placing spent nuclear fuel and high-level radioactive waste packages to account for their individual heat generation rates.

Alternatives

DOE has preliminarily identified for analysis in the EIS a full range of reasonable implementation alternatives for the construction, operation, and closure/post-closure of a repository at Yucca Mountain. These implementation alternatives are based on thermal load objectives and include High Thermal Load, Intermediate Thermal Load, and Low Thermal Load alternatives.

Under each implementation alternative, DOE will evaluate different spent nuclear fuel and high-level radioactive waste packaging and transportation options. DOE anticipates that these options would produce the broadest range of potential configurations for both surface facilities and possible operational and disposal conditions at the repository. Evaluation of these options will identify the full range of reasonably foreseeable impacts to human health and the environment associated with each implementation alternative.

High Thermal Load Alternative

Under the High Thermal Load implementation alternative, spent nuclear fuel and high-level radioactive waste would be disposed in an underground configuration that would generate the upper range of repository temperatures while meeting performance objectives to isolate the material in compliance with Environmental Protection Agency standards and Nuclear Regulatory Commission requirements. Under this alternative, the emplacement density would likely be greater than 80 MTHM per acre. This alternative would represent the highest repository thermal loading based on available information and expected test results.

Intermediate Thermal Load Alternative

Under the Intermediate Thermal Load implementation alternative, spent nuclear fuel and high-level radioactive waste would be disposed in an underground configuration that would generate an intermediate range of repository temperatures (compared to the High and Low Thermal Load alternatives) while meeting performance objectives to isolate the material in compliance with Environmental Protection Agency standards and Nuclear Regulatory Commission requirements. Under this alternative, the disposal density would likely range between 40 to 80 MTHM per acre.

Low Thermal Load Alternative

Under the Low Thermal Load implementation alternative, spent nuclear fuel and high-level radioactive waste would be disposed in an underground configuration that would provide the lowest potential repository thermal loading (based on available information and expected test results) while meeting performance objectives to isolate the material in compliance with Environmental Protection Agency standards and Nuclear Regulatory Commission requirements. Under this alternative, the disposal density would likely be less than 40 MTHM per acre.

Packaging Options

As part of each implementation alternative, two packaging options would be evaluated. Under Option 1, spent nuclear fuel assemblies would be packaged and sealed in multi-purpose canisters at the generator sites prior to being transported to the repository in Nuclear Regulatory Commission-certified casks. High-level radioactive waste also would be packaged and sealed in canisters prior to shipment in similar casks. Under Option 2, spent nuclear fuel assemblies (without canisters) and sealed canisters of high-level radioactive waste would be transported to the repository in Nuclear Regulatory Commission-certified casks. Under both options, assemblies and canisters with intact seals would be removed from the casks and placed in disposal containers at the repository.

DOE recognizes that it is likely that a mix of spent nuclear fuel assemblies and canisters (and canister systems) of spent nuclear fuel and vitrified high-level radioactive waste would arrive at the repository during disposal operations. However, since the specific mix is speculative, the above packaging options were chosen to produce the broadest range of potential configurations for both surface facilities and possible operational and disposal conditions at the repository. These options were also selected to reflect the potential range of exposures to workers and the public at the generator sites, along transportation routes, and at the repository from the packaging, transport, and disposal of spent nuclear fuel and high-level radioactive waste.

Transportation

As part of each implementation alternative, two national transportation options and three regional (i.e., within the State of Nevada) transportation options would be evaluated. These options would be expected to result in the broadest range of operating conditions relevant to potential impacts to human health and the environment.

In a national context, the first option would consist of shipping all spent nuclear fuel and high-level radioactive waste by truck, from the generator site to the repository.

The second national option would consist of shipment by rail, except from those generator sites (as many as 19) that may not have existing capabilities to load and ship rail casks. For such sites, the spent nuclear fuel would be transported by truck to the repository, or to a facility near the nuclear power plant where it would be transferred to rail cars for shipment to the repository.

In a regional context, there are three transportation options: two of these options apply to shipments that would arrive in Nevada by rail, and the third applies to shipments that would arrive in Nevada by legal weight truck.[7]

The first regional transportation option would consist of several rail corridors to the repository. The rail corridor option would involve identifying and applying siting criteria, based on engineering considerations (e.g., topography and soils), potential land use restrictions (e.g., wilderness areas and existing conflicting uses), and any other factors identified from the scoping process.

The second regional transportation option would involve the use of heavy haul truck[8] routes to the repository. The heavy haul option would include the construction and use of an intermodal transfer facility to receive shipments that would arrive in Nevada by rail; the intermodal transfer facility would be located at the beginning of the heavy haul route. The heavy haul option would include any need to improve the local transportation infrastructure.

The third regional transportation option would involve legal weight truck shipments directly to the repository. Under this option, a transfer facility would not be required.

No Action

The No Action alternative would evaluate termination of site

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[7] A legal weight truck consists of a tractor, semi-trailer, and loaded cask, with a maximum gross weight of 80,000 pounds.

[8] A heavy haul truck consists of a tractor, semi-trailer, and loaded cask, with a gross weight in excess of 129,000 pounds.

characterization activities at Yucca Mountain and the continued accumulation of spent nuclear fuel and high-level radioactive waste at commercial storage sites and DOE facilities. Spent nuclear fuel and high-level radioactive waste would continue to be managed for the foreseeable future at existing commercial storage sites and DOE facilities located in 34 States. The No Action alternative, although contrary to the Congressional desire to provide a permanent solution for isolation of the Nation's spent nuclear fuel and high-level radioactive waste, provides a baseline against which the implementation alternatives can be compared.

At the Yucca Mountain site, the surface facilities, excavation equipment, and other support facilities would be dismantled and removed for reuse or recycling, or would be disposed of in solid waste landfills. Disturbed surface areas would be reclaimed and excavated openings to the subsurface would be sealed and backfilled.

At commercial reactors, spent nuclear fuel would continue to be generated and stored in either water pools or in canisters, until storage space at individual reactors becomes inadequate, at which time reactor operations would cease. DOE-owned spent nuclear fuel and high-level radioactive waste would continue to be managed at three primary sites—the Hanford Reservation, Savannah River Site, and the Idaho National Engineering Laboratory.

Environmental Issues To Be Examined in the EIS

This EIS will examine the site-specific environmental impacts from construction, operation, and eventual closure of a repository for spent nuclear fuel and high-level radioactive waste disposal at Yucca Mountain, Nevada. Transportation-related impacts of the alternatives will also be analyzed. Through internal discussion and outreach programs with the public, DOE is aware of many environmental issues related to the construction, operation, and closure/post-closure phases of such a repository. The issues identified here are intended to facilitate public scoping. The list is not intended to be all-inclusive or to predetermine the scope of the EIS, but should be used as a starting point from which the public can help DOE define the scope of the EIS.

- Radiological and non-radiological releases. The potential effects to the public and on-site workers from radiological and nonradiological releases;
- Public and Worker Safety and Health. Potential health and safety impacts (e.g., injuries) to on-site workers during the unloading, temporary surface storage, and underground emplacement of waste packages at Yucca Mountain;
- Transportation. The potential impacts associated with national and regional shipments of spent nuclear fuel and high-level radioactive waste from reactor sites and DOE facilities to the Yucca Mountain site will be assessed. Regional transportation issues include: (a) technical feasibility, (b) socioeconomic impacts, (c) land use and access impacts, and (d) impacts of constructing and operating a rail spur, a heavy haul route, and/or a transfer facility;
- Accidents. The potential impacts from reasonably foreseeable accidents, including any accidents with low probability but high potential consequences;
- Criticality. The likelihood that a self-sustaining nuclear chain reaction could occur and its potential consequences;
- Waste Isolation. Potential impacts associated with the long-term performance of the repository;
- Socioeconomic Conditions. Potential regional (i.e., in Nevada) socioeconomic impacts to the surrounding communities, including impacts on employment, tax base, and public services;
- Environmental Justice. Potential for disproportionately high and adverse impacts on minority or low-income populations;
- Pollution Prevention. Appropriate and innovative pollution prevention, waste minimization, and energy and water use reduction technologies to eliminate or significantly reduce use of energy, water, hazardous substances, and to minimize environmental impacts;
- Soil, Water, and Air Resources. Potential impacts to soil, water quality, and air quality;
- Biological Resources. Potential impacts to plants, animals, and habitat, including impacts to wetlands, and threatened and endangered species;
- Cultural Resources. Potential impacts to archaeological/historical sites, Native American resources, and other cultural resources;
- Cumulative impacts from the proposed action and implementing alternatives and other past, present, and reasonably foreseeable future actions;
- Potential irreversible and irretrievable commitment of resources.

Under the No Action alternative, potential environmental effects associated with the shutdown of site characterization activities at Yucca Mountain will be estimated. Potential environmental effects from the continued accumulation of spent nuclear fuel and high-level radioactive waste at commercial reactors and DOE sites will be addressed by summarizing previous relevant environmental analyses and by performing new analyses of representative sites, as appropriate. At the Yucca Mountain site, the potential environmental consequences from the reclamation of disturbed surface areas, and the sealing of excavated openings following the dismantlement and removal of facilities and equipment, will be quantified. These analyses would be similar in level of detail to the analyses of the implementing alternatives. At the commercial reactor and DOE sites, the potential environmental consequences will be addressed in terms of risk to the environment and the public from long-term management of spent nuclear fuel and high-level radioactive waste. In addition, the loss of storage capacity, the need for additional capacity, and their potential consequences to continued reactor operations, will be described.

Consultations With Other Agencies

The NWPA requires DOE to solicit comments on the EIS from the Department of the Interior, the Council on Environmental Quality, the Environmental Protection Agency, and the Nuclear Regulatory Commission (42 U.S.C. § 10134(a)(1)(D)). DOE also intends to consult with the Departments of the Navy and Air Force and will solicit comments from other agencies, the State of Nevada, affected units of local government, and Native American tribal organizations, regarding the environmental issues to be addressed by the EIS.

Relationship to Other DOE NEPA Reviews

DOE is preparing or has completed other NEPA documents that may be relevant to the Office of Civilian Radioactive Waste Management Program and this EIS. If appropriate, this EIS will incorporate by reference and update information taken from these other NEPA documents. These documents (described below) are available for inspection by the public at the DOE Freedom of Information Reading Room (1E–190), Forrestal Building, 1000 Independence Ave., S.W., Washington, D.C. and will be made available in Nevada at locations to be announced at the public scoping meetings. These documents include the following:

- *Environmental Assessment, Yucca Mountain Site,* Nevada Research and

Development Area, Nevada, DOE/RW–0073, 1986.

- *Environmental Assessment for a Monitored Retrievable Storage Facility,* DOE/RW–0035, 1986.
- *Environmental Impact Statement for a Multi-Purpose Canister System for the Management of Civilian and Naval Spent Nuclear Fuel.* The Notice of Intent was published on October 24, 1994 (59 FR 53442). The scoping process for this EIS has been completed and an Implementation Plan is being prepared. The Draft EIS is scheduled to be issued for public review in late 1995.
- *Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Environmental Impact Statement* [Final EIS issued April 1995 (DOE/EIS–0203–F); Record of Decision (60 FR 28680–96, June 1, 1995)]. This EIS analyzes the potential environmental consequences of managing DOE's inventory of spent nuclear fuel over the next 40 years. The Nevada Test Site was considered but was not selected as a DOE spent nuclear fuel management site.
- *Waste Management Programmatic Environmental Impact Statement* (formerly Environmental Management Programmatic EIS). A revised Notice of Intent was published January 24, 1995 (60 FR 4607). This Programmatic EIS will address impacts of potential DOE waste management actions for the treatment, storage, and disposal of waste. The Draft EIS is scheduled to be issued for public review in September 1995.
- *Environmental Impact Statement for a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel* [Notice of Intent published October 21, 1993 (58 FR 54336)]. The draft EIS was issued for public review in March 1995 (DOE/EIS–0218D). This EIS addresses the potential environmental impacts of the proposed policy's implementation. Under the proposed policy, the United States could accept up to 22,700 foreign research reactor spent nuclear fuel elements over a 10–15 year period.
- *Environmental Impact Statement on the Transfer and Disposition of Surplus Highly Enriched Uranium* (formerly part of the Programmatic Environmental Impact Statement for Long-Term Storage and Disposition of Weapons-Usable Fissile Materials). The Notice of Intent was issued April 5, 1995 (60 FR 17344). This EIS will address disposition of DOE's surplus highly enriched uranium to support the President's Nonproliferation Policy. The Draft EIS is scheduled to be issued in September 1995.
- *Programmatic Environmental Impact Statement for Storage and Disposition of Weapons-Usable Fissile Materials* [Notice of Intent published June 21, 1994 (59 FR 31985)]. This Programmatic EIS will evaluate alternatives for long-term storage of all weapons-usable fissile materials (primarily plutonium and highly enriched uranium retained for strategic purposes—not surplus) and disposition of surplus weapons-usable fissile materials (excluding highly enriched uranium), so that risk of proliferation is minimized. The Nevada Test Site is a candidate storage site.
- *Tritium Supply and Recycling Programmatic Environmental Impact Statement.* A revised Notice of Intent was published October 28, 1994 (59 FR 54175), and the Draft Programmatic EIS was issued in March 1995 (60 FR 14433, March 17, 1995). Public hearings on the Draft Programmatic EIS were held in April 1995, and a Final Programmatic EIS is scheduled for October 1995. This EIS addresses how to best assure an adequate tritium supply and recycling capability. The Nevada Test Site is an alternative site for new tritium supply and recycling facilities.
- *Stockpile Stewardship and Management Programmatic Environmental Impact Statement.* A Notice of Intent was published June 14, 1995 (60 FR 31291). A prescoping workshop was held on May 19, 1995, and scoping meetings are scheduled to be held during July and August 1995. This Programmatic EIS will evaluate proposed future missions of the Stockpile Stewardship and Management Program and potential configuration (facility locations) of the nuclear weapons complex to accomplish the Stockpile Stewardship and Management Program missions. The Nevada Test Site is an alternative site for potential location of new or upgraded Stockpile Stewardship and Management Program facilities.
- *Site-Wide Environmental Impact Statement for the Nevada Test Site* [Notice of Intent published August 10, 1994 (59 FR 40897)]. This EIS will address resource management alternatives for the Nevada Test Site to support current and potential future missions involving defense programs, research and development, waste management, environmental restoration, infrastructure maintenance, transportation of wastes, and facility upgrades and alternative uses. The public scoping process has been completed, and the Implementation Plan was issued in July 1995. The Draft EIS is scheduled to be issued for public review in September 1995.
- *Environmental Impact Statement for the Continued Operation of the Pantex Plant and Associated Storage of Nuclear Weapon Components* [Notice of Intent published May 23, 1994 (59 FR 26635); an amended Notice of Intent published June 23, 1995 (60 FR 32661)]. This EIS will address the potential environmental impacts of the continued operation of the Pantex Plant, which includes near- to mid-term foreseeable activities and the nuclear component storage activities at other DOE sites associated with nuclear weapon disassembly operations at the Pantex Plant. The Nevada Test Site is being considered as an alternative site for relocation of interim plutonium pit storage.

Public Reading Rooms

Copies of the Implementation Plan, and the Draft and Final EISs, will be available for inspection during normal business hours at the following public reading rooms. DOE may establish additional information locations and will provide an updated list at the public scoping meetings.

Albuquerque Operations Office, National Atomic Museum, Bldg. 20358, Wyoming Blvd., S.E., Kirtland Air Force Base, Albuquerque, NM 87117. Attn: Diane Leute (505) 845–4378

Atlanta Support Office, U.S. Dept. of Energy, Public Reading Room, 730 Peachtree Street, Suite 876, Atlanta, GA 30308–1212. Attn: Nancy Mays/Laura Nicholas (404) 347–2420

Bartlesville Project Office/National Institute for Petroleum and Energy Research, Library, U.S. Dept. of Energy, 220 Virginia Avenue, Bartlesville, OK 74003. Attn: Josh Stroman (918) 337–4371

Bonneville Power Administration, U.S. Dept. of Energy, BPA–C–KPS–1, 905 N.E. 11th Street, Portland, OR 97208. Attn: Sue Ludeman (503) 230–7334

Chicago Operations Office, Document Dept., University of Illinois at Chicago, 801 South Morgan Street, Chicago, IL 60607. Attn: Seth Nasatir (312) 996–2738

Dallas Support Office, U.S. Dept. of Energy, Public Reading Room, 1420 Mockingbird Lane, Suite 400, Dallas, TX 75247. Attn: Gailene Reinhold (214) 767–7040

Fernald Area Office, U.S. Dept. of Energy, Public Information Room, FERMCO, 7400 Willey Road, Cincinnati, OH 45239. Attn: Gary Stegner (513) 648–3153

Headquarters Office, U.S. Dept. of Energy, Room 1E–190, Forrestal Bldg.,

1000 Independence Avenue, S.W., Washington, D.C. 20585. Attn: Gayla Sessoms (202) 586–5955
Idaho Operations Office, Idaho Public Reading Room, 1776 Science Center Dr., Idaho Falls, ID 83402. Attn: Brent Jacobson (208) 526–1144
Kansas City Support Office, U.S. Dept. of Energy, Public Reading Room, 911 Walnut Street, 14th Floor, Kansas City, MO 64106. Attn: Anne Scheer (816) 426–4777
Office of Civilian Radioactive Waste Management National Information Center, 600 Maryland Avenue, S.W., Suite 760, Washington, D.C. 20024. Attn: Paul D'Anjou (202) 488–6720
Oak Ridge Operations Office, U.S. Dept. of Energy, Public Reading Room, 55 South Jefferson Circle, Room 112, Oak Ridge, TN 37831–8510. Attn: Amy Rothrock (615) 576–1216
Oakland Operations Office, U.S. Dept. of Energy, Public Reading Room, EIC, 8th Floor, 1301 Clay Street, Room 700N, Oakland, CA 94612–5208. Attn: Laura Noble (510) 637–1762
Pittsburgh Energy Technology Center, U.S. Dept. of Energy, Bldg. 922/M210, Receiving Department, Building 166, Cochrans Mill Road, Pittsburgh, PA 15236–0940. Attn: Ann C. Dunlap (412) 892–6167
Richland Operations Office, U.S. Dept. of Energy, Public Reading Room, 100 Sprout Rd., Room 130 West, Mailstop H2–53, Richland, WA 99352. Attn: Terri Traub (509) 376–8583
Rocky Flats Field Office, Front Range Community College Library, 3645 West 112th Avenue, Westminster, CO 80030. Attn: Nancy Ben (303) 469–4435
Savannah River Operations Office, Gregg-Graniteville Library, University of S. Carolina-Aiken, 171 University Parkway, Aiken, SC 29801. Attn: James M. Gaver (803) 725–2889
Southeastern Power Administration, U.S. Dept. of Energy, Legal Library, Samuel Elbert Bldg., 2 South Public Square, Elberton, GA 30635–2496. Attn: Joel W. Seymour/Carol M. Franklin (706) 213–3800
Southwestern Power Administration, U.S. Dept. of Energy, Public Reading Room, 1 West 3rd, Suite 1600, Tulsa, OK 74103. Attn: Marti Ayers (918) 581–7426
Strategic Petroleum Reserve Project Management Office, U.S. Dept. of Energy, SPRPMO/SEB Reading Room, 900 Commerce Road East, New Orleans, LA 70123. Attn: Ulysess Washington (504) 734–4243
Yucca Mountain Science Centers
  Yucca Mountain Science Center, U.S. 95—Star Route 374, Beatty, NV 89003. Attn: Marina Anderson (702) 553–2130
  Yucca Mountain Science Center, 4101–B Meadows Lane, Las Vegas, NV 89107. Attn: Melinda D'ouville (702) 295–1312
  Yucca Mountain Science Center, 1141 South Hwy. 160, Pahrump, NV 89041. Attn: Lee Krumm (702) 727–0896

TABLE 1.—SCOPING MEETINGS

Location of scoping meeting	Dates/times [1]
Pahrump Community Center, 400 N. Hwy. 160, Pahrump, NV 89048	Tuesday, August 29, 1995, morning/evening sessions.
Boise Centre on the Grove, 850 W. Front St., Boise, ID 83702	Wednesday, September 6, 1995, morning/evening sessions.
Lawlor Events Center, University of Nevada-Reno Campus, Reno, NV 89667.	Friday, September 8, 1995, morning/evening sessions.
University of Chicago, Downtown MBA Center, 450 N. Cityfront Plaza Drive, Chicago, IL 60611.	Tuesday, September 12, 1995, morning/evening sessions.
Cashman Field, 850 Las Vegas Blvd. North, Las Vegas, NV 89101	Friday, September 15, 1995, morning/evening sessions .
Denver Convention Complex, 700 14th Street, Denver, CO 80202	Tuesday, September 19, 1995, afternoon/evening sessions.
Sacramento Public Library, 828 I Street, Sacramento, CA 95814	Thursday, September 21, 1995, afternoon/evening sessions.
Arlington Community Center, 2800 South Center Street, Dallas, TX 76004.	Tuesday, September 26, 1995, afternoon/evening sessions.
Caliente Youth Center, Highway 93, Caliente, NV 89008	Thursday, September 28, 1995, morning/evening sessions.
Hilton Inn, 150 West 500 South, Salt Lake City, UT 84111	Thursday, October 5, 1995, afternoon/evening sessions.
Maritime Institute of Technology and Graduate Studies, 5700 Hammonds Ferry Rd., Linthicum (near Baltimore), MD 21090.	Wednesday, October 11, 1995, morning/evening sessions.
Russell Sage Conference Center, 45 Ferry St., Troy (Albany), NY 12180.	Friday, October 13, 1995, afternoon/evening sessions.
Georgia International Convention Center, 1902 Sullivan Road, College Park (Atlanta), GA 30337.	Tuesday, October 17, 1995, morning/evening sessions.
Penn Valley Community College, 3201 S.W. Trafficway, Kansas City, MO 64111.	Friday, October 20, 1995, afternoon/evening sessions.
Tonopah Convention Center, 301 Brougher, Tonopah, NV 89049	Tuesday, October 24, 1995, morning/evening sessions.

[1] Session times are as follows: Morning (8:30 a.m.–12:30 p.m.), Afternoon (12:00 a.m.–4:00 p.m.), Evening (6:00 p.m.–10:00 p.m.).

Issued in Washington, D.C., this 1st day of August, 1995.

Peter N. Brush,

Acting Assistant Secretary, Environment, Safety and Health.

[FR Doc. 95–19396 Filed 8–4–95; 8:45 am]

BILLING CODE 6450–01–P

Floodplain/Wetland Involvement Notification and Statement of Findings for a Proposed Removal Action at the Weldon Spring Site, St. Charles Co., Missouri

AGENCY: Office of Environmental Management, Department of Energy (DOE).

ACTION: Notice of floodplain/wetland involvement and statement of findings.

SUMMARY: The U.S. Department of Energy (DOE) is proposing to conduct a removal action at the Weldon Spring site to remove radiologically contaminated soil from a vicinity property within a floodplain and wetland located within the heavily used State of Missouri Weldon Spring Conservation Area. The proposed action will eliminate any potential risk to the health of recreational users of the conservation area. In accordance with 10 CFR Part 1022, DOE has prepared a floodplain and wetlands assessment. The proposed action will be performed in a manner so as to avoid or minimize

Alternative. The Strategic Arms Reduction Treaty II (START II) requires deactivation of the Peacekeeper Missile System. Deactivation will only occur if the Treaty is ratified by Russia and entered into force. As modified by the Helsinki Agreement, the Treaty requires complete dismantlement by December 31, 2007. In order to meet the Treaty deadline, deactivation could start as early as October 2000.

Public scoping meetings are planned in the towns of Cheyenne, Wheatland, and Torrington, Wyoming. The purpose of these meetings is to determine the scope of issues to be addressed and to help identify significant environmental issues to be analyzed in depth. Notice of the times and locations of the meetings will be made available to the community using the local news media. The schedule for the scoping meetings is as follows:

Date	Location	Time
June 28, 1999	East High School, 2800 E. Pershing Blvd., Cheyenne, WY	6:30–9:30 p.m.
June 29, 1999	Wheatland High School, 1207 13th Street, Wheatland, WY	6:30–9:30 p.m.
June 30, 1999	Torrington High School, 23rd Ave & West C, Torrington, WY	6:30–9:30 p.m.

In addition to seeking public input on environmental issues and concerns at the scoping meetings, the Air Force is soliciting written comments regarding the EIS scope. To ensure the Air Force will have sufficient time to fully consider public inputs on issues, written comments should be mailed for receipt no later than August 2, 1999.

Please direct written comments or requests for further information concerning the Peacekeeper system deactivation/dismantlement EIS to: Mr. Jonathan D. Farthing, HQ AFCEE/ECA 3207 North Road, Brooks AFB, TX 78235–5363, (210) 536–3787.

Janet A. Long,

Air Force Federal Register Liaison Officer.

[FR Doc. 99–14847 Filed 6–10–99; 8:45 am]

BILLING CODE 5001–05–U

DEPARTMENT OF ENERGY

Office of Arms Control and Nonproliferation Policy; Proposed Subsequent Arrangement

AGENCY: Department of Energy.

ACTION: Subsequent arrangement.

SUMMARY: The Department is providing notice of a proposed ‘‘subsequent arrangement’’ under the Agreement for Cooperation Between the Government of the United States of America and the Government of Canada Concerning the Civil Uses of Atomic Energy and the Agreement for Cooperation Between the Government of the United States of America and the Government of the Republic of Korea Concerning Civil Uses of Atomic Energy. This notice is being issued under the authority of Section 131 of the Atomic Energy Act of 1954, as amended (42 U.S.C. 2160).

The subsequent arrangement RTD/CA(KO)–1 concerns the return of 8,431 grams of CANFLEX Fuel Bundle of which 6,747 grams consists of 111.7 grams of the isotope U–235 (1.64 percent enrichment) and the remaining 1,684 grams consists of 33.3 grams of the isotope U-235 (1.98 percent enrichment). Included in this return is 5,153 grams of enriched sintered UO2 pellets of which 3,965 grams consists of 65 grams of the isotope U-235 (1.64 percent enrichment) and the remaining 1,188 grams consists of 23.5 grams of the isotope U-235 (1.98 percent enrichment). The material is being returned to Canada from the Republic of Korea to be irradiated for performance test in NRU reactor in Canada as part of a Joint Canada/Korea fuel development program. This will be the first of a series of returns to Canada until the total amount of material originally transferred to the Republic of Korea to be incorporated into CANFLEX fuel bundles is returned to AECL. The original retransfer was implemented September 1998 and is documented as RTD/KO(CA)–7.

In accordance with Section 131 of the Atomic Energy Act of 1954, as amended, we have determined that this subsequent arrangement will not be inimical to the common defense and security.

This subsequent arrangement will take effect no sooner than June 28, 1999.

Dated: June 7, 1999.

For the Department of Energy.

Edward T. Fei,

Deputy Director, International Policy and Analysis Division, Office of Arms Control and Nonproliferation.

[FR Doc. 99–14883 Filed 6–10–99; 8:45 am]

BILLING CODE 6450–01–P

DEPARTMENT OF ENERGY

Floodplain and Wetlands Involvement; Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada

AGENCY: Department of Energy.

ACTION: Notice of floodplain and wetlands involvement.

SUMMARY: The U.S. Department of Energy (DOE) is proposing to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nye County, Nevada. As part of its proposal, DOE is considering shipping spent nuclear fuel and high-level radioactive waste in the State of Nevada over a rail line that would be constructed or over an existing highway route that may need upgrading to accommodate heavy-haul trucks. Portions of the rail corridor or highway route would cross perennial and ephemeral streams and their associated floodplains, as well as possible wetlands. Furthermore, portions of the transportation system in the immediate vicinity of the proposed repository would be located within the 100-year floodplains of Midway Valley Wash, Drillhole Wash, Busted Butte Wash and/or Fortymile Wash. No other aspect of repository-related operations or nuclear or nonnuclear repository facilities would be located within the 500-year or 100-year floodplains of these washes. In accordance with DOE regulations for Compliance with Floodplain/Wetlands Environmental Review Requirements (10 CFR Part 1022), DOE will prepare a floodplain and wetlands assessment commensurate with proposed decisions and available information. The assessment will be included in the Environmental Impact Statement (EIS) for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada. A draft of this EIS is scheduled to be published during the summer of 1999.

DATES: The public is invited to comment on this notice on or before July 1, 1999. Comments received after this date will be considered to the extent practicable.

ADDRESSES: Comments on this notice should be addressed to Ms. Wendy Dixon, EIS Project Manager, Yucca Mountain Site Characterization Office, U.S. Department of Energy, P.O. Box 30307, M/S 010, Las Vegas, Nevada 89036–0307. Comments also can be submitted via electronic mail to: eisr@notes.ymp.gov.

FOR FURTHER INFORMATION CONTACT:

Proposed Action: Ms. Wendy Dixon, EIS Project Manager, at the above address, or by calling (800)–881–7292.

Floodplain and Wetlands Environmental Review Requirements: Ms. Carol Borgstrom, Office of NEPA Policy and Assistance (EH–42), U.S. Department of Energy, 1000 Independence Avenue, S.W., Washington, D.C. 20585, (202)–586–4600 or leave a message at (800) 472–2756.

SUPPLEMENTARY INFORMATION: In accordance with the Nuclear Waste Policy Act, as amended, DOE is studying Yucca Mountain in Nye County, Nevada, to determine its suitability for the deep geologic disposal of commercial and DOE spent nuclear fuel and high-level radioactive waste. In 1989, DOE published a Notice of Floodplain/Wetlands Involvement (54 FR 6318, February 9, 1989) for site characterization at Yucca Mountain, and in 1992 published a Floodplain Statement of Findings (57 FR 48363, October 23, 1992).

DOE is now preparing an EIS (DOE–EIS–0250) to assess the potential environmental impacts from the construction, operation and monitoring, and eventual closure of the proposed geologic repository. DOE issued a Notice of Intent to prepare the EIS on August 7, 1995 (60 FR 40164). As part of its proposal, DOE is considering shipping spent nuclear fuel and high-level radioactive waste in the State of Nevada over a rail line that would be constructed or over an existing highway route that may need upgrading to accommodate heavy-haul trucks. For the rail mode, DOE is evaluating five potential corridors (Figure 1). For the heavy-haul truck mode, DOE is evaluating three potential locations for an intermodal transfer station associated with five potential highway routes (Figure 2; an intermodal transfer station is a facility at which shipping casks containing spent nuclear fuel and high-level radioactive waste would be transferred from trains to trucks, and empty shipping casks would be transferred from trucks to trains). The rail corridors would be about 400 meters (0.25 mile) wide. The Carlin Corridor would be the longest at 520 kilometers (323 miles) followed by the Caliente (513 kilometers, 319 miles), Caliente-Chalk Mountain (345 kilometers, 214 miles), Jean (181 kilometers, 112 miles), and Valley Modified (159 kilometers, 98 miles) corridors. The heavy-haul routes would utilize existing roads and rights-of-ways which typically would be less than 400 meters (0.25 miles) in width. The Caliente Route would be the longest at 533 kilometers (331 miles) followed by the Caliente-Las Vegas (377 kilometers, 234 miles), Caliente-Chalk Mountain (282 kilometers, 175 miles), Sloan/Jean (190 kilometers, 118 miles) and Apex/Dry Lake (183 kilometers, 114 miles) routes.

Portions of the transportation system in the immediate vicinity of the proposed repository are likely to be located within the 100-year floodplains of Midway Valley Wash, Drillhole Wash, Busted Butte Wash and/or Fortymile Wash (Figure 3). Fortymile Wash, a major wash that flows to the Amargosa River, drains the eastern side of Yucca Mountain. Midway Valley Wash, Drillhole Wash and Busted Butte Wash are tributaries to Fortymile Wash. Although water flow in Fortymile Wash and its tributaries is rare, the area is subject to flash flooding from thunderstorms and occasional sustained precipitation. There are no naturally occurring wetlands near the proposed repository facilities, although there are two man-made well ponds in Fortymile Wash that support riparian vegetation.

If the Proposed Action were implemented, DOE would use an existing road during construction of the repository that crosses the 100-year floodplain of Fortymile Wash (Figure 3). This road and other features of site characterization that involve floodplains have previously been examined by DOE and a Statement of Findings was issued in 1992 (57 FR 48363, October 23, 1992). It is uncertain at this time whether this existing road would require upgrading to accommodate the volume and type of construction vehicles.

In addition, transportation infrastructure would be constructed either in Midway Valley Wash, Drillhole Wash and Busted Butte Wash, or in Midway Valley Wash, Drillhole Wash and Fortymile Wash. The decision on which washes would be involved is dependent on future decisions regarding the mode of transport (rail or truck) which, in turn, would require the selection of one rail corridor or the selection of one site for an intermodal transfer station and its associated heavy-haul route. Structures that might be constructed in a floodplain could include one or more bridges to span the washes, one or more roads that could pass through the washes, or a combination of roads and culverts in the washes. No other aspect of repository-related operation of nuclear or nonnuclear facilities would be located within 500-year or 100-year floodplains.

Outside of the immediate vicinity of the proposed repository, the five rail corridors, and the three sites for an intermodal transfer station and associated five heavy-haul routes, would cross perennial and ephemeral streams, and possibly wetlands. It is likely that a combination of bridges, roads and culverts, or other engineered features, would be needed to span or otherwise cross the washes and possible wetlands, although the location of such structures is uncertain at this time.

DOE will prepare an initial floodplain and wetlands assessment commensurate with the proposed decisions and available information. This assessment will be included in the Draft EIS that is scheduled to be issued for public comment later this summer. If, after a possible recommendation by the Secretary of Energy, the President considers the site qualified for an application to the U.S. Nuclear Regulatory Commission for a construction authorization, the President will submit a recommendation of the site to Congress. If the site designation becomes effective, the Secretary of Energy will submit to the Nuclear Regulatory Commission a License Application for a construction authorization. DOE would then probably select a rail corridor or a site for an intermodal transfer station among those considered in the EIS. Following such a decision, additional field surveys, environmental and engineering analyses, and National Environmental Policy Act reviews would likely be needed regarding a specific rail alignment for the selected corridor or the site for the intermodal transfer station and its associated heavy-haul truck route. When more specific information becomes available about activities proposed to take place within floodplains and wetlands, DOE will conduct further environmental review in accordance with 10 CFR Part 1022. Information that would be considered in a subsequent assessment includes, for example, the identification of 500-year and 100-year floodplains among feasible alignments of the selected rail corridor or the site of the intermodal transfer station and its associated heavy-haul route, identification of individual wetlands, and whether the floodplains and wetlands could be avoided. If the floodplains and wetlands could not be avoided, information on specific engineering designs and associated construction activities in the floodplains and wetlands also would be needed to permit a more detailed assessment and to ensure that DOE minimizes potential harm to or within any affected floodplains or wetlands.

Issued in Las Vegas, Nevada, on the 4th day of June 1999.

Wendy Dixon,

EIS Project Manager.

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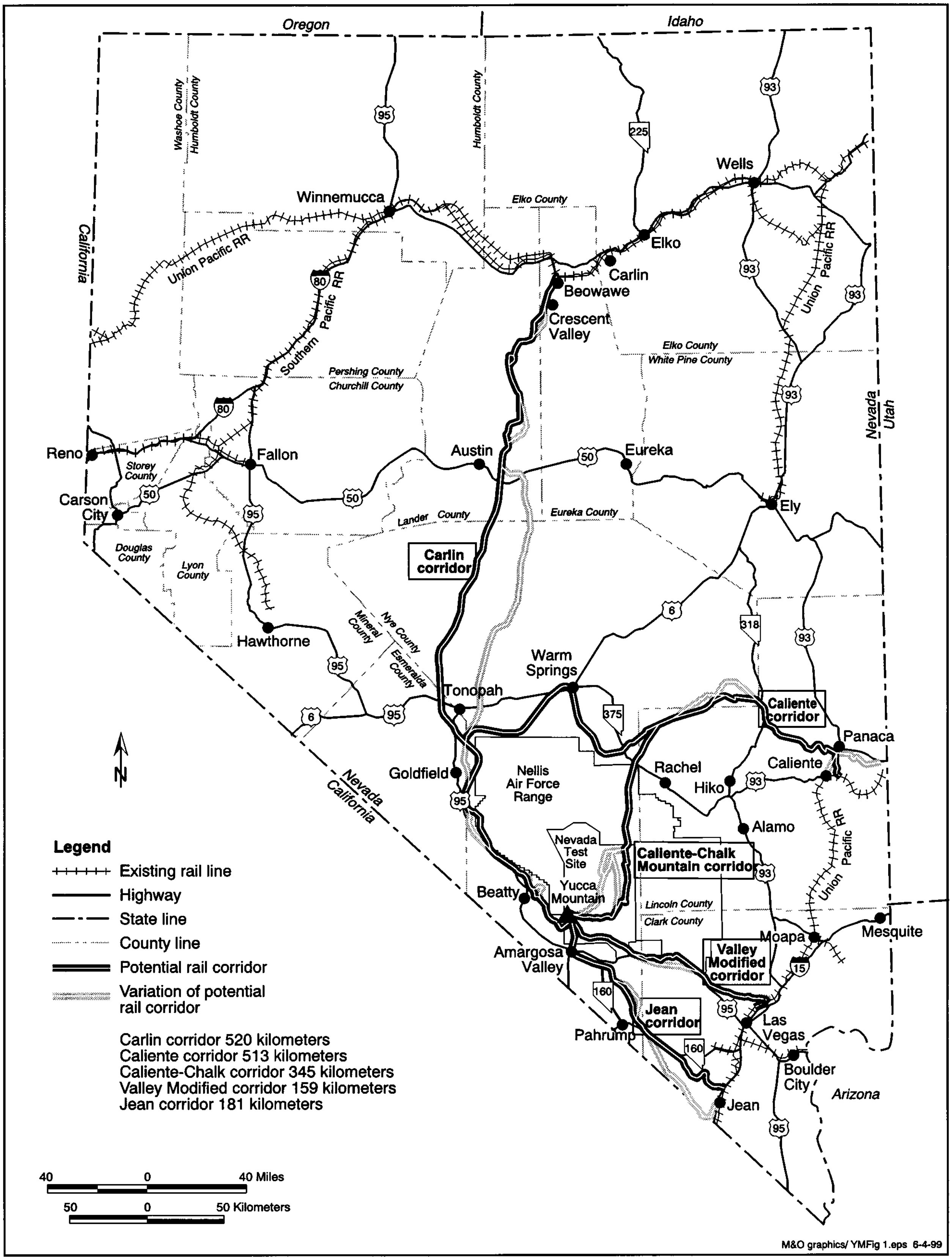

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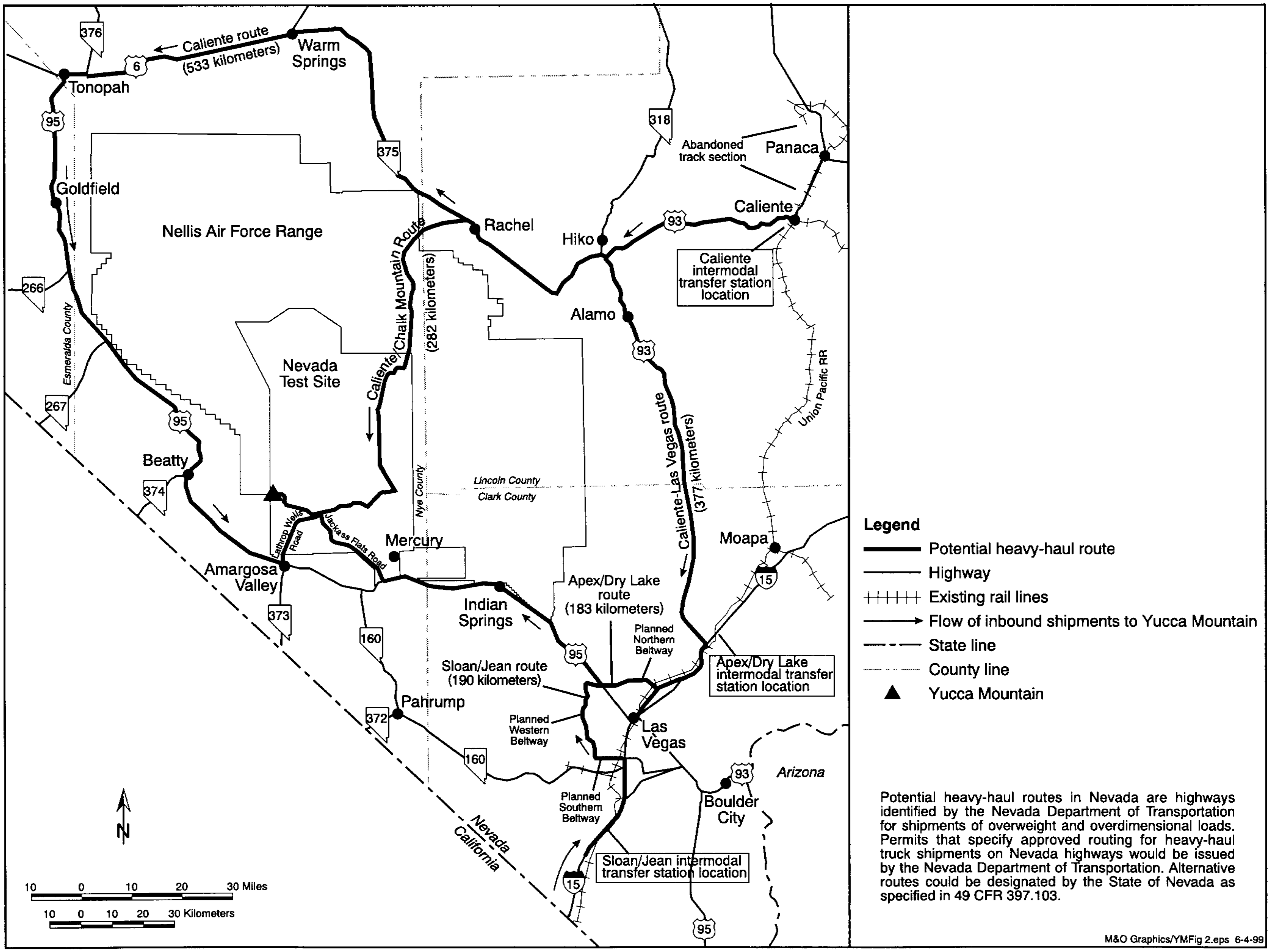
Figure 1. Potential Nevada rail corridors to Yucca Mountatin.



Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. Permits that specify approved routing for heavy-haul truck shipments on Nevada highways would be issued by the Nevada Department of Transportation. Alternative routes could be designated by the State of Nevada as specified in 49 CFR 397.103.

Figure 2. Potential routes in Nevada for heavy-haul trucks.

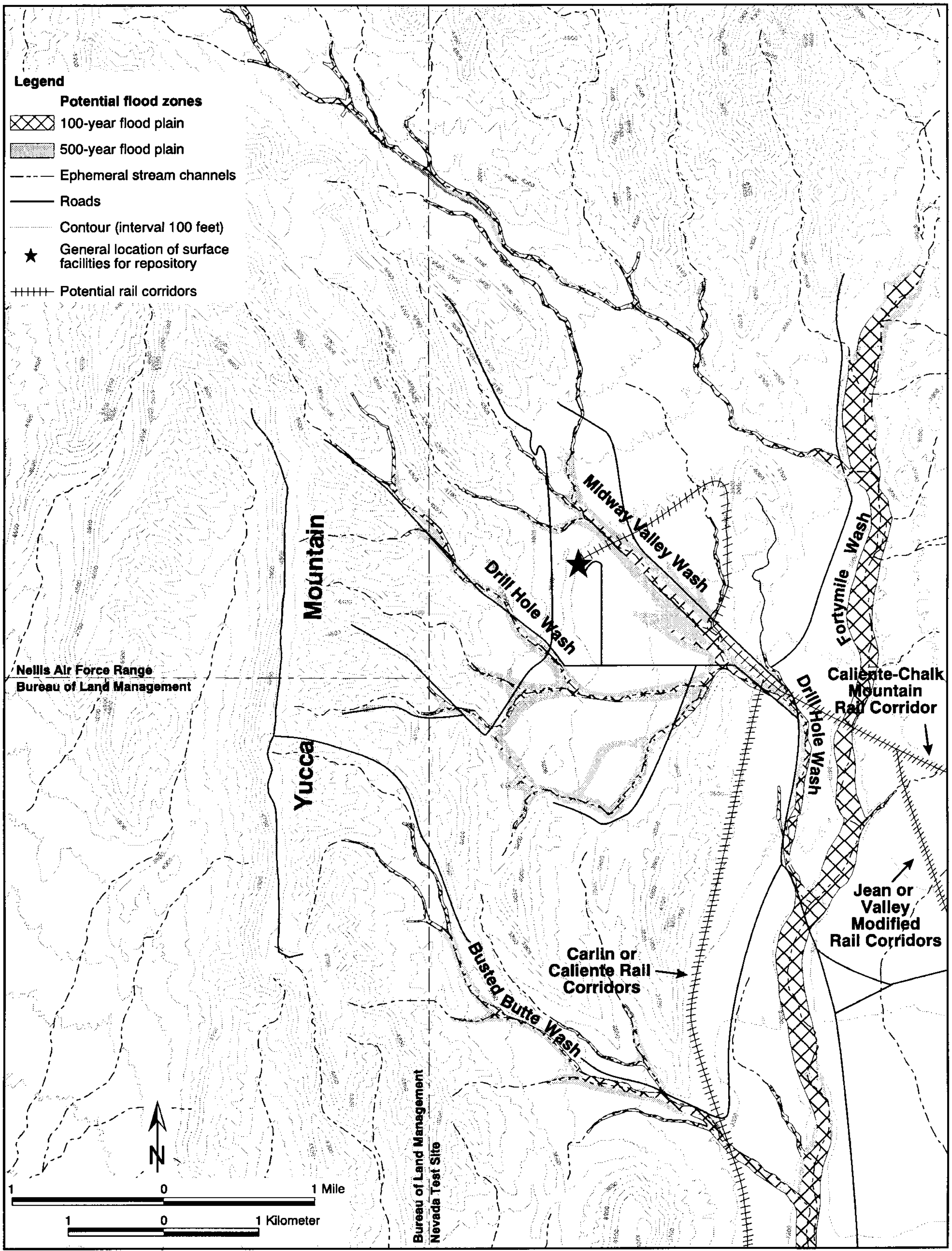


Figure 3. Yucca Mountain site topography, plains, and potential rail corridors.

[FR Doc. 99–14880 Filed 6–10–99; 8:45 am]

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Appendix C

Interagency and Intergovernmental Interactions

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LIST OF TABLES

APPENDIX C. INTERAGENCY AND INTERGOVERNMENTAL INTERACTIONS

In the course of producing this environmental impact statement (EIS), the U. S. Department of Energy (DOE) has interacted with a number of governmental agencies and other organizations. These interaction efforts have several purposes, as follows:

- Discuss issues of concern with organizations having an interest in or authority over land that the Proposed Action (to construct, operate and monitor, and eventually close a geologic repository at Yucca Mountain) would affect directly, or organizations having other interests that some aspect of the Proposed Action could affect.

- Obtain information pertinent to the environmental impact analysis of the Proposed Action.

- Initiate consultations or permit processes, including providing data to agencies with oversight, review, or approval authority over some aspect of the Proposed Action.

Section C.1 summarizes the interactions. DOE has completed several efforts and will complete all required consultations before publishing the Final EIS. Section C.2 describes interests held by agencies and organizations involved in consultations and other interactions.

C.1 Summary of Activity

Table C-1 lists organizations with which DOE has initiated interaction processes concerning the proposed Yucca Mountain Repository and the status of those interactions.

C.2 Interests of Selected Agencies and Organizations in the Yucca Mountain Repository Proposal

Regulations that establish a framework for interactions include 40 CFR 1502.25, which provides for consultations with agencies having authority to issue applicable licenses, permits, or approvals, or to protect significant resources, and 10 CFR 1021.341(b), which provides for interagency consultations as necessary or appropriate.

C.2.1 BUREAU OF LAND MANAGEMENT

The Bureau of Land Management has a range of interests potentially affected by the Proposed Action. The Bureau, as a part of the U.S. Department of the Interior:

- Controls a portion of the land that would need to be withdrawn by Congress to accommodate the proposed repository

- Controls portions of land in Nevada in the five corridors for a potential branch rail line and along the five potential routes for heavy-haul trucks

- Has responsibility for wild horse and wild burro management areas (Public Law 92-195, as amended, Section 3; 43 CFR Part 2800) and wildlife management areas (43 CFR 24.4) in Nevada that alternative rail corridors and routes for heavy-haul trucks cross

- Has power to grant rights-of-way and easements for transportation routes across lands it controls

Table C-1. Organizations with which DOE has initiated interactions (page 1 of 2).

Organization	Authority/interest	Interactions
Bureau of Land Management	Controls part of land required for repository. Controls portions of lands in Nevada that transportation corridors cross. Has responsibility for management and use of lands it controls, including management of habitat and species. Has data on topography, habitat, species, and other topics on land it controls.	DOE provided a briefing on the EIS during a meeting on September 15, 1998.
U.S. Air Force	Controls part of land being considered for withdrawal for repository (on the Nellis Air Force Range) and for one Nevada rail implementing alternative and one heavy-haul truck implementing alternative. Has identified security concerns over potential development of the Nevada rail and heavy-haul truck implementing alternatives that would pass through land it controls.	DOE has provided a briefing for USAF personnel on the process DOE is following for this EIS and on the range of issues being analyzed. DOE and Air Force personnel have held informal meetings to discuss specific issues and update EIS status. The Air Force has provided a statement of its concerns regarding certain transportation alternatives DOE is considering.
Naval Nuclear Propulsion Program	The Naval Nuclear Propulsion Program is a joint U.S. Navy and DOE organization responsible for management of naval spent nuclear fuel.	Ongoing dialogue and information exchange.
Fish and Wildlife Service	Oversees compliance with the Endangered Species Act for some species and compliance with the Fish and Wildlife Coordination Act.	Discussions have been held and species list information has been obtained. Interaction activities under the Endangered Species Act are ongoing.
National Marine Fisheries Service	Oversees compliance with Marine Protection Research and Sanctuaries Act and, for some species, with the Endangered Species Act.	Discussions have been held and information has been obtained. Interaction activities under the Endangered Species Act are ongoing.
U.S. Department of Transportation	Has regulatory authority over transportation of nuclear and hazardous waste materials, including packaging design, manufacture and use, pickup, carriage, and receipt, and highway route selection.	EIS status briefing has been provided. DOE and DOT have held informal discussions concerning modeling techniques and analytical methods DOE is using in its evaluation of transportation issues.
U.S. Environmental Protection Agency	Has regulatory authority over radiological standards and groundwater protection standards. Mandatory role in review of EIS adequacy.	DOE and EPA have held a meeting at which DOE provided a briefing on its approach to the EIS and on scope and content. At this meeting, EPA described its EIS rating process and personnel from the two agencies discussed methods for addressing any EIS comments that EPA may submit.
U.S. Nuclear Regulatory Commission	Required by NWPA to adopt Yucca Mountain Repository EIS to the extent practicable with the issuance by the Commission of any construction authorization and license for a repository. Has licensing authority over spent nuclear fuel and high-level radioactive waste geologic repositories. Has licensing authority over spent nuclear fuel and high-level radioactive waste geologic repositories. Has regulatory authority over commercial nuclear power plants, storage of spent nuclear fuel at commercial sites, and packaging for transportation of spent nuclear fuel and high-level radioactive waste. Has general authority over possession and transfer of radioactive material.	Discussions have been held on the purpose and need for the action and on the status of the EIS. Numerous interactions related to the potential repository program in general.

Table C-1. Organizations with which DOE has initiated interactions (page 2 of 2).

Organization	Authority/interest	Interactions
U.S. Army Corps of Engineers	Has authority over activities that discharge dredge or fill material into waters of the United States.	Discussed strategies for minimizing impacts and obtaining permits for waters of the United States.
U.S. Department of Agriculture	Responsible for protection of prime farm lands for agriculture in areas potentially affected by the Proposed Action.	Letter exchange has resolved issues regarding repository's potential effect on farmlands. Need for additional interaction is uncertain.
Native American Tribes	Have concern for potential consequences of repository development and transportation activities on cultural resources, traditions, and spiritual integrity of the land. Have governmental status. All interactions required for the American Indian Religious Freedom Act, the Native American Graves Protection and Repatriation Act, and the National Historic Preservation Act are being accomplished.	Ongoing discussions on a range of topics at least twice per year. Tribal representatives have prepared and submitted the *American Indian Perspectives on the Yucca Mountain Site Characterization Project and the Repository Environmental Impact Statement* (AIWS 1998, all).
Affected units of local government	Local governments with general jurisdiction over regions or communities that could be affected by implementation of the Proposed Action.	Meetings that include discussions, information exchange, and status briefings.
National Park Service	Potential for proposal to affect water supply in Death Valley region. Effect of any water appropriation required for repository, EIS status, and approach to EIS development.	Discussion completed. National Park Service concerns in regard to use of water for repository construction and operation were addressed.
Advisory Council on Historic Preservation and Nevada State Historic Preservation Officer	Protection and preservation of historic properties and cultural resources of importance to Native Americans and others. Administration of the National Historic Preservation Act and of regulatory requirements supporting that act.	Following discussions among DOE, the Advisory Council on Historic Preservation, and the Nevada State Historic Preservation Officer, DOE and the Advisory Council on Historic Preservation have entered into a programmatic agreement (DOE 1988, all) establishing procedures DOE is to follow during site characterization and during the Secretary of Energy's development of a repository site recommendation. The Advisory Council on Historic Preservation indicated that it would be available to assist DOE in complying with environmental review requirements for historic properties.
State of Nevada Department of Transportation	Has authority over transportation and highways in Nevada.	DOE and Nevada Department of Transportation personnel have had informal discussions on Nevada transportation issues. The State of Nevada has requested a formal briefing on this draft EIS after DOE publishes the document. DOE has agreed to provide a briefing to the state.

The Bureau of Land Management would have a continuing interest in the development of a repository at Yucca Mountain and associated transportation routes in the State of Nevada. Any comments from the Secretary of the Interior on the EIS must be included in the Secretary of Energy's recommendations to the President on the Yucca Mountain site.

Interaction

DOE held a meeting with the Bureau of Land Management on September 15, 1998.

C.2.2 U.S. AIR FORCE

The U.S. Air Force operates Nellis Air Force Base northeast of Las Vegas, and the Nellis Air Force Range, which occupies much of south-central Nevada. The Nellis Range is an important facility for training American and Allied combat pilots and crews (USAF 1999, pages 1-1 and 1-3).

A portion of the land being considered for withdrawal for the proposed repository is on the Nellis Range. If the land were withdrawn and development of the proposed repository proceeded, the Air Force would hold a continuing interest in the potential for construction, operation and monitoring, and closure activities at the repository to have consequences for Air Force operations on the adjoining land.

One Nevada rail implementing alternative and one Nevada heavy-haul truck implementing alternative that DOE is evaluating for the transportation of spent nuclear fuel and high-level radioactive waste would pass through a portion of the Nellis Range, for which the Air Force has national security concerns.

Interaction

DOE provided a briefing for USAF personnel on the process DOE is following for this EIS and on the range of issues being analyzed. DOE and Air Force personnel have held informal meetings to discuss specific issues. The Air Force has provided a statement of concerns about certain transportation alternatives DOE considered in the EIS.

C.2.3 NAVAL NUCLEAR PROPULSION PROGRAM

The Naval Nuclear Propulsion Program is a joint U.S. Navy and DOE program responsible for all matters pertaining to naval nuclear propulsion (USN 1996, page 2-2). This program is responsible for the nuclear propulsion plants aboard more than 93 nuclear-powered warships with more than 108 reactors and for nuclear propulsion work performed at four naval shipyards and two private shipyards. It is also responsible for two government-owned, contractor-operated laboratories, two moored training ships, two land-based prototype reactors, and the Expended Core Facility at the Naval Reactors Facility at the Idaho National Engineering and Environmental Laboratory.

The Naval Nuclear Propulsion Program manages naval spent fuel after its withdrawal from nuclear-powered warships and prototype reactors at the Expended Core Facility. The program has conducted studies and performed environmental impact analyses on the management and containerization of naval spent nuclear fuel to prepare it for shipment to the proposed repository or other spent fuel management system (USN 1996, all). Information from these studies is relevant to the containerization of other spent nuclear fuel that could be shipped to the proposed repository.

Interaction

Since the beginning of preparations for this EIS, the Naval Nuclear Propulsion Program has participated in quarterly meetings with DOE to discuss information relevant to the emplacement of naval spent nuclear fuel in a monitored geologic repository. Detailed information about naval spent nuclear fuel is classified; therefore, the Naval Nuclear Propulsion Program performed a parallel set of thermal, nuclear, and dose calculations and provided unclassified results to DOE for inclusion in this EIS. In some cases DOE used those results as input parameters for additional analyses. Representatives of the program participated throughout the review process to ensure the accurate presentation of information on naval spent nuclear fuel.

C.2.4 FISH AND WILDLIFE SERVICE

The Fish and Wildlife Service, a bureau of the U.S. Department of the Interior, has a role in the overall evaluation of the impacts from the Proposed Action under consideration in the repository EIS. Under the Endangered Species Act of 1973, as amended, the Fish and Wildlife Service has responsibility to determine if projects such as the proposed Yucca Mountain Repository would have an adverse impact on endangered or threatened species or on species proposed for listing. Any comments from the Secretary of the Interior on the EIS must accompany the Secretary of Energy's recommendation to the President on the Yucca Mountain site.

No endangered or proposed species occur on lands that would be needed for the repository. The desert tortoise is the only threatened species known to exist on this land, which lies at the northern edge of the range for desert tortoises (Buchanan 1997, pages 1 to 4). The repository would not need or impact any critical habitat.

To evaluate the potential for the proposed repository to affect the desert tortoise, DOE and the Fish and Wildlife Service are following a process that, in summary, includes three steps:

1. DOE submits a study (biological assessment) containing information on desert tortoise activities and habitat in the vicinity of the proposed project, a description of project activities that could affect the desert tortoise, and the potential for adverse impacts to desert tortoises or habitat. Based on this information, DOE will determine if the project would result in adverse impacts to the species.

2. DOE and the Fish and Wildlife Service will meet as necessary to discuss details of the potential for interaction between desert tortoises and project activities, and to consider appropriate protective measures DOE could take to reduce the potential for project impact to desert tortoises.

3. The Fish and Wildlife Service will issue a biological opinion that states its opinion on whether the proposed project may proceed without causing adverse impacts to the desert tortoise, jeopardizing the continued existence of the species, or resulting in harassment, harm, or death of individual animals. The biological opinion may contain protective measures and conditions that DOE would have to implement during construction, operation and monitoring, and closure of the proposed repository to minimize adverse impacts and the potential for tortoise deaths.

DOE, which has conducted site characterizations at Yucca Mountain since 1986, and the Fish and Wildlife Service have conducted previous consultation processes that addressed the potential for site characterization activities to affect the desert tortoise. These processes resulted in biological opinions, published in 1990 and 1997, that determined that site characterization activities could proceed without unacceptable harm to the desert tortoise and that the protective measures and conditions stated in the biological opinions should apply to DOE activities. None of the proposed repository land is critical habitat for tortoises. The current consultation process on the desert tortoise will build on the information gathered and the practices developed in the previous consultations, and on the positive results obtained.

Interaction

DOE is currently preparing a Biological Assessment to be submitted to the Fish and Wildlife Service.

C.2.5 NATIONAL MARINE FISHERIES SERVICE

The National Marine Fisheries Service exercises protective jurisdiction over aspects of the marine environment, including research activities, marine sanctuaries, and certain species protected by the Endangered Species Act. Potential DOE actions associated with transportation to the repository (for example, barging and construction or modification of bridges and docking facilities) could require interaction with the National Marine Fisheries Service.

Interaction

DOE participated in an informal discussion that identified National Marine Fisheries Service jurisdiction relevant to the Yucca Mountain Project and potential project activities of jurisdictional interest to the National Marine Fisheries Service in fulfilling its responsibilities.

C.2.6 U.S. DEPARTMENT OF TRANSPORTATION

The U.S. Department of Transportation has the authority to regulate several aspects of the transportation of spent nuclear fuel and high-level radioactive waste to the proposed Yucca Mountain Repository. The general authority of the Department of Transportation to regulate carriers and shippers of hazardous materials includes packaging procedures and practices, shipping of hazardous materials, routing, carrier operations, equipment, shipping container construction, and receipt of hazardous materials (49 USC 1801; 49 CFR Parts 171 through 180).

Interaction

DOE and the Department of Transportation have exchanged letters and informal communications on topics pertaining to the proposed Yucca Mountain Project that are within the Department of Transportation’s regulatory interest. DOE and the Department of Transportation have held informal discussions on the modeling techniques and analytical methods DOE used in its evaluation of transportation issues.

C.2.7 U.S. ENVIRONMENTAL PROTECTION AGENCY

The U.S. Environmental Protection Agency has two primary responsibilities in relation to the proposed Yucca Mountain Repository. It is responsible for promulgating regulations that set radiological protection standards for media that would be affected if radionuclides were to escape the confinement of the repository. In addition, the Agency oversees the National Environmental Policy Act process for Federal EISs. Council on Environmental Quality regulations implementing the National Environmental Policy Act specify procedures that agencies must follow and actions that agencies must take in preparing EISs. Depending on the level of concern that the Agency might have with environmental aspects of the Yucca Mountain Project Draft EIS, it can initiate a consultation between DOE and the Council on Environmental Quality. The Secretary of Energy’s recommendation to the President must include both the Final EIS and the Environmental Protection Agency’s comments on the EIS.

Interaction

DOE and the Environmental Protection Agency held a meeting at which DOE provided a briefing on its approach to the EIS and its scope and content. At that meeting, the Environmental Protection Agency described its EIS rating process, and personnel from the two agencies discussed methods for addressing EIS comments that the Agency might submit.

C.2.8 U.S. NUCLEAR REGULATORY COMMISSION

The Nuclear Waste Policy Act (42 USC 10101 *et seq.*) establishes a multistep procedure for reviews and decisions on the proposal to construct, operate and monitor, and close a geologic repository at Yucca Mountain. The final steps in this procedure require DOE to make an application to the U.S. Nuclear Regulatory Commission for authorization to construct a repository at Yucca Mountain and the Commission to consider this information and make a final decision within 3 years on whether to approve the application. The Nuclear Waste Policy Act directs the Commission to adopt this EIS to the extent practicable in support of its decisionmaking process. Any Nuclear Regulatory Commission comment on this EIS must accompany the Secretary of Energy's recommendation to the President.

The Nuclear Regulatory Commission also has authority under the Atomic Energy Act of 1954, as amended, to regulate persons authorized to own, possess, or transfer radiological materials. In addition, the Commission regulates transportation packaging, transportation operations, and the design, manufacture, and use of shipping containers for radiological materials with levels of radioactivity greater than Department of Transportation Type A materials. Determination as to whether radiological materials are Type A or greater are made in accordance with a procedure set forth in 49 CFR 173.431.

Interaction

Discussions have been held on the purpose and need for the Proposed Action and on the status of the EIS. Interactions with the Nuclear Regulatory Commission will include those necessary to process any application to construct a repository at Yucca Mountain.

C.2.9 U.S. ARMY CORPS OF ENGINEERS

The Clean Water Act of 1977 (42 USC 1251 *et seq.*) gives the U.S. Army Corps of Engineers permitting authority over activities that discharge dredge or fill material into waters of the United States. If DOE activities associated with a repository at Yucca Mountain discharged dredge or fill into any such waters, DOE could need to obtain a permit from the Corps. The construction or modification of rail lines or highways to the repository would also require Section 404 permits if those actions included dredge and fill activities or other activities that would discharge dredge or fill into waters of the United States. DOE has obtained a Section 404 permit for site characterization-related construction activities it might conduct in Coyote Wash or its tributaries or in Fortymile Wash.

Interaction

Strategies for minimizing any impacts and obtaining permits have been discussed.

C.2.10 U.S. DEPARTMENT OF AGRICULTURE

The U.S. Department of Agriculture has the responsibility to ensure that the potential for Federal programs to contribute to unnecessary and irreversible conversion of farmlands to nonagricultural uses is kept to a minimum. Proposed Federal projects must obtain concurrence from the Natural Resource Conservation Service of the Department of Agriculture that potential activities would not have unacceptable effects on farmlands (7 USC 4201 *et seq.*).

Interaction

DOE has had written communication with the Department of Agriculture. The process has resulted in a concurrence that a repository at Yucca Mountain would not affect farmlands.

C.2.11 NATIVE AMERICAN TRIBES

Many tribes have historically used the area being considered for the proposed Yucca Mountain Repository, as well as nearby lands (AIWS 1998, page 2-1). The region around the site holds a range of cultural resources and animal and plant resources. Native American tribes have concerns about the protection of cultural resources and traditions and the spiritual integrity of the land. Tribal concerns extend to the propriety of the Proposed Action, the scope of the EIS, and opportunities to participate in the EIS process, as well as issues of environmental justice and the potential for transportation impacts (AIWS 1998, pages 2-2 to 2-26, and 4-1 to 4-12). Potential rail and legal-weight truck routes would follow existing rail lines and highways, respectively. The legal-weight truck route would pass through the Moapa Indian Reservation and the potential rail line would pass near the Reservation. Potential routes for legal-weight and heavy-haul trucks would follow existing highways, and would pass through the Las Vegas Paiute Indian Reservation.

DOE Order 1230.2 recognizes that Native American tribal governments have a special and unique legal and political relationship with the Government of the United States, as defined by history, treaties, statutes, court decisions, and the U.S. Constitution. DOE recognizes and commits to a government-to-government relationship with Native American tribal governments. DOE recognizes tribal governments as sovereign entities with, in most cases, primary authority and responsibility for Native American territory. DOE recognizes that a trust relationship derives from the historic relationship between the Federal Government and Native American tribes as expressed in certain treaties and Federal law. DOE has and will consult with tribal governments to ensure that tribal rights and concerns are considered before taking actions, making decisions, or implementing programs that could affect tribes. These interactions ensure compliance with provisions of the American Indian Religious Freedom Act (42 USC 1996 *et seq.)*, the Native American Graves Protection and Repatriation Act (25 USC 3001 *et seq.*), DOE Order 1230.2 (*American Indian Tribal Government Policy*), Executive Order 13007 (*Sacred Sites*), Executive Order 13084 (*Consultation and Coordination with Indian Tribal Governments*), and the National Historic Preservation Act (16 USC 470f).

Interaction

The Native American Interaction Program was formally begun in 1987. Representatives from the Consolidated Group of Tribes and Organizations have met in large group meetings twice yearly with DOE on a range of cultural and other technical concerns. Additionally, specialized Native American subgroups have been periodically convened to interact with DOE on specific tasks including ethnobotany, review of artifact collections, field archaeological site monitoring, and the EIS process.

The Consolidated Group of Tribes and Organizations consists of the following:

- *Southern Paiute*
    - Kaibab Paiute Tribe, Arizona
    - Paiute Indian Tribes of Utah
    - Moapa Band of Paiutes, Nevada
    - Las Vegas Paiute Tribe, Nevada
    - Pahrump Paiute Tribe, Nevada
    - Chemehuevi Paiute Tribe, California
    - Colorado River Indian Tribes, Arizona
- *Western Shoshone*
    - Duckwater Shoshone Tribe, Nevada
    - Ely Shoshone Tribe, Nevada
    - Yomba Shoshone Tribe, Nevada
    - Timbisha Shoshone Tribe, California
- *Owens Valley Paiute and Shoshone*
    - Benton Paiute Tribe, California
    - Bishop Paiute Tribe, California
    - Big Pine Paiute Tribe, California
    - Lone Pine Paiute Tribe, California
    - Fort Independence Paiute Tribe, California
- *Other Official Native American Organizations*
    - Las Vegas Indian Center, Nevada

Tribal representatives have prepared and submitted the *American Indian Perspectives on the Yucca Mountain Site Characterization Project and the Repository Environmental Impact Statement* (AIWS 1998, all). This document discusses site characterization at Yucca Mountain and the Proposed Action in the context of Native American culture, concerns, and views and beliefs concerning the surrounding region. It has been used as a resource in the preparation of the EIS; excerpts are presented in Chapter 4, Section 4.1.13.4, to reflect a Native American point of view. The issues discussed ranged from traditional resources to concerns related to the potential repository.

C.2.12 AFFECTED UNITS OF LOCAL GOVERNMENT

As defined by the NWPA, the affected units of local government are local governments (counties) with jurisdiction over the site of a repository. Concerns of the affected units of local government range from socioeconomic impacts to potential consequences of transportation activities. Nye County, Nevada, in which DOE would build the repository, is one of the affected units of local government. Others include Clark, Lincoln, Esmeralda, Mineral, Churchill, Lander, Eureka, White Pine, and Elko Counties in Nevada and Inyo County in California.

DOE has offered local governments the opportunity to submit documents providing perspectives of issues associated with the EIS. At Draft EIS publication, Nye County had prepared such a document. In addition, other documents related to the Yucca Mountain region have been prepared in the past by several local government units including Clark, Lincoln, and White Pine Counties.

Interaction

DOE has held formal meetings twice a year with the affected units of local government. These meetings have included discussions and status briefings on a range of issues of interest to local governments. DOE has also held numerous informal meetings with representatives. Documents have been received from units of local government.

C.2.13 NATIONAL PARK SERVICE

The National Park Service, which is a bureau of the U.S. Department of the Interior, is responsible for the management and maintenance of the Nation's national parks and monuments. The implementation of the Proposed Action could potentially affect the water supply in Death Valley National Park, which is downgradient from Yucca Mountain. The National Park Service, therefore, would have an interest in any water appropriation granted to DOE for the repository. In addition, the Park Service has expressed its interest in this EIS, its status, and the approach DOE has followed in developing the EIS.

Interaction

DOE and National Park Service representatives held a discussion during which they addressed Park Service concerns about water use for repository construction and operation.

C.2.14 STATE OF NEVADA

If DOE receives authorization to construct, operate and monitor, and eventually close a geologic repository at Yucca Mountain, DOE would need to obtain a range of permits and approvals from the State of Nevada. DOE would need to coordinate application processing activities with the State to complete the permitting processes. DOE could require permits or approvals such as the following:

- An operating permit for control of gaseous, liquid, and particulate emissions associated with construction and operation
- A public water system permit and a water system operating permit for provision of potable water

- A general permit for storm-water discharge
- A National Pollutant Discharge Elimination System permit for point source discharges to waters of the State
- A hazardous materials storage permit to store, dispense, use, or handle hazardous materials
- A permit for a sanitary and sewage collection system
- A solid waste disposal permit
- Other miscellaneous permits and approvals

DOE required similar permits and approvals from the State of Nevada to conduct site characterization activities at Yucca Mountain. DOE and the State coordinated on a range of activities, including an operating permit for surface disturbances and point source emissions, an Underground Injection Control Permit and a Public Water System Permit, a general discharge permit for effluent discharges to the ground surface, a permit for the use of groundwater, a permit from the State Fire Marshal for the storage of flammable materials, and a permit for operation of a septic system. DOE could apply for additional or expanded authority under the existing permits, where needed, if provisions for expansion became applicable. DOE or its contractors could also need to coordinate transportation activities, highway uses, and transportation facility construction and maintenance activities with the Nevada Department of Transportation.

Interaction

The State of Nevada has requested a formal briefing on this Draft EIS after its publication, and DOE has agreed to provide the briefing. DOE and the Nevada Department of Transportation personnel have had information discussions on Nevada transportation issues.

C.2.15 ADVISORY COUNCIL ON HISTORIC PRESERVATION AND NEVADA STATE HISTORIC PRESERVATION OFFICER

In the mid- to late-1980s, DOE, the Nevada State Historic Preservation Officer and the Advisory Council on Historic Preservation discussed the development of a Programmatic Agreement to address DOE responsibilities under Sections 106 and 110 of the National Historic Preservation Act and the Council's implementing regulations. These discussions led to a Programmatic Agreement between DOE and the Advisory Council on Historic Preservation (DOE 1988, all) that records stipulations and terms to resolve potential adverse effects of DOE activities on historic properties at Yucca Mountain. The activities covered by the Agreement include site characterization of the Yucca Mountain site under the NWPA and the DOE recommendation to the President on whether or not to develop a repository, informed by a final EIS prepared pursuant to the National Environmental Policy Act and the NWPA.

Although not a formal signatory, the Nevada State Historic Preservation Officer has the right at any time, on request, to participate in monitoring DOE compliance with the Programmatic Agreement. In addition, DOE must provide opportunities for consultations with the Advisory Council on Historic Preservation, the Nevada State Historic Preservation Officer, and Native American tribes as appropriate throughout the process of implementing the Agreement. DOE submits an annual report to the Advisory Council and the Nevada State Historic Preservation Officer describing the activities it conducts each year to implement the stipulations of the Programmatic Agreement. This report includes a description of DOE coordinations and consultations with Federal and State agencies and Native American Tribes on historic and culturally significant properties at Yucca Mountain.

DOE will continue to seek input from the Nevada State Historic Preservation Officer and the Advisory Council on Historic Preservation, and will interact appropriately to meet the reporting and other stipulations of the Programmatic Agreement.

Interaction

DOE has submitted annual reports to the Nevada State Historic Preservation Officer and the Advisory Council on Historic Preservation and has provided opportunities for consultations with agencies and Native American Tribes as appropriate in accordance with the terms of the Programmatic Agreement.

C.3 Requests for Cooperating Agency Status

This EIS addresses a range of potential activities that are of potential concern to other agencies and to Native Americans. Governmental agencies and Native American tribes participated in the EIS process by submitting scoping comments and may submit comments on this Draft EIS. Representatives of Native American tribes have submitted a document that provides their perspective on the Proposed Action. Moreover, DOE has invited local governments in Nevada to submit reference documents providing information on issues of concern.

DOE is the lead agency for this EIS. Regulations of the Council on Environmental Quality allow the lead agency to request any other Federal agency that has jurisdiction by law or special expertise regarding any environmental impact involved in a proposal (or a reasonable alternative) to be a cooperating agency for an EIS (40 CFR 1501.6 and 1508.5). The regulations also allow another Federal agency to request that the lead agency designate it as a cooperating agency. Finally, the regulations allow state or local agencies of similar qualifications or, when the effects are on a reservation, a Native American Tribe, by agreement with the lead agency to become a cooperating agency (40 CFR 1508.5). Table C-2 lists requests for cooperating agency status and other proposals.

If the lead agency designates a cooperating agency, the lead agency's duties toward the cooperating agency include the following:

- Requesting early participation in the National Environmental Policy Act (that is, EIS) process
- Using any environmental analysis or proposal provided by a cooperating agency with legal jurisdiction or special expertise to the greatest extent possible consistent with its responsibilities as a lead agency
- Meeting with a cooperating agency when the cooperating agency requests

A cooperating agency's duties include the following:

- Participating early in the National Environmental Policy Act process
- Participating in the scoping process
- If requested by the lead agency, assuming responsibility for developing information and preparing environmental analyses including portions of the EIS for which the cooperating agency has special expertise
- If the lead agency requests, making staff support available
- Using its own funds, except the lead agency is to fund major activities or analyses it requests to the extent available

Table C-2. History of requests for cooperating status and similar proposals (page 1 of 4).

Agency	Request/statement/offer	Date	DOE response	Date
U.S. Department of the Navy	Request for cooperating agency status (Guida 1995, all)	May 23, 1995	DOE can draw on existing information from Navy participation in other EISs. DOE will conduct close consultations to ensure accuracy of information used. DOE declines cooperating agency status (Dixon 1995a, all).	July 10, 1995
U.S. Department of the Interior, National Park Service	Request for cooperating agency status (Martin 1995, all)	September 21, 1995	DOE prefers to address NPS comments or issues related to the Death Valley National Park through close consultations between the two agencies. DOE declines cooperating agency status (Dixon 1995b, all).	November 11, 1995
Nye County	Request for cooperating agency status (McRae 1995, all) (Bradshaw 1995, all) (DOE 1997, all) (Bradshaw 1998, all)	August 15, 1995 October 4, 1995 December 5, 1995 July 30, 1998	DOE expresses appreciation for the County's interest and desire to participate, commits to active consultations with Nye County and other entities on selected issues during EIS development, outlines general elements of consultation and coordination contemplated by DOE. DOE declines cooperating agency status (Barnes 1995a, all) (Barnes 1995b, all) (Barrett 1998, all).	November 21, 1995 December 1, 1995 September 24, 1998
Churchill County	Request for cooperating agency status (Regan 1995, all)	May 30, 1995	DOE does not foresee the need to establish formal MOUs to govern Churchill County's or other parties' participation in the NEPA process for the Repository EIS. CEQ and DOE regulations provide sufficient guidance for participation of all affected units of local government and members of the public. DOE describes steps being taken to ensure all interested and potentially affected organizations and individuals have early and equal opportunity to participate in EIS development. DOE declines cooperating agency status (Barnes 1995c, all).	July 21, 1995

Table C-2. History of requests for cooperating status and similar proposals (page 2 of 4).

Agency	Request/statement/offer	Date	DOE response	Date
Lincoln County	Proposal for a cooperative agreement with DOE in assessing the continued development of rail and highway route options to the Yucca Mountain site (Wright 1996, all).	April 22, 1996	DOE expresses appreciation for the County's desire to participate in DOE transportation planning activities, but indicates that, because much of the planning will be done to support the EIS, a cooperative agreement would be unnecessary. DOE identifies active consultation and coordination as an objective of the EIS process (Benson 1996, all).	August 2, 1996
Nuclear Regulatory Commission	NRC does not intend to participate as a cooperating agency (Holonich 1995, all)	March 1, 1995	DOE sent no response to this letter.	NA
Nuclear Regulatory Commission	NRC sent a letter (July 7, 1997) to the Navy. The NRC letter responded to a Navy transmission to the NRC of information on naval spent nuclear fuel. The information had been prepared for EIS use. In its letter, the NRC indicated that it would evaluate the information as part of prelicensing consultations with DOE on waste form issues but that, because NRC is required to review and adopt any EIS submitted as part of a DOE License Application, including information on naval SNF, NRC staff does not intend to formally review and comment on the Navy data. NRC sent DOE a copy of its response to the Navy (Stablein 1997, all).	August 22, 1996	NA	NA

Table C-2. History of requests for cooperating status and similar proposals (page 3 of 4).

Agency	Request/statement/offer	Date	DOE response	Date
U.S. Department of Air Force	Letter from USAF to the State of Nevada, stating that DOE has no obligation to consult with USAF regarding the transportation options DOE elects to evaluate as a result of NEPA public scoping comments, including the Caliente-Chalk Mountain heavy-haul route through Nellis Air Force Range. USAF acknowledged its close interaction with YMP and its intent to "continue this close relationship" (Esmond 1997, all).	September 4, 1997	NA	NA
Council of Energy Resources Tribes	Concept paper for Native American participation in the production of the YMP EIS (Burnell 1996, all).	June 19, 1996	DOE expressed thanks for the concept paper, described the status of the EIS (deferred during Fiscal Year 1996), committed to consideration of comments expressed in the concept paper along with all other comments received during the public scoping process. DOE stated that it would prepare a scoping comment summary and make the summary publicly available, indicated its active consideration of various approaches to consultations with other agencies and Native American tribes, including possible preparation of an EIS-referenceable document (Dixon 1996, all).	July 26, 1995
Advisory Council on Historic Preservation	Expressed thanks for DOE invitation to participate in the EIS process. Indicated desire to assist with development of the EIS and availability to assist DOE in complying with environmental review requirements; expressed intent to provide comments on the draft EIS (Nissley 1995, all).	October 12, 1995	DOE did not prepare a response to this formal scoping comment.	NA

Table C-2. History of requests for cooperating status and similar proposals (page 4 of 4).

Agency	Request/statement/offer	Date	DOE response	Date
Timbisha Shoshone Tribe of Death Valley, California	Letter to President Clinton expressing opposition to YMP; enclosed a Tribal Resolution condemning the siting of YMP; requested active involvement/consultation at a government-to-government level (Boland 1996, all).	August 14, 1996	DOE acknowledged expressed concerns and Tribal Resolution; identified ongoing Native American Interaction Program as vehicle to promote consultations and protection of cultural resources in YMP area; stated that comments from tribal governments were actively solicited during scoping period and Timbisha Shoshone will be afforded opportunity to comment on Draft EIS following its publication (Barnes 1996, all).	11/12/96
National Congress of American Indians	Letter expressed thanks to DOE (Secretary O'Leary) for invitation to meeting of public and private officials to exchange views on DOE management of SNF and radioactive waste, described NCAI as an organization, described Federal Government's fiduciary duty to tribes as sovereign nations, discussed lack of "affected status" for tribes under the NWPA, state Secretary O'Leary's three commitments to Federally recognized tribes in the Yucca Mountain area during the last year, including inclusion in future Yucca Mountain consultations, requested that DOE and Congress mandate a participatory role for tribal governments as part of any proposals to change the NWPA (Gaiashkibos 1995, all).	March 1, 1995	NA	NA

a. Abbreviations: CEQ = Council on Environmental Quality; MOU = Memorandum of Understanding; NA = not applicable; NCAI = National Congress of American Indians; NEPA = National Environmental Policy Act; NPS = National Park Service; NRC = U.S. Nuclear Regulatory Commission; NWPA = Nuclear Waste Policy Act; SNF = spent nuclear fuel; USAF = U.S. Air Force; YMP = Yucca Mountain Project.

Several agencies, tribes, or tribal organizations have either requested cooperating agency status for this EIS, made comparable proposals for participation, or stated positions in regard to the extent of their participation. Table C-2 summarizes agency requests, proposals, and position statements together with the DOE responses, if appropriate.

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Barnes 1995a	Barnes, W. E., 1995a, "Nye County's Request for Cooperating Agency Designation," letter to The Honorable Cameron McRae (Nye County Commissioners, Tonopah, Nevada), November 21, Office of Civilian and Radioactive Waste Management, U.S. Department of Energy, Las Vegas, Nevada. [MOL.19960424.0182]
Barnes 1995b	Barnes, W. E., 1995b, letter to L. Bradshaw (Nuclear Waste Repository Project Office, Tonopah, Nevada), December 1, Office of Civilian and Radioactive Waste Management, U.S. Department of Energy, Las Vegas, Nevada. [MOL.19960425.0310]
Barnes 1995c	Barnes, W. E., 1995c, "Proposed Memorandum Of Understanding (MOU) Regarding The U.S. Department Of Energy's (DOE) Preparation Of An Environmental Impact Statement (EIS) For A Potential Repository At Yucca Mountain, Nevada," letter to J. Regan (Office of the Churchill County Commissioners, Fallon Nevada), July 21, Office of Civilian and Radioactive Waste Management, U.S. Department of Energy, Las Vegas, Nevada. [MOL.19951220.0136]
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Barrett 1998	Barrett, L. H., 1998, letter to L. W. Bradshaw (Department of Natural Resources and Federal Facilities, Nuclear Waste Repository Project Office, Pahrump, Nevada), September 24, Office of Civilian and Radioactive Waste Management, U.S. Department of Energy, Washington, D.C. [MOL.19990610.0300]
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Bradshaw 1995	Bradshaw, L. W., 1995, letter to Dr. D. Dreyfus (Office of Civilian and Radioactive Waste Management, U.S. Department of Energy), October 4, Nuclear Waste Repository Project Office, Tonopah, Nevada. [MOL.19990319.0217]
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Buchanan 1997	Buchanan, C. C., 1997, "Final Biological Opinion for Reinitiation of Formal Consultation for Yucca Mountain Site Characterization Studies," letter to W. Dixon (U.S. Department of Energy, Yucca Mountain Site Characterization Office), File No. 1-5-96-F-307R, Fish and Wildlife Service, U.S. Department of the Interior, Nevada State Office, Reno, Nevada. [MOL.19980302.0368]
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Dixon 1995b	Dixon, W. R., 1995b, "Letter Requesting Cooperating Agency Involvement In The Repository Environmental Impact Statement (EIS)," letter to R. Martin, (Death Valley National Park, National Park Service, U.S. Department of the Interior), November 14, Office of Civilian and Radioactive Waste Management, U.S. Department of Energy, Las Vegas, Nevada. [MOL.19960419.0246]
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Nissley 1995	Nissley, C., 1995, letter to W. Dixon (Office of Civilian Radioactive Waste Management, U.S. Department of Energy), October 12, Advisory Council on Historic Preservation, Washington, D.C. [MOL.19990319.0206]
Regan 1995	Regan, J., 1995, letter to M. Powell (U.S. Department of Energy), May 30, Office of the Churchill County Commissioners, Fallon, Nevada. [MOL.19990610.0299]

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Appendix D

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Appendix E

Environmental Considerations for Alternative Design Concepts and Design Features for the Proposed Monitored Geologic Repository at Yucca Mountain, Nevada

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APPENDIX E. ENVIRONMENTAL CONSIDERATIONS FOR ALTERNATIVE DESIGN CONCEPTS AND DESIGN FEATURES FOR THE PROPOSED MONITORED GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA

E.1 Introduction

E.1.1 OBJECTIVE

This appendix discusses design features and alternatives for a repository at Yucca Mountain in Nevada that were under consideration by the U.S. Department of Energy (DOE) in the winter of 1998 and early 1999. It represents a forward look at how the repository design might evolve to incorporate these and/or other features into a reference design that could be submitted in a repository license application. This appendix also addresses how this design evolution might affect parameters important to the assessment of environmental impacts. The design features and alternatives analyzed as part of the Yucca Mountain Site Characterization Project were conceptual in nature (that is, not developed or analyzed in detail). This appendix presents a qualitative description of the design features and alternatives and a brief assessment of factors associated with each that could cause changes to the environmental impacts analyzed in this environmental impact statement (EIS). This assessment generally indicates that the EIS reasonably represents the foreseeable evolutions in repository design related to environmental impact considerations and bounds potential impacts. Possible design evolutions that occur after DOE issues this Draft EIS will be factored into the Final EIS, as appropriate, and any such refined design concepts will be carried forward to license application if Yucca Mountain is determined to be a suitable site for a repository.

E.1.2 BACKGROUND

DOE has completed the *Viability Assessment of a Repository at Yucca Mountain* (DOE 1998, all). The Viability Assessment included a preliminary design concept (referred to as the *Viability Assessment reference design* throughout this appendix), which presented preliminary design concepts for the repository surface facilities, underground facilities, and waste packages. The Viability Assessment reference design is the same as the high thermal load implementing alternative in the EIS.

Technical work associated with the Viability Assessment and the Viability Assessment reference design was not intended to support the selection of a repository design concept or specific alternative for licensing. Rather, the Viability Assessment identified areas requiring further study to determine site suitability to support a Site Recommendation and a License Application for a repository at Yucca Mountain. One area of further study and evaluation identified in the Viability Assessment was the assessment of alternative repository design features and concepts. The License Application Design Selection Process was established to study a broad range of alternative design concepts and design features to support the selection of the design to be incorporated into a license application.

The License Application Design Selection Process used a multistep approach for evaluating a selected set of features and alternatives against several criteria, including postclosure waste isolation performance, preclosure performance, assurance of safety, engineering acceptance, operations and maintenance, schedule, cost, and environmental considerations. In the first step, features and alternatives are evaluated against these criteria. Following this initial evaluation, enhanced design alternatives (which provide a unique approach to repository design and rely on the attributes of selected design features) were developed. In the development of enhanced design alternatives, there were no limitations placed on the development team to restrict consideration of features and alternatives to those on the initially selected list. From the inception of the License Application Design Selection Process, additional or evolved alternatives were expected to result. The process called for ranking of the enhanced design alternatives against a selected set of criteria using decision analysis methods. At the time of development of this appendix, enhanced design alternatives that were not part of the Viability Assessment had been developed, but documentation of that development and ranking had not been completed. Therefore, the information presented in this appendix is preliminary and based on both observations of the process and informal discussions with License Application Design Selection Process participants. This appendix will be revised as necessary to incorporate the final results of the License Application Design Selection Process. For the purposes of the License Application Design Selection Process, the following terms were defined:

- *Design Feature.* A design feature is a particular element or attribute of the repository design for which postclosure performance could be evaluated independently of a specific repository design alternative (fully developed design concept) or other design features. An individual design feature could encompass separate discrete concepts or a continuous range of parametric values. Design features can be added singularly or in combination to a design alternative. A design feature could theoretically be applied to any design alternative, although logical compatibility and expected postclosure waste isolation performance enhancement might be evident only when applied to particular design alternatives. Section E.2 of this appendix discusses the design features that were considered in the License Application Design Selection Process.

- *Design Alternative.* Each design alternative represents a fundamentally different conceptual design for the repository, which could potentially stand alone as the license application repository design concept. A design alternative can define major sections or the entire repository design. Design alternatives are distinguished from design features by their complexity and their inclusion of several features. Furthermore, a number of attributes are required to distinguish one design alternative from another. While not mutually exclusive, design alternatives represent diverse and independent methods of accomplishing the repository mission. Section E.2 discusses the design alternatives that were considered in the License Application Design Selection Process.

- *Enhanced Design Alternative.* Enhanced design alternatives are combinations (and/or variations) of one or more design alternative and design feature. While an enhanced design alternative could be made up of any conceivable combination of design alternatives and design features, enhanced design alternatives selected for further evaluation are those combinations that include mutually compatible attributes and expected postclosure waste isolation performance characteristics that exceed those of the basic design alternatives. In other words, the enhanced design alternatives are all improvements to the design alternatives in the first phase of the License Application Design Selection Process, including the Viability Assessment reference design. Other considerations in developing the enhanced design alternatives include the compatibility of the features and alternatives; the developmental, operational, and maintenance simplicity of the resulting combination; and the ability of the set of enhanced design alternatives to address the entire set of design features and alternatives under consideration.

Recommendations for the repository design concept that resulted from the License Application Design Selection Process will be part of a technical report scheduled for completion after this appendix was prepared. The design concept to be carried forward is expected to be one of the five enhanced design alternatives currently identified or minor variations of one of those enhanced design alternatives. Section E.3 of this appendix discusses the enhanced design alternatives that are the subject of consideration in the License Application Design Selection Process.

E.1.3 SCOPE

This appendix discusses the evolution of the EIS repository design concept to the concept that will ultimately be submitted as part of the license application for the Yucca Mountain repository, should the site be approved. The discussion is broken down into three basic categories that reflect the potential types of benefits from the design features and alternatives under consideration. The benefits that could be derived from each of the features and alternatives are not necessarily limited to the categorization presented, and some features and alternatives could fit into more than one category. However, the three categories were chosen to facilitate an understanding of the design evolution process that is presented in the main body of the EIS. Section E.2 discusses the set of selected design features and alternatives.

The categories, as presented in Sections E.2.1 through E.2.3, are Barriers to Limit Release and Transport of Radionuclides; Repository Designs to Control Thermal/Moisture Environment; and Repository Designs to Support Operational and Cost Considerations. Within each category, the text includes descriptions of the features and alternatives, explanations of why each feature/alternative was considered, and discussions of the potential for environmental impacts associated with each feature/alternative.

Section E.3 presents the five enhanced design alternatives that were considered in the first phase of the License Application Design Selection Process to develop a design concept for the proposed Yucca Mountain Repository that was an improvement over the Viability Assessment reference design. This improvement could take many forms, including enhanced licensibility, reduced uncertainty, and ease of construction and operation. The five enhanced design alternatives represent five complete basic design concepts that evolved from consideration of the features and alternatives discussed in Section E.2. The enhanced design alternatives were selected to represent the potential differences in waste isolation performance among differing repository designs. The participants in the License Application Design Selection Process determined that a major factor in selecting the final design for the Yucca Mountain Repository would be the thermal loading of the repository. As such, the five enhanced design alternatives represent a range of thermal loads from 40 metric tons of heavy metal (MTHM) per acre to 150 MTHM per acre. Important differences between the enhanced design alternatives and the Viability Assessment reference design include differences in waste package materials and the addition of a drip shield to each of the enhanced design alternatives. Each of the enhanced design alternatives was selected to improve on the Viability Assessment reference design from a waste isolation performance perspective. As was the case with the basic design features and alternatives discussed in Section E.2, there is the potential for environmental impacts associated with the enhanced design alternatives.

E.2 Design Features and Alternatives

E.2.1 BARRIERS TO LIMIT RELEASE AND TRANSPORT OF RADIONUCLIDES

E.2.1.1 Ceramic Coatings

A thin coating [1.5 millimeters (0.06 inch) or more] of a ceramic oxide on the outer surface of the waste package could increase the life of the waste package by slowing the rate at which the waste package will corrode. Candidate materials for the ceramic coating are magnesium aluminate spinel, aluminum oxide, titanium oxide, and zirconia-yttria. Spinel is the leading alternative.

E.2.1.1.1 *Potential Benefits*

The ceramic coating could increase waste package life and repository waste isolation performance by reducing corrosion of the waste package surface and, therefore, delaying the release of radionuclides.

E.2.1.1.2 *Potential Environmental Considerations*

There are no significant environmental considerations associated with ceramic coatings.

E.2.1.2 Drip Shields

Drip shields would provide a partial barrier by diverting infiltrating water away from waste packages in an emplacement drift. Drip shields could be metal (for example, Alloy-22, a nickel-chromium-molybdenum alloy, or titanium-7, a titanium metal alloyed with 0.15 percent palladium) or ceramic-coated metal. One option is to place drip shields under backfill; another is to place the drip shields over the backfill. Drip shields could be implemented with or without backfill.

If the drip shield was placed under backfill, it would fit over the entire length of each waste package, configured to the outer diameter with an unspecified clearance between drip shield and waste package, and enclosed at each end. Backfill, which would be emplaced during the repository’s closure, would be comprised of a heaped, single-layered material that covers the waste package and drip shield to some unspecified depth. Another form of backfill, the Richards Barrier, could also be used. Backfill and Richards Barriers are discussed later in this appendix.

The drip shield, as used in the second option, is formed to the approximate backfill surface profile and placed atop the backfill (or Richards Barrier). With this option, the drip shield is placed in conjunction with the placement of backfill at the closure of the repository.

E.2.1.2.1 *Potential Benefits*

Drip shields are intended to enhance long-term repository performance by reducing waste package corrosion and extending waste package life.

E.2.1.2.2 *Potential Environmental Considerations*

Additional labor hours would be required for the generation and placement of backfill material, and industrial accidents could increase proportionately. Although drip shields would be emplaced remotely, there could be some incidental radiological doses to workers.

Drip shields of titanium-7, Alloy-22, or other corrosion-resistant material would increase the demand for such materials. Costs for repository closure would increase due to the cost of procuring and installing the drip shields.

E.2.1.3 Backfill

At repository closure, loose, dry, granular material such as sand or gravel would be placed over the waste packages in a continuous, heaped pile. Other materials for backfill, such as crushed rock and depleted uranium, may be evaluated in the future.

E.2.1.3.1 *Potential Benefits*

Backfill would provide protection of waste packages and drip shields (if placed over the drip shields) from rockfall. It could protect against corrosion of the waste packages by (1) potentially capturing the corrosive salts of various soluble chemicals that might enter with water intrusion, (2) retarding advective flow, and/or (3) increasing the temperature of the emplacement drift to decrease relative humidity.

E.2.1.3.2 *Potential Environmental Considerations*

Additional workers would be needed, and there would be a potential increase for industrial accidents because of the additional operations. Although backfill would be placed remotely, there could be some incidental radiological doses to workers.

E.2.1.4 Waste Package Corrosion-Resistant Materials

The Viability Assessment reference design for the waste package uses two concentric barrier layers: an outer 100-millimeter (3.9-inch)-thick A516 carbon steel structural corrosion-allowance material, and an inner 20-millimeter (0.8-inch)-thick nickel-based alloy-22 corrosion-resistant material. These two barriers would be expected to provide substantially complete containment of the waste for the lifetime goals established in the Viability Assessment; however, a waste package with the capability to provide substantially complete containment for a significantly extended lifetime would be more desirable.

A variation of the waste package design would replace the corrosion-allowance barrier with a second corrosion-resistant barrier. This design would provide in-depth defense if the second corrosion-resistant barrier was independent of the first (for example, made of a different metal or ceramic). A number of configurations of waste package containers with two corrosion-resistant materials were analyzed, including designs with an inner layer of titanium and outer layer of nickel-based Alloy-22, with a combined thickness of about 55 millimeters (2.2 inches).

E.2.1.4.1 *Potential Benefits*

Longer waste package lifetimes would lead to improved long-term waste isolation performance of the repository.

E.2.1.4.2 *Potential Environmental Considerations*

The addition of a second independent corrosion-resistant layer would prolong waste package lifetimes, resulting in delay and minimization of potential groundwater contamination.

Radiological dose to workers would increase without compensating changes in operating procedures, because the total thickness of the waste package container could be less than the Viability Assessment reference design. Appropriate shielding might have to be provided for the workers engaged in waste package handling and emplacement operations. However, there would be a potential increased occupational dose to the workers because the calculated dose rates at the waste package surface would be higher.

E.2.1.5 Richards Barrier

A Richards Barrier would be formed by placing two layers of backfill over the emplaced waste packages at closure. The barrier would consist of a coarse-grained, sand-sized material underlying a fine-grained, sand-sized material. Both materials would be placed as a continuous, heaped pile extending along the alignment of the waste packages. A variety of materials could be used for both layers, including depleted uranium as a coarse-grained material.

The Richards Barrier would be designed to divert water that might enter the emplacement drifts away from the waste packages by transferring the vertical migration of water seepage laterally along the interface between the two layers. The particle size distribution, shape, and porosity of material in the two layers would provide a permeability difference and would cause the upper layer to channel water seepage along the boundary of the lower layer.

E.2.1.5.1 *Potential Benefits*

The Richards Barrier would delay the transport of water to the waste packages, thereby delaying waste package corrosion and improving long-term repository performance.

E.2.1.5.2 *Potential Environmental Considerations*

Dust and equipment emissions could be a concern during the placement phase of the Richards Barrier.

If the chosen coarse material was depleted uranium, there would be an increase in radon emissions. Uranium might also lead to an increase in the contamination of groundwater because the uranium in the Richards Barrier would not be contained or restricted by other engineered barriers. Radiation exposure would also have to be considered in design and operations of depleted uranium handling.

Additional workers would be needed during closure to implement this design feature, and there would be an increased potential for industrial accidents. Although personnel would not be in the drifts, there might be some incidental radiation dose to workers outside the drifts; therefore, additional shielding might be required for personnel.

E.2.1.6 Diffusive Barrier Under the Waste Package

A diffusive barrier would consist of loose, dry, granular material placed in the space between each waste package and the bottom of the emplacement drift to form a restrictive barrier to seepage. Below a critical seepage flux, water would disperse throughout the porous medium of the diffusive barrier, providing both lateral vertical dispersion and thereby slowing the fluid movement to the natural environment. Radionuclides, which might be released from breached waste packages, could become solubilized or suspended within the seepage flow and be retarded by the porous material forming the barrier.

The diffusive barrier could be anything from common sand to gravel-size material without any special qualifications to mineralogy, grain size distribution, shape, or density. Depleted uranium could also be used. The diffusive barrier would be installed prior to waste emplacement.

E.2.1.6.1 *Potential Benefits*

Improved waste isolation performance could be achieved by slowing radionuclide movement to the natural environment.

E.2.1.6.2 *Potential Environmental Considerations*

If the diffusive barrier material were depleted uranium, there would be increased radon emissions and increased radiological dose to workers. There could be an increase in the contamination of groundwater because the uranium would not be contained or restricted by other engineered barriers.

Additional workers would be needed to construct the diffusive barrier; therefore, there would be a proportional increase in the potential for industrial accidents.

E.2.1.7 Getter Under Waste Packages

A getter would be a fine-grained material [either phosphate rock (apatite) or iron oxide (hematite, geothite, etc.] with an affinity for radionuclides. This material would be placed in the invert recess below the waste packages prior to waste emplacement.

E.2.1.7.1 *Potential Benefits*

A getter material below the waste packages could improve long-term waste isolation through retardation of radionuclide movement from the repository drifts.

E.2.1.7.2 *Potential Environmental Considerations*

Additional workers would be needed to place the getter material in the drifts; therefore, there would be a proportional increase in the potential for industrial accidents.

E.2.1.8 Canistered Assemblies

Placing spent fuel assemblies in canisters at the Waste Handling Building before inserting them into waste packages would provide an additional barrier and further limit mobilization of radionuclides if the waste package is breached. The canisters would be fabricated from a corrosion-resistant material (for example, Alloy-22 or a zirconium alloy). There are three general concepts for the placement of fuel assemblies in canisters:

- Rectangular canisters designed to hold individual fuel assemblies: these canisters could be placed into a waste package with a basket containing neutron absorber and aluminum thermal shunts, similar to the current basket designs.

- Rectangular canisters designed to hold a few fuel assemblies: these canisters could have neutron absorber between assemblies and fit into a basket containing neutron absorber and aluminum thermal shunts.

- Large circular canister designed to hold multiple fuel assemblies and fit one per waste package: the canister would have an internal basket with neutron absorber, aluminum thermal shunts, and fuel tubes, similar to previous canistered fuel waste package designs.

E.2.1.8.1 *Potential Benefits*

Placing spent fuel assemblies in canisters before inserting them into waste packages would provide an additional barrier and limit mobilization of radionuclides in breached waste packages.

E.2.1.8.2 *Potential Environmental Considerations*

Use of this feature could cause an increase in the size of the Waste Handling Building and require additional workers. There would be an increase in operations and a possible increase in the number of lifts required per fuel assembly. This increase could be as much as one extra lift per assembly (canister), due to the moving of the canister to the waste package, which would lead to the potential for greater exposure to radiation for workers.

Implementation of this feature could increase the amount of rejected materials due to faulty welding, potentially generating more low-level radioactive waste and/or solid waste.

E.2.1.9 Additives and Fillers

Additives and fillers are materials that could be placed into waste packages (in addition to those normally required for the basket material) to fill the basket and waste form void spaces. The additives and fillers would:

- Sorb radionuclides and retard their release from a breached waste package
- Sorb boron neutron absorber that might be released from corrosion of the borated stainless steel absorber plates
- Displace moderator from the interior of the waste package to provide additional defense-in-depth for nuclear criticality control

Potential additives and fillers would be oxides of iron and aluminum. These materials could be placed within the waste package as a powder or as shot following loading of the waste form, or integrated into the basket design.

E.2.1.9.1 *Potential Benefits*

Additives and fillers could improve long-term repository performance by retardation of release of radionuclides to the groundwater and could also improve long-term criticality control.

E.2.1.9.2 *Potential Environmental Considerations*

Adding additives and fillers would make it more difficult to remove spent nuclear fuel assemblies from waste packages following retrieval, if necessary. Operations would have to include the additional step of removing this material before removal of the fuel.

E.2.1.10 Ground Support Options

Ground support in the repository ensures drift stability before closure. Selection of ground support options could affect repository waste isolation performance. Considerations of ground support options include functional requirements for ground support, the use of either concrete or steel-lined systems, and the feasibility of using an unlined drift ground support system with grouted rock bolts.

A concrete lining has been studied for its structural/mechanical behavior and subjected to the load conditions expected of emplacement drifts. However, a number of postclosure performance assessment issues related to the presence of concrete within the emplacement drift environment have been identified.

An all-steel ground support system (for example, steel sets with partial or full steel lagging) has been considered to be a viable ground support candidate for emplacement drifts. Use of an all-steel lining system would provide a means of limiting or eliminating the introduction of cementitious materials (that is, concrete, shotcrete, or grout), including organic compounds into the emplacement drift environment. The potential for corrosion of steel subjected to the emplacement drift environment is a concern with this system. Another concern is the interaction of steel ground supports with waste package materials.

For an unlined drift scenario, rockbolts and mesh could be considered as permanently maintainable ground support. Design and performance advantages associated with the use of rockbolts as permanent ground support for emplacement drifts include durability and longevity of this system. A postclosure concern would be the suitability of cementitious grout, which would be used for installing rockbolts.

E.2.1.10.1 *Potential Benefits*

Safety during emplacement and potential retrieval would be enhanced by use of appropriate ground supports. Long-term repository performance could be improved by reducing or delaying damage to canisters from rockfall, because damaged areas would be locations for enhanced corrosion even if the canister was not breached by the rockfall.

E.2.1.10.2 *Potential Environmental Considerations*

The choice of ground support options does not significantly impact any environmental consideration except for long-term repository waste isolation performance.

E.2.2 REPOSITORY DESIGNS TO CONTROL HEAT AND MOISTURE

E.2.2.1 Design Alternative 1, Tailored Waste Package Spatial Distribution

Tailored spatial distributions of waste packages within the repository block emplacement drifts could improve the postclosure waste isolation performance of the repository. The EIS design assumes the various waste package types would be emplaced on a random basis, modified only to meet the areal mass loading requirement of 25 to 85 MTHM per acre and the commercial fuel cladding and drift wall thermal goals of 350°C and 200°C (662°F and 392°F), respectively. There are three different methods of spatial distribution under review, including:

- Distribution of waste packages as a function of infiltrating water percolation rate within various regions of the repository block. Higher heat-producing packages would be placed in areas with higher percolation rates.

- Distribution of commercial spent nuclear fuel waste package types as a function of the distance to the water table and/or unsaturated zone zeolite content. Waste packages with radionuclides with the highest tendency to travel would be placed furthest from the water table, and waste packages with radionuclides with a higher tendency to be sorbed would be placed above areas with the highest zeolite content.

- Grouping waste package types into categories of hot, medium, and cold waste packages to even out the temperature differences across the repository.

E.2.2.1.1 *Potential Benefits*

Tailoring spatial distribution of the waste packages within the repository block might improve the performance of waste packages by delaying and reducing contact of water and/or increasing sorption of released radionuclides by zeolites in the unsaturated zone. This form of distribution has the potential to improve repository waste isolation performance.

E.2.2.1.2 *Potential Environmental Considerations*

Larger surface storage facilities could be needed to allow appropriate selection of waste packages for the desired spatial distribution. However, if the retrieval pad can be used for this purpose, no additional land would be needed.

E.2.2.2 Design Alternative 2, Low Thermal Load

The low thermal load design alternative would limit the temperature of the drift wall and host rock. It would cause less thermal change in the host rock than the Viability Assessment reference design. Limiting temperature rise would also reduce the uncertainty in predicting several processes, and thermal, chemical, mechanical, and hydrological effects would be easier to describe because coupling of these effects would extend over a smaller region than the Viability Assessment reference design. In this evaluation, a low thermal load refers to 40 MTHM per acre.

- *Option 1.* The waste package spacing would be the same as the spacing of the drifts, creating a square area between waste packages. The spacing of waste packages would be farther apart than in the Viability Assessment reference design. This option is the equivalent of the low thermal load implementing alternative analyzed in the EIS.

- *Option 2.* The spacing of the waste packages within the drifts would be 9 meters (30 feet) as in the Viability Assessment reference design, but drift spacing is increased to about 90 meters (300 feet). This can be compared to 28 meters (92 feet) for the Viability Assessment reference design.

- *Option 3.* This option consists of a greater number of smaller waste packages than in Option 1 or 2, and spacing of waste packages within the drifts is similar to Option 2. Drift spacing and excavated rock volume are about the same as for Option 1.

E.2.2.2.1 *Potential Benefits*

The primary benefit would be the reduction in uncertainties associated with higher thermal loads and the elevated temperature of the host rock. Lower repository temperatures could also potentially reduce waste package material corrosion rates.

E.2.2.2.2 *Potential Environmental Considerations*

Options 1 and 3 would result in generation of more excavated rock compared to the Viability Assessment reference design, and therefore requires a larger area for storage/disposal of excavated rock. Subsurface costs would increase. Option 2 would result in less volume of excavated rock than Option 1 or 3.

E.2.2.3 Design Alternative 3, Continuous Postclosure Ventilation

Under this alternative there would be continuous ventilation of the emplacement drifts during the postclosure period. Ventilation would occur by natural ventilation pressure induced by the difference in air density between hot and cool areas. Three primary options were considered:

- Closed loop airways connected underground but sealed to the surface

- Open loop airways where the primary airways stay open and in which the repository drifts are open to exchange air with the atmosphere; two additional ventilation shafts would be needed

- Open/closed loop ventilation where primary airways would be sealed, but drifts would be located very close to a system of tunnels open to the atmosphere

E.2.2.3.1 *Potential Benefits*

Postclosure ventilation would increase the removal of moisture from air around the waste packages for a period of time (estimated to be 1,000 to 2,000 years for the closed loop system), but moisture would eventually reestablish itself. Reduced moisture could improve performance by retarding waste package corrosion.

E.2.2.3.2 *Potential Environmental Considerations*

Excavated rock piles would increase in size in proportion to the increase in drift excavation required. Additional shafts would result in additional surface disturbed areas (small, relative to the Viability Assessment reference design). Additional occupational exposure to radon-222 associated with excavation would occur.

Overall, work force would increase by less than 10 percent, as would associated impacts such as industrial accidents.

E.2.2.4 Design Alternative 6, Viability Assessment Reference Design

The Viability Assessment reference design is equivalent to the high thermal load alternative evaluated in the EIS.

E.2.2.5 Design Alternative 7, Viability Assessment Reference Design with Options

The Viability Assessment reference design with options was considered as a design alternative in the License Application Design Selection Process. The Viability Assessment reference and design is analyzed in detail in the EIS. Options considered include ceramic coatings, drip shields, and backfill (see Sections E.2.1.1, E.2.1.2, and E.2.1.3, respectively).

E.2.2.6 Aging and Blending of Waste

Pre-emplacement aging and blending of wastes provides mechanisms for managing the thermal output of a waste package and the total thermal energy that must be accommodated by the repository.

Aging the waste before emplacement results in less variable (over time) thermal output of the waste packages and lower waste package temperatures. Aging could be performed at the repository, at the reactor sites, or at other locations.

Blending would allow a more uniform heat output from the waste packages. Blending would be accomplished by selecting waste forms for insertion in waste packages based on their heat output to minimize the variability in the thermal energy of each waste package.

E.2.2.6.1 *Potential Benefits*

Aging would reduce the temperature increase expected at the surface above the repository because the total heat load of the repository would be decreased. Lower heat output could also result in a smaller repository footprint by allowing more dense waste emplacement schemes without violating waste package or drift wall temperature goals. Both blending and aging reduce the variability of the temperature distribution in the repository, and drifts might be spaced more closely. Lower and equalized temperatures could improve structural stability of the drifts. Aging and blending would improve waste package stability (reducing rockfall-induced damage and corrosion) and improve long-term repository performance.

E.2.2.6.2 *Potential Environmental Considerations*

The blending feature might require a significantly larger storage pool size. This would increase the size of the pool storage building, and result in correspondingly higher costs. The Viability Assessment reference design staging pools have the capacity for about 300 MTHM. This would be reconfigured and expanded to allow for storage of up to 6,500 MTHM. Expanded pool storage would require additional resources (steel, concrete, gravel and asphalt, fuel, electricity and water for construction and operation, but the increases would not be significant (about 10 percent). Waste generation would also increase. During operations, use of well water will increase by about 15 percent. Well water is used to replace evaporative losses in the pools. Land use does not increase. Increases in worker population mean an increase in the potential for industrial accidents. Cumulative annual dose to workers would increase slightly, but the average dose to workers would not increase.

If aging is done at the Yucca Mountain site, a surface storage facility would be required. The effects of the aging feature are identical to the retrieval contingency discussed in the EIS because the same size storage facility/pad would be needed. The retrieval contingency assumes a surface storage facility able to handle the entire repository inventory.

E.2.2.7 Continuous Preclosure Ventilation

Continuous preclosure ventilation would provide increased air flow in the emplacement drifts compared to the reference design preclosure ventilation rate of 0.1 cubic meter (3.5 cubic feet) per second. The system would be shut off at closure.

Additional excavation would be required for an additional exhaust main. The actual number of emplacement drifts would not change, but the layout of drifts would vary slightly to accommodate the additional ventilation shafts. The sizes of the shafts would have to be increased and more would need to be added. Access drifts and additional connections would have to be added between the exhaust mains and the shafts.

E.2.2.7.1 *Potential Benefits*

Continuous ventilation in the preclosure period could reduce the rock wall and air temperature. It could also remove enough moisture to reduce the length of time the waste packages are exposed to temperature/moisture conditions that could result in higher corrosion rates. The removal of moisture also would increase the stability of the ground-support system. In addition, with lower drift temperatures retrieval would be easier.

E.2.2.7.2 *Potential Environmental Considerations*

Additional drifts and intake and exhaust shafts would be required to handle the additional airflow quantities, resulting in additional excavated rock. Additional shaft locations would disturb land surface in the limited locations available to place the` shafts, and roads would have to be constructed to the shaft sites. Additional shafts and night lighting at the top of the mountain might be visible from off the Yucca Mountain site.

The changes in repository ventilation would increase emissions of naturally occurring radon-222 and its radioactive decay products in the air exhausted from the subsurface. Power requirements could increase substantially during emplacement operations and postclosure monitoring.

The number of workers would increase by less than 10 percent, with an attendant increase in the potential for industrial accidents.

Closure would be more difficult because there would be additional openings to seal.

E.2.2.8 Drift Diameter

The emplacement drift diameter is a secondary design feature because the diameter is determined by a number of primary design features. The size of the emplacement drift could directly affect design considerations such as opening stability (rockfall potential), the extent of the mechanically induced disturbed zone, and the amount and location of seepage into the drifts.

The drift diameter for the Viability Assessment reference design is 5.5 meters (18 feet). A range of drift diameters is being considered [from 3.5 meters (11 feet) to 7.5 meters (25 feet)].

E.2.2.8.1 *Potential Benefits*

A smaller diameter drift is inherently more stable and could reduce the need for ground-support systems, potentially reducing costs. The smaller drift diameter would also be less susceptible to water seepage. A larger diameter allows for other modes of emplacement, such as horizontal or vertical borehole emplacement. Both of these emplacement modes would reduce the potential for damage to waste packages from rockfall, therefore potentially improving long-term performance of the repository.

E.2.2.8.2 *Potential Environmental Considerations*

An increase in drift diameter could increase the potential for rockfall (both size and frequency) and decrease the overall opening stability. Rockfall could breach waste packages or cause lesser damage to the packages, providing locations for accelerated corrosion. Also, the larger the drift diameter, the more vulnerable it would be to water entry from seepage flow.

A smaller drift diameter would be inherently more stable in highly jointed rock and a decreased rockfall size would be anticipated. A change to a smaller diameter could allow modification to the ground-support system with possible elimination of a full circle drift liner. Although a smaller drift diameter would be less susceptible to seepage, the smaller diameter drift might result in short-term increases of temperature, which could affect the characteristics of potential groundwater movement.

Increasing the emplacement drift diameter would result in an increase in the quantity of excavated rock and increased use of equipment and materials, higher releases of radon-222, and lower ventilation air velocity. The lower air velocity would result in greater quantities of radon–222 and dust during development, an important consideration for preventing suspension of respirable silica dust.

A smaller drift diameter, although reducing the potential of radon-222 releases, might not be able to provide the quantities of air necessary for ventilation without raising velocities to undesirable levels. Increased drift diameter would require more workers for tunnel boring machine operations, excavated rock handling, ground-support installation and finishing works, surface equipment operators, and maintenance. A decrease in the drift diameter would have an opposite affect on the worker requirements;

that is, with a larger drift diameter, the additional excavation work would produce an increase in worker accidents. Larger tunnel boring machines could require substantially more electrical power.

E.2.2.9 Drift Spacing and Waste Package Spacing

In repository design, thermal load refers to a density at which the waste packages will be emplaced in the repository. The Viability Assessment reference design involves emplacement of waste packages in drifts in a horizontal mode, and thermal load is directly related to the emplacement drift and waste package spacing. The Viability Assessment reference design used a spacing of 28 meters (92 feet) between drifts.

For a given drift spacing, emplacement of waste packages can be arranged by using point load (waste package spacing determined based on individual waste package characteristics, such as mass content or equivalent heat output of each waste package), or line load [waste packages are emplaced nearly end to end that is, with a 0.1-meter (0.3-foot) gap with no considerations of individual waste package characteristics].

The point load approach was used for the Viability Assessment reference design. Waste-package spacing was determined based on mass content of waste packages, to achieve an overall area mass loading of 85 MTHM per acre for commercial spent nuclear fuel.

The line load method would be expected to provide a more intense and uniform heat source along the length of emplacement. An increase in emplacement drift spacing would be required in conjunction with line loading to maintain a constant overall thermal loading density (for example, 85 MTHM per acre).

E.2.2.9.1 *Potential Benefits*

The line load approach would keep the emplacement drifts hot and dry longer and would decrease the amount of water that could contact waste packages. Consequently, waste package performance could be improved. The line load approach would also reduce the number of emplacement drifts needed for waste emplacement. However, the concentrated heat load in the drifts could require continuous ventilation of emplacement drifts to meet the near-field temperature requirements. Continuous ventilation is discussed in Section E.2.2.7.

E.2.2.9.2 *Potential Environmental Considerations*

Line loading would require excavation of about 30 fewer emplacement drifts, with correspondingly less excavated rock, dust, and pollutants from diesel- and gasoline-powered equipment and vehicles. Decreased excavation would also reduce radon-222 release in the underground facility. However, decreasing the waste package spacing would result in potentially large increases in the rock temperatures in and near the emplacement drifts. This could create the need for continuous ventilation of emplacement drifts, which could increase emissions of naturally occurring radon-222 and its radioactive decay products in the air exhausted from the subsurface.

The reduction in total work and material requirements would be expected to be linearly proportional to the reduction in required drift length. Fewer work hours would also result in less potential for industrial accidents during construction. Decreased emplacement drift excavation would reduce the demand for electric power, equipment fuel, construction materials, and site services. However, the higher drift temperature associated with the line load option could require continuous ventilation of emplacement drifts.

E.2.2.10 Near-Field Rock Treatment

Near-field rock treatment involves injection of a grout material into the cracks in a portion of the rock above each emplacement drift to reduce the hydraulic conductivity of the treated rock. Injection would start at least 6 meters (20 feet) above the drift crown and would form a zone at least 4 meters (13 feet) thick, extending at least 6 meters on each side of the drift. Injection would be through holes 2.5 to 5 centimeters (1 to 2 inches) in diameter drilled from inside each drift prior to waste emplacement. Injection pressures would not exceed a certain minimum pressure, selected to limit rock fracturing or joint opening.

The candidate materials include Portland cement grout, sodium silicate, bentonite (a clay), and calcite.

E.2.2.10.1 *Potential Benefits*

Reducing the hydraulic conductivity of the rock would improve long-term repository performance by reducing or retarding postclosure water seepage into the drifts.

E.2.2.10.2 *Potential Environmental Considerations*

Installation of the grout material would require additional labor hours, with an associated change in the potential for industrial accidents.

E.2.2.11 Surface Modification – Alluvium Addition

Covering the surface of Yucca Mountain above the repository footprint with alluvium could decrease the net infiltration of precipitation water into the repository by increasing evapotranspiration. To cover the mountain with alluvium, the surface of the mountain would be modified to prevent the alluvium from washing away. Ridge tops on the eastern flank of Yucca Mountain would be removed and the excavated rock placed in Solitario Canyon and in Midway Valley or used to fill the alluvium borrow pit. The maximum slope of the ground surface remaining would be approximately 10 percent. Alluvium [approximately 2 meters (7 feet) thick] would be placed on the new surface and vegetation would be established. New haul roads to move the necessary materials would have to be constructed.

E.2.2.11.1 *Potential Benefits*

Reduced net infiltration would improve long-term repository performance. However, there is uncertainty about the permanence of both the vegetation and the alluvium that would be added to the surface of Yucca Mountain.

E.2.2.11.2 *Potential Environmental Considerations*

Approximately 8 square kilometers (2,000 acres) on Yucca Mountain would be resloped and covered. The excavated material would cover 4.8 square kilometers (1,200 acres) in the fill area in Solitario Canyon. The borrow pit would be about 5.2 square miles (1,300 acres). Additional access roads would also be needed. Yucca Crest would be lower by approximately 30 to 60 meters (98 to 197 feet) the ridges on the east side of Yucca Crest would be lowered by as much as 80 meters (262 feet). Quantities of material to be moved would include:

- Total rock cut from Yucca Mountain 220 million cubic meters (17,600 acre-feet)
- Total alluvium removed from the alluvium borrow pit (probably in Midway Valley) about 22 million cubic meters (17,600 acre-feet)

The operation would be equivalent to a major, large-scale open pit mining operation. It would likely require a labor force of about 75 people per shift. There would be an increase in the potential for industrial accidents because of the additional work. Generation of particulate emissions (fugitive dust) and gaseous criteria pollutant emissions from vehicles would increase.

There would be alterations to natural drainage; however, the potential for flooding would not increase with proper design.

The view to and from Yucca Mountain would be altered. Mining operations at the top of the mountain would be visible for some distance, and the mountain would be considerably lower. Vegetation would be restored because the design requires vegetation as part of the evapotranspiration process. The operation would be carried out on three shifts, and night lighting on the top of the mountain could be visible to the public.

E.2.2.12 Surface Modification – Drainage

Surface modification could reduce infiltration at the surface of the mountain. Net infiltration into Yucca Mountain could be significantly decreased if the thin alluvium layer over the footprint of the repository were removed to promote rapid runoff of the surface water. It has been shown that where the alluvium is thin, it retains the surface water and allows it to infiltrate into the unsaturated zone. Where bedrock is exposed on slopes, the water runs off rapidly and net infiltration is very small or reduced to zero.

The thin alluvium layer would be stripped from the topographic surface above the repository footprint and a 300-meter (984-foot) buffer surrounding it.

E.2.2.12.1 *Potential Benefits*

Reduced infiltration would result in improved long-term repository waste isolation. However, there is uncertainty about the permanence of alluvium removal. In addition, while infiltration might be reduced on the top of the mountain, infiltration could increase in other areas because of the higher volumes of surface water runoff.

E.2.2.12.2 *Potential Environmental Considerations*

The amount of land modified to improve drainage would be approximately 1,100 acres, located mainly on the eastern flank of Yucca Mountain. Additional road construction would also be required. The removed alluvium, about 2.1 million cubic meters (2.7 million cubic yards), would be placed in Midway Valley. There would be alterations to natural drainage, and the increased runoff could increase the potential for flooding. The landforms would be changed only slightly because of the thin [less than 0.5-meter (1.6-foot) thick] alluvium that would be removed. Any existing vegetation on the side of the ridges would be removed during the process of alluvium removal. Bare bedrock would be exposed, which would discourage vegetation from growing except from cracks in the rock.

Additional workers would be required, and there would be an accompanying increase in the potential for industrial accidents.

Night lighting would be needed to support this operation that could be visible from off the site.

E.2.2.13 Higher Thermal Loading

Higher thermal loading would keep the drift temperature above the boiling point longer, thereby minimizing the amount of moisture around the waste package during a longer postclosure period. The higher thermal loading could also have adverse effects on the surrounding rock. This feature could also be combined with aging to achieve greater mass loading per acre of repository area.

Higher thermal loads could be achieved by either decreasing drift spacing, by placing waste packages closer together in the drift, or by a combination of drift spacing and waste package spacing. In all three cases, the increased number of waste packages in a given area would result in a higher thermal load to a given area of the repository.

The benefits and environmental considerations associated with this feature would be similar to those discussed under Drift Spacing and Waste Package Spacing (Section E.2.2.9).

E.2.3 REPOSITORY DESIGNS TO SUPPORT OPERATIONAL AND/OR COST CONSIDERATIONS

E.2.3.1 Design Alternative 4, Enhanced Access

The purpose of the enhanced access design would be to provide additional shielding around the waste package to allow for personnel accessibility during waste package loading, transfer to the drift, emplacement, and performance confirmation. Shielding would lower the dose rate to less than 25 millirem per hour. Enhanced access could be provided by:

- Additional shielding integral to the waste package
- Supplemental (separate from the waste package) shielding in the emplacement drifts only
- Portable shielding for personnel to access the drift

E.2.3.1.1 *Potential Benefits*

The major benefit of these three options would be to provide access to the emplacement drifts so personnel could carry out performance confirmation activities. Enhanced access designs could also offer increased access for maintenance and ease of operations, and the potential elimination of some remote handling equipment. If shielding were left in place at closure, it could provide additional protection for waste packages from rock falls.

E.2.3.1.2 *Potential Environmental Considerations*

Increased personnel access would increase occupational exposure, even with the additional shielding. Enhanced access would decrease the number of observation and performance confirmation drifts needed, and slightly decrease the volume of excavated rock piles.

The addition of shielding to waste packages would result in increased materials usage. Shielding materials could be steel, concrete, magnetite concrete (concrete with iron shot included), or Ducrete® (concrete with depleted uranium included).

E.2.3.2 Design Alternative 5, Modified Waste Emplacement Mode

In a modified waste emplacement design, unshielded waste packages would be emplaced in a configuration in which the repository's natural or engineered barriers would provide shielding. Examples include placing waste packages in boreholes drilled into the floor or wall of emplacement drifts, in alcoves off the emplacement drifts, in trenches at the bottom of the emplacement drifts, or in short cross drifts excavated between pairs of excavated drifts. In each case, some type of cover plug would be used to shield radiation in the emplacement drifts.

Unshielded waste packages, which in some designs would have a smaller capacity than specified in the Viability Assessment reference design, would be used.

E.2.3.2.1 *Potential Benefits*

Natural or engineered barriers would enhance human access, reduce performance confirmation costs, and facilitate conducting inspections and maintaining ground support. Retrieval operations would also be easier because of easier access.

E.2.3.2.2 *Potential Environmental Considerations*

The footprint of the repository would not change, but the amount of excavated rock would increase. The vertical borehole emplacement concept would generate the most additional excavated rock. Peak power consumption would increase substantially because of the use of additional boring machines.

E.2.3.3 Design Alternative 8, Modular Design (Phased Construction)

Modular design is an alternative that could reduce annual expenditures during construction if annual funding is constrained below that required for the Viability Assessment reference design. This alternative would include staged modular construction of repository surface and subsurface facilities.

The modularized Waste Handling Building would be designed to handle specific types of waste forms and quantities. The modular concept would include one Waste Handling Building completed in modular phases or two separate buildings constructed in sequence.

E.2.3.3.1 *Potential Benefits*

The primary benefit would be leveled cash flow during construction.

E.2.3.3.2 *Potential Environmental Considerations*

The dual buildings would increase the overall size of the Waste Handling Building by an estimated 10 percent. The Radiologically Controlled Area could increase by about 10 percent or less. Operating times (years of operation) would be extended and operations would be at a lower rate.

Some options would involve receipt of spent nuclear fuel from reactor sites prior to the start of emplacement that could increase worker dose because it would have to be handled twice.

E.2.3.4 Rod Consolidation

Both pressurized-water reactor and boiling-water reactor fuel assemblies have fuel rods arranged in regular square arrays with rod-to-rod separation maintained by the fuel assembly hardware. Rod consolidation would involve eliminating this separation and bringing the fuel rods into close contact. Reducing the volume taken up by fuel assemblies would allow the capacity of waste packages to be increased and/or the size of waste packages to be reduced. Consolidation could be done at either the current spent fuel storage locations or at the repository.

Rod consolidation would be accomplished by removing fuel rods from an assembly, repackaging the rods in a denser arrangement in a suitable canister, and loading the new canister into a waste container. This process could occur either in a pool or in a dry (hot cell) environment.

E.2.3.4.1 *Potential Benefits*

A reduced number or size of waste packages would be possible and could result in reduced emplacement costs. If rod consolidation took place at the reactor sites, waste transportation requirements might be reduced.

E.2.3.4.2 *Potential Environmental Considerations*

Because of the disassembly operations, the size of the Waste Handling Building would more than double in area if rod consolidation were done at the repository. With the large number of fuel rod handling operations in the hot cells, there would be a greater potential for radiological releases due to fuel handling accidents (such as dropping a fuel rod/assembly).

The number of workers at the repository could increase if rod consolidation were performed at the repository. With an increase in the number of fuel handling operations, the number of fuel handling accidents would increase and result in a small increase in radiological exposure for onsite workers.

Approximately 10 to 40 kilograms (22 to 88 pounds) of leftover, nonfuel components from each as-received fuel assembly would be packaged as Class C or Greater-Than-Class-C low-level wastes. In addition, low-level waste would be generated by decontamination and disposal of equipment. Low-level waste would be transported to the Nevada Test Site or other appropriate facility for disposal. Greater-than-Class-C wastes could be disposed of offsite or in the repository with approval of the U.S. Nuclear Regulatory Commission.

Waste packages containing consolidated fuel rods might result in higher cladding temperatures, which could damage the cladding and have negative impacts on waste isolation performance.

E.2.3.5 Timing of Repository Closure

The first option assumes that the subsurface facilities would be fully maintained to the same level of readiness during the 300-year period as planned for the 100-year period assumed for the Viability Assessment reference design. There would be continuous ventilation during the entire 300-year period. The second option assumes the Nuclear Regulatory Commission would have approved completion of the Performance Confirmation Program at the end of the first 100 years, and that continued access to the emplacement drifts would no longer be required. The second option considers that ventilation, maintenance, and repairs would be reduced to a minimum for cost considerations, but that temperatures would be maintained at 50°C (122°F) or less for human access to the subsurface (nonemplacement) facilities.

E.2.3.5.1 *Potential Benefits*

Extending the period before final closure would allow for reduction of waste package heat output, extended monitoring, and extended retrieval period for the waste.

E.2.3.5.2 *Potential Environmental Considerations*

Delayed closure of the repository would lengthen the time that land would remain disturbed through the occupation of surface facilities necessary to support extended operations from 100 to 300 years. It would delay the reclamation of surface stockpiles retained for filling the mains, ramps, and shafts.

The release of radon-222 from excavations is proportional to time. Delayed closure from 100 to 300 years would increase the emissions of radon-222 by a factor of approximately 3.6.

The number of workers required for monitoring would not change. However, the number of labor hours required, compared to the Viability Assessment reference design monitoring period, would be 3.6 times the number required for closure at 100 years. The base case scenario requires the periodic retrieval of waste packages for performance confirmation testing. An increase in the monitoring period from 76 to 276 years would increase radiation exposure due to increased waste package handling. More frequent inspections would be likely during this extended period due to aging. Additionally, emplacement drifts maintenance would require removal and re-emplacement of waste packages. An increased monitoring period would increase the potential for industrial accidents and radiological exposure.

E.2.3.6 Maintenance of Underground Features and Ground Support

A maintenance program in the emplacement drifts would be needed to accommodate an extended long-term repository service life and to reduce the risk of keeping the repository open for an additional 200 years. Repository emplacement drift ground support components would have to be designed and maintained for a service life of greater than 300 years, including closure and retrieval times.

E.2.3.6.1 *Potential Benefits*

The benefits are the same as those listed in Section E.2.3.5.1

E.2.3.6.2 *Potential Environmental Considerations*

Some types of maintenance in the emplacement drifts would require retrieval of waste packages for maintenance access. Blast cooling would be needed to lower the temperature to below 50°C for worker access. There could be additional radiological exposure to workers.

E.2.3.7 Waste Package Self-Shielding

In the Viability Assessment reference design, handling of waste packages in the emplacement drifts would be performed remotely, and human access to the emplacement drifts would be precluded when waste packages are present. Waste package self-shielding would reduce the radiation in the drifts to levels such that personnel access would be possible. This would allow direct access to the performance confirmation instrumentation, and maintenance and repair in the drifts.

Self-shielding would be accomplished by adding a shielding material around the waste packages. Candidate materials include A516 carbon steel, concrete with depleted uranium (Ducrete®), magnetite concrete, and a composite material of boron-polyethylene and carbon steel.

The amount of shielding would depend on the target radiation dose level in the drift environment. For a 25-millirem-per-hour waste package contact dose, the estimated thickness of the concrete would be about 0.6 meter (2 feet). For higher contact doses, less shielding material would be required.

E.2.3.7.1 *Potential Benefits*

Monitoring, maintenance, and retrieval would be easier with contact handling of the waste packages.

E.2.3.7.2 *Potential Environmental Considerations*

Self-shielding could not be used with high thermal loading because the shielding would provide a thermal barrier that would result in excessive fuel cladding temperature. Smaller waste packages would maintain a constant outside diameter but would also require about four times as many waste packages and more drifts. Radon-222 emissions would increase in proportion to the additional excavation.

Concrete shielding would be applied at the repository, and the number of workers would slightly increase, as would the number of industrial accidents. There could be a reduction in radiological exposure to workers during emplacement operations. The concrete shielding could degrade the long-term performance of the waste packages.

E.2.3.8 Repository Horizon Elevation

This feature considers a two-level repository to increase repository capacity without moving out of the characterized area.

One two-level concept would divide the Viability Assessment reference design layout along a north-south axis and would relocate the western half above the eastern half. A second two-level concept would duplicate the Viability Assessment reference design layout 50 meters (164 feet) above the current footprint. The thermal loading of each level could be adjusted to increase the capacity.

E.2.3.8.1 *Potential Benefits*

There would be two potential advantages to repository long-term performance. Increased thermal load would potentially enhance the umbrella effect (this could reduce the amount of water that could come in contact with the waste package). There would also be added flexibility in emplacing waste packages on the lower level, which could be shielded from moisture infiltration by the upper level horizon.

Retrieval could be accomplished more quickly due to the ability to operate two independent retrieval operations at the same time.

E.2.3.8.2 *Potential Environmental Considerations*

The first two-level concept could use slightly less land area to store excavated rock because less material would be excavated. The second two-level concept could double the excavation and double the excavated rock volume that would require storage.

Surface soil temperatures could increase due to locating waste closer to the surface and/or increasing thermal loading per acre.

Construction of the full size footprint two-tier repository would require slightly less than double the number of workers and a longer construction period, with associated changes in the potential for industrial accidents. Power consumption would approximately double.

E.3 Enhanced Design Alternatives

Enhanced Design Alternatives are combinations of the alternatives and design features described in preceding sections. These concepts were developed to cover a range of potential repository designs as part of the License Application Design Selection Process described in Section E.1.2. Enhanced Design Alternatives are intended to be improvements to the basic design alternatives discussed in Section E.2. Five Enhanced Design Alternatives are described below, along with the design concepts that led to their development. Potential benefits and environmental considerations are discussed in the sections above dealing with the design alternative and design features incorporated into each Enhanced Design Alternative.

At the time of development of this appendix, the Enhanced Design Alternatives discussed below had been developed, but documentation of the Enhanced Design Alternative development process was forthcoming. That documentation was scheduled to be complete in May 1999. The Enhanced Design Alternatives described in the following sections are preliminary and based on observations of the License Application Design Selection Process and informal discussions with process participants.

E.3.1 ENHANCED DESIGN ALTERNATIVE I

Enhanced Design Alternative I is a low-temperature design intended to remove uncertainties and modeling difficulties associated with above-boiling temperatures. Lower temperatures would mean less disturbance of the subsurface and limit the combined effects of thermal, hydrological, and geochemical processes that are more pronounced in above-boiling-temperature environments.

The goals of Enhanced Design Alternative I are to keep the drift wall temperature below the boiling point of water and the commercial fuel cladding temperature below 350°C (662°F). This would be achieved for the Enhanced Design Alternative I design by limiting areal mass loading to 45 MTHM per acre, increasing the size of the repository to 6 square kilometers (1,500 acres), and using smaller waste packages. Drift spacing would be 43 meters (141 feet) between drift centerlines, with an average end-to-end waste package spacing of 3 meters (10 feet). Preclosure ventilation would use two intake and three exhaust shafts.

The waste package design for this Enhanced Design Alternative would consist of two layers, with Alloy-22 on the outside and 316L stainless steel (nuclear grade) on the inside. Flexible waste package spacing would be used to control the drift temperature. Blending would be used to reduce the maximum thermal output of a waste package to 6.7 kilowatts. To optimize selection of waste for emplacement, additional surface storage capacity above and beyond that in the Viability Assessment reference design would be necessary. A 2-centimeter (0.8-inch)-thick titanium-7 drip shield, to be placed over the waste package just prior to closure, is included in this design to provide defense in depth.

This design allows human access using blast cooling and portable shielding [15 centimeters (6 inches) stainless steel and 7.5 centimeters (3 inches) borated polyethylene].

The major disadvantage of this design is that it uses all of the available space in the upper repository block. Another disadvantage is that it uses smaller waste packages, requiring about 6,000 more waste packages than other Enhanced Design Alternatives.

E.3.2 ENHANCED DESIGN ALTERNATIVE II

Enhanced Design Alternative II is a moderate temperature design intended to keep commercial fuel cladding temperature below 350°C (662°F) and to keep the boiling fronts from merging in the rock walls between the drifts. Keeping a non-boiling area between the drifts ensures that there would be sufficient area between the drifts that would be below the boiling point to allow water to drain. The areal mass loading could be up to 60 MTHM per acre and still achieve these goals.

The waste package design would consist of two layers with Alloy-22 on the outside and 316L stainless steel on the inside. Blending would be used to reduce the maximum heat output of a waste package to 9 kilowatts. The emplacement area would be 4.3 square kilometers (1,064 acres), and the waste package design would be the same as for Enhanced Design Alternative I. The Enhanced Design Alternative II design would use closely spaced waste packages, line loading, and a drift spacing of 81 meters (266 feet). To optimize selection of waste for emplacement, additional surface storage capacity above and beyond that in the Viability Assessment reference design would be necessary. This design also includes backfill, a 2-centimeter (0.8-inch)-thick titanium-7 drip shield placed just prior to closure, as in Enhanced Design Alternative I. Continuous ventilation would be used for the 50-year preclosure period.

An advantage of this design is that it would reduce or avoid uncertainties associated with the thermal period or thermal pulse where large quantities of water could pool above the repository area. The cooler pillars between the drifts would allow for drainage of waters. However, an uncertainty is that the drainage of water has not been demonstrated. Another advantage is that the design provides flexibility for modification to either a hotter or cooler design.

E.3.3 ENHANCED DESIGN ALTERNATIVE III

Enhanced Design Alternative III is a high thermal load design. The goals are to keep the drift wall temperatures below 200°C (329°F), the commercial fuel cladding temperature below 350°C (662°F), and to ensure that the waste package surface temperature cools to below 80°C (176°F) before the relative humidity at the waste package surface rises above 90 percent. These goals would be met with an 85 MTHM per acre loading, close [0.1 meter, (0.3 foot)] spacing of line-loaded waste packages, and a drift spacing of 56 meters (184 feet).

Two different waste packages are considered (Enhanced Design Alternatives IIIa and IIIb). The Enhanced Design Alternative IIIa waste package would use a two-layer design with 2 centimeters (0.8-inch) of Alloy-22 over 5 centimeters (2 inches) of 316L stainless steel (as in Enhanced Design Alternatives I, II, and V). The Enhanced Design Alternative IIIb waste package design would use a waste package with an outer layer of 2.2 centimeters (0.9 inch) of Alloy-22 over 1.5 centimeter (0.6 inch) of titanium-7 that have been shrink-fitted together, and a 4-centimeter (1.6-inch) inner layer of 316L stainless steel that would fit loosely (gap of 4 millimeters or less) inside the Alloy-22/titanium-7 shell.

Blending would not be used in Enhanced Design Alternative III. However, preclosure ventilation of at least 5 cubic meters (177 cubic feet) per second would be needed for a minimum of 50 years to achieve the temperature goals of this Enhanced Design Alternative. This would require two intake and three exhaust shafts in addition to the access tunnels. Enhanced Design Alternative III also includes a titanium-7 drip shield.

The advantage of Enhanced Design Alternative III is that the surface of the waste package is predicted to cool below 80°C (176°F) before the relative humidity exceeds 90 percent, thus avoiding the worst of the corrosive, warm-moist environment after closure. The disadvantages are the uncertainties connected with temperatures over 100°C (212°F).

E.3.4 ENHANCED DESIGN ALTERNATIVE IV

Enhanced Design Alternative IV is a shielded waste package design located entirely in the upper block with a high thermal load (85 MTHM per acre). The goals of this Enhanced Design Alternative are to keep the gamma radiation dose at the surface of the waste package below 200 millirem per hour, keep the fuel cladding below 350°C (662°F), and keep the emplacement drifts dry for thousands of years.

The waste package would be 30-centimeter (12-inch)-thick A516 steel, and it would have an integral filler that acted as a sponge for oxygen. Waste packages would be line-loaded with a separation of 0.1 meter (0.3 feet). Continuous ventilation at 2 to 5 cubic meters (71 to 177 cubic feet) per second would be required for the 50-year preclosure period. Two intake and three exhaust shafts would be required in addition to the access tunnels. Human access would require blast cooling to reduce temperatures in the drift using a portable 5-centimeter (2-inch)-thick borated polyethylene neutron shielding over the waste packages. Backfill material and drip shields are used in this Enhanced Design Alternative.

The Enhanced Design Alternative IV waste packages would weigh 18,140 metric tons (20 tons) more than those used with other Enhanced Design Alternatives. Since this Enhanced Design Alternative requires a hot postclosure environment to be successful, it would be necessary to manage the waste stream to ensure uniform heat in the repository. Backfill would be placed at closure.

If this design concept does not properly control temperature and relative humidity to protect the drip shield, the carbon steel waste packages would be expected to fail much earlier than the waste packages in the other Enhanced Design Alternatives.

E.3.5 ENHANCED DESIGN ALTERNATIVE V

Enhanced Design Alternative V is a very high thermal load alternative (150 MTHM per acre) and covers the smallest area [168 square kilometers (420 acres)] of the five Enhanced Design Alternatives. The purpose of the very high thermal load is to provide a hot, dry drift environment for thousands of years and avoid extended periods of warm, moist conditions. The goals of this Enhanced Design Alternative were to have drift wall temperatures less than 225°C (437°F) to maintain stability, commercial fuel cladding temperature less than 350°C, and to keep the drift dry for several thousand years.

Waste blending would be required so that waste temperatures were all within 20 percent of the average. Waste packages would be 2-centimeter (0.8-inch) Alloy-22 over 5-centimeter (2-inch) 316L stainless steel, and they would be line loaded with a 0.1-meter (0.3-foot) spacing between waste packages. To optimize selection of waste for emplacement, additional surface storage capacity above and beyond that in the Viability Assessment reference design would be necessary. Drift spacing would be 32.4 meters (106 feet). Preclosure ventilation would reduce air and drift temperatures and remove moisture from the drifts. Four air shafts as well as three access tunnels would be needed. Titanium-7 drip shields would be placed at the time of closure.

The advantage of this design is that it would be located entirely in the lower block of the repository, where the percolation rate is less than half that in the upper block. However, access to the lower block would require a third tunnel. In addition, postclosure conditions could lead to localized corrosion and early failure of waste packages. The high temperatures also could create the possibility that the cladding temperature goal would be exceeded for some waste packages.

REFERENCE

DOE 1998	DOE (U.S. Department of Energy), 1998, *Viability Assessment of a Repository at Yucca Mountain,* DOE/RW-0508, Office of Civilian Radioactive Waste Management, Washington, D.C. [U.S. Government Printing Office, MOL.19981007.0027, Overview; MOL.19981007.0028, Volume 1; MOL.19981007.0029, Volume 2; MOL.19981007.0030, Volume 3; MOL.19981007.0031, Volume 4; MOL.19981007.0032, Volume 5]

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Appendix F

Human Health Impacts Primer and Details for Estimating Health Impacts to Workers from Yucca Mountain Repository Operations

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APPENDIX F. HUMAN HEALTH IMPACTS PRIMER AND DETAILS FOR ESTIMATING HEALTH IMPACTS TO WORKERS FROM YUCCA MOUNTAIN REPOSITORY OPERATIONS

Section F.1 of this appendix contains information that supports the estimates of human health and safety impacts in this environmental impact statement (EIS). Specifically, Section F.1 is a primer that explains the natures of radiation and toxic materials, where radiation comes from in the context of the radiological impacts discussed in this EIS, how radiation interacts with the human body to produce health impacts, and how toxic materials interact with the body to produce health impacts. The remainder of the appendix discusses the methodology that was used to estimate worker health impacts and the input data to the analysis, and presents the detailed results of the analysis of worker health impacts.

Section F.2 discusses the methodology and data that the U.S. Department of Energy (DOE) used to estimate worker health and safety impacts for the Proposed Action. It also discusses the detailed results of the impact analysis.

Section F.3 discusses the methodologies and data that DOE used to estimate worker health and safety impacts for Inventory Modules 1 and 2. It also discusses the detailed results of the impact analysis.

Section F.4 discusses the methodology and data that DOE used to estimate worker health and safety impacts for retrieval, should such action become necessary. In addition, it discusses the detailed results from the impact analysis.

Radiological impacts to the public from operations at the Yucca Mountain site could result from release of naturally occurring radon-222 and its decay products in the ventilation exhaust from the subsurface repository operations. The methodology and input data used in the estimates of radiological dose to the public are presented in Appendix G, Air Quality. Outside of the radiation primer, health impacts to the public are not treated in this appendix.

F.1 Human Health Impacts from Exposure to Radioactive and Toxic Materials

This section introduces the concepts of human health impacts as a result of exposure to radiation and potentially toxic materials.

F.1.1 RADIATION AND HUMAN HEALTH

F.1.1.1 Radiation

Radiation is the emission and propagation of energy through space or through a material in the form of waves or bundles of energy called photons, or in the form of high-energy subatomic particles. Radiation generally results from atomic or subatomic processes that occur naturally. The most common kind of radiation is *electromagnetic radiation,*

RADIATION

Radiation occurs on Earth in many forms, either naturally or as the result of human activities. Natural forms include light, heat from the sun, and the decay of unstable radioactive elements in the Earth and the environment. Some elements that exist naturally in the human body are radioactive and emit ionizing radiation. They include an isotope of potassium that is an essential element for health and the elements of the uranium and thorium naturally occurring decay series. Human activities have also led to sources of ionizing radiation for various uses, such as diagnostic and therapeutic medicine and nondestructive testing of pipes and welds. Nuclear power generation produces ionizing radiation as well as radioactive materials, which undergo radioactive decay and can continue to emit ionizing radiation for long periods of time.

which is transmitted as photons. Electromagnetic radiation is emitted over a range of wavelengths and energies. We are most commonly aware of visible light, which is part of the spectrum of electromagnetic radiation. Radiation of longer wavelengths and lower energy includes infrared radiation, which heats material when the material and the radiation interact, and radio waves. Electromagnetic radiation of shorter wavelengths and higher energy (which are more penetrating) includes ultraviolet radiation, which causes sunburn, X-rays, and gamma radiation.

Ionizing radiation is radiation that has sufficient energy to displace electrons from atoms or molecules to create ions. It can be electromagnetic (for example, X-rays or gamma radiation) or subatomic particles (for example, alpha and beta radiation). The ions have the ability to interact with other atoms or molecules; in biological systems, this interaction can cause damage in the tissue or organism.

F.1.1.2 Radioactivity, Ionizing Radiation, Radioactive Decay, and Fission

Radioactivity is the property or characteristic of an unstable atom to undergo spontaneous transformation (to *disintegrate* or *decay*) with the emission of energy as radiation. Usually the emitted radiation is ionizing radiation. The result of the process, called *radioactive decay*, is the transformation of an unstable atom (a *radionuclide*) into a different atom, accompanied by the release of energy (as radiation) as the atom reaches a more stable, lower energy configuration.

Radioactive decay produces three main types of ionizing radiation—alpha particles, beta particles, and gamma or X-rays—but our senses cannot detect them. These types of ionizing radiation can have different characteristics and levels of energy and, thus, varying abilities to penetrate and interact with atoms in the human body. Because each type has different characteristics, each requires different amounts of material to stop (shield) the radiation. Alpha particles are the least penetrating and can be stopped by a thin layer of material such as a single sheet of paper. However, if radioactive atoms (called radionuclides) emit alpha particles in the body when they decay, there is a concentrated deposition of energy near the point where the radioactive decay occurs. Shielding for beta particles requires thicker layers of material such as several reams of paper or several inches of wood or water. Shielding from gamma rays, which are highly penetrating, requires very thick material such as several inches to several feet of heavy material (for example, concrete or lead). Deposition of the energy by gamma rays is dispersed across the body in contrast to the local energy deposition by an alpha particle. In fact, some gamma radiation will pass through the body without interacting with it.

FISSION

Fission is the process whereby a large nucleus (for example, uranium-235) absorbs a neutron, becomes unstable, and splits into two fragments, resulting in the release of large amounts of energy per unit of mass. Each fission releases an average of two or three neutrons that can go on to produce fissions in nearby nuclei. If one or more of the released neutrons on the average causes additional fissions, the process keeps repeating. The result is a self-sustaining chain reaction and a condition called criticality. When the energy released in fission is controlled (as in a nuclear reactor), it can be used for various benefits such as to propel submarines or to provide electricity that can light and heat homes.

In a nuclear reactor, heavy atoms such as uranium and plutonium can undergo another process, called *fission*, after the absorption of a subatomic particle (usually a neutron). In fission, a heavy atom splits into two lighter atoms and releases energy in the form of radiation and the kinetic energy of the two new lighter atoms. The new lighter atoms are called fission products. The fission products are usually unstable and undergo radioactive decay to reach a more stable state.

Some of the heavy atoms might not fission after absorbing a subatomic particle. Rather, a new nucleus is formed that tends to be unstable (like fission products) and undergo radioactive decay.

The radioactive decay of fission products and unstable heavy atoms is the source of the radiation from spent nuclear fuel and high-level radioactive waste that makes these materials hazardous in terms of potential human health impacts.

F.1.1.3 Exposure to Radiation and Radiation Dose

Radiation that originates outside an individual's body is called *external* or *direct radiation*. Such radiation can come from an X-ray machine or from *radioactive materials* (materials or substances that contain radionuclides), such as radioactive waste or radionuclides in soil. *Internal radiation* originates inside a person's body following intake of radioactive material or radionuclides through ingestion or inhalation. Once in the body, the fate of a radioactive material is determined by its chemical behavior and how it is metabolized. If the material is soluble, it might be dissolved in bodily fluids and be transported to and deposited in various body organs; if it is insoluble, it might move rapidly through the gastrointestinal tract or be deposited in the lungs.

Exposure to ionizing radiation is expressed in terms of *absorbed dose,* which is the amount of energy imparted to matter per unit mass. Often simply called *dose,* it is a fundamental concept in measuring and quantifying the effects of exposure to radiation. The unit of absorbed dose is the *rad.* The different types of radiation mentioned above have different effects in damaging the cells of biological systems. *Dose equivalent* is a concept that considers (1) the absorbed dose and (2) the relative effectiveness of the type of ionizing radiation in damaging biological systems, using a radiation-specific quality factor. The unit of dose equivalent is the *rem.* In quantifying the effects of radiation on humans, other types of concepts are also used. The concept of *effective dose equivalent* is used to quantify effects of radionuclides in the body. It involves estimating the susceptibility of the different tissue in the body to radiation to produce a tissue-specific weighting factor. The weighting factor is based on the susceptibility of that tissue to cancer. The sum of the products of each affected tissue's estimated dose equivalent multiplied by its specific weighting factor is the *effective dose equivalent.* The potential effects from a one-time ingestion or inhalation of radioactive material are calculated over a period of 50 years to account for radionuclides that have long half-lives and long residence time in the body. The result is called the *committed effective dose equivalent.* The unit of effective dose equivalent is also the *rem. Total effective dose equivalent* is the sum of the committed effective dose equivalent from radionuclides in the body plus the dose equivalent from radiation sources external to the body (also in rem). All estimates of dose presented in this environmental impact statement, unless specifically noted as something else, are total effective dose equivalents, which are quantified in terms of rem or millirem (which is one one-thousandth of a rem).

More detailed information on the concepts of radiation dose and dose equivalent are presented in publications of the National Council on Radiation Protection and Measurements (NCRP 1993, page 16-25) and the International Commission on Radiological Protection (ICRP 1991, page 4-11). The DOE implementation guide for occupational exposure assessment (DOE 1998a, pages 3 to 11) also provides additional information.

The factors used to convert estimates of radionuclide intake (by inhalation or ingestion) to dose are called *dose conversion factors*. The National Council on Radiation Protection and Measurements and Federal agencies such as the U.S. Environmental Protection Agency publish these factors (NCRP 1996, all; Eckerman and Ryman 1993, all; Eckerman, Wolbarst, and Richardson 1988, all). They are based on original recommendations of the International Commission on Radiological Protection (ICRP 1977, all).

The radiation dose to an individual or to a group of people can be expressed as the total dose received or as a dose rate, which is dose per unit time (usually an hour or a year).

Collective dose is the total dose to an exposed population. *Person-rem* is the unit of collective dose. Collective dose is calculated by summing the individual dose to each member of a population. For example, if 100 workers each received 0.1 rem, then the collective dose would be 10 person-rem (100 × 0.1 rem).

Exposures to radiation or radionuclides are often characterized as being acute or chronic. Acute exposures occur over a short period of time, typically 24 hours or less. Chronic exposures occur over longer times (months to years); they are usually assumed to be continuous over a period, even though the dose rate might vary. For a given dose of radiation, chronic radiation exposure is usually less harmful than acute exposure because the dose rate (dose per unit time, such as rem per hour) is lower, providing more opportunity for the body to repair damaged cells.

F.1.1.4 Background Radiation from Natural Sources

Nationwide, on average, members of the public are exposed to approximately 360 millirem per year from natural and manmade sources (Gotchy 1987, page 53). Figure F-1 shows the relative contributions by radiation sources to people living in the United States (Gotchy 1987, page 55).

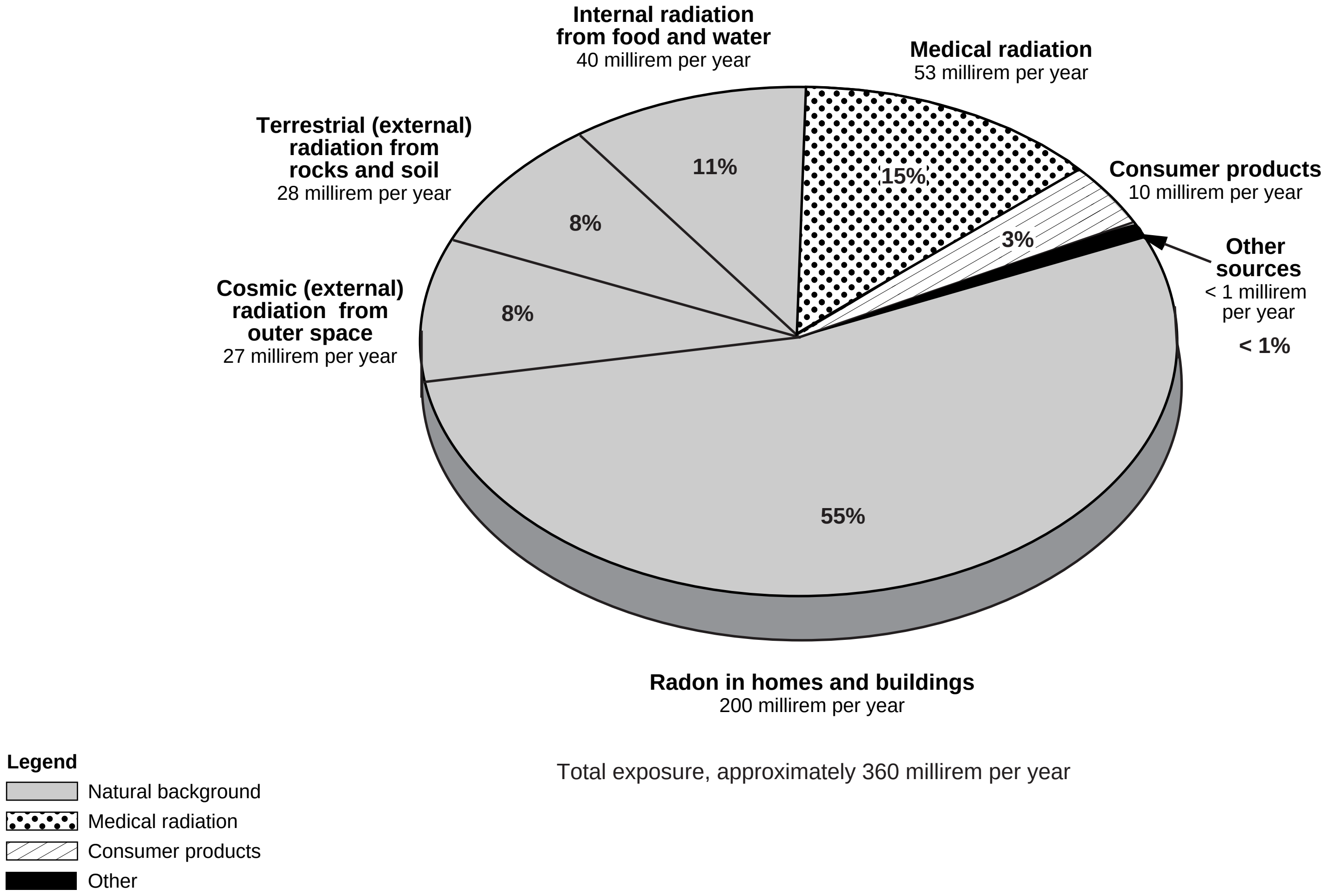
The estimated average annual dose rate from natural sources is only about 300 millirem per year. This represents about 80 percent of the annual dose received by an average member of the U.S. public. The largest natural sources are radon-222 and its radioactive decay products in homes and buildings, which contribute about 200 millirem per year. Additional natural sources include radioactive material in the Earth (primarily the uranium and thorium decay series, and potassium-40) and cosmic rays from space filtered through the atmosphere. With respect to exposures resulting from human activities, medical exposure accounts for 15 percent of the annual dose, and the combined doses from weapons testing fallout, consumer and industrial products, and air travel (cosmic radiation) account for the remaining 3 percent of the total annual dose. Nuclear fuel cycle facilities contribute less than 0.1 percent (0.005 millirem per year per person) of the total dose (Gotchy 1987, pages 53 to 55).

F.1.1.5 Impacts to Human Health from Exposure to Radiation

Chronic Exposure

Cancer is the principal potential risk to human health from exposure to low or chronic levels of radiation. This EIS expresses radiological health impacts as the incremental changes in the number of expected fatal cancers (latent cancer fatalities) for populations and as the incremental increases in lifetime probabilities of contracting a fatal cancer for an individual. The estimates are based on the dose received and on dose-to-health effect conversion factors recommended by the International Commission on Radiological Protection (ICRP 1991, page 22). The Commission estimated that, for the general population, a collective dose of 1 person-rem will yield 0.0005 excess latent cancer fatality. For radiation workers, a collective dose of 1 person-rem will yield an estimated 0.0004 excess latent cancer fatality. The higher risk factor for the general population is primarily due to the inclusion of children in the population group, while the radiation worker population includes only people older than 18. These risk coefficients were adopted by the National Council on Radiation Protection and Measurements in 1993 (NCRP 1993, page 3).

Other health effects such as nonfatal cancers and genetic effects can occur as a result of chronic exposure to radiation. Inclusion of the incidence of nonfatal cancers and severe genetic effects from radiation exposure increases the total change by a factor of 1.5 to 5, compared to the change for latent cancer fatalities (ICRP 1991, page 22). As is the general practice for any DOE EIS, estimates of the total change were not included in the Yucca Mountain EIS.



Note: Other sources include nationwide commercial nuclear facilities, occupational exposure, air travel, and fallout.

Source: NCRP (1987, page 55).

Figure F-1. Sources of radiation exposure.

Acute Exposure

Exposures to high levels of radiation at high dose rates over a short period (less than 24 hours) can result in acute radiation effects. Minor changes in blood characteristics might be noted at doses in the range of 25 to 50 rad. The external symptoms of radiation sickness begin to appear following acute exposures of about 50 to 100 rad and can include anorexia, nausea, and vomiting. More severe symptoms occur at higher doses and can include death at doses higher than 200 to 300 rad of total body irradiation, depending on the level of medical treatment received. Information on the effects of acute exposures on humans was obtained from studies of the survivors of the Hiroshima and Nagasaki bombings and from studies following a multitude of acute accidental exposures (Mettler and Upton 1995, pages 276 to 280).

Factors to relate the level of acute exposure to health effects exist but are not applied in this EIS because expected exposures during normal operations for the Proposed Action (including transportation), and for accident scenarios during the Proposed Action and the associated transportation activities, would be well below 50 rem. See Appendix J for exposures from accident scenarios during transportation activities.

F.1.1.6 Exposures from Naturally Occurring Radionuclides in the Subsurface Environment

The estimates of worker doses from inhalation of radon-222 and its decay products while in the subsurface environment and from the ambient radiation fields in the subsurface environment were based on measurements taken in the existing Exploratory Studies Facility drifts. The measurements and the annual dose rates derived from them are discussed below.

Annual Dose Rate for Subsurface Facility Worker from Inhalation of Radon-222

The annual dose rate for a subsurface worker from inhalation of radon-222 and radon decay products was estimated using site-specific measurements of the concentrations of radon-222 and its decay products in the Yucca Mountain Exploratory Studies Facility drifts. Measurements were made at a number of locations in the drifts (TRW 1999a, page 12). After examination of the data from various locations, the measurements taken at the 5,035-meter (about 16,500-foot) station in the main drift, with the ventilation system operating, were determined to provide the best basis for estimating the concentration of radon-222 in the subsurface atmosphere during the various Yucca Mountain Repository phases (TRW 1999a, page 12). The measured concentrations ranged from 0.22 to 72 picocuries per liter, with a median value of 6.5 picocuries per liter.

For each project phase, the measured average value (6.5 picocuries per liter) was adjusted to take into account the difference between the average air residence time in the repository at the time of measurement of radon-222 concentration and the average air residence time for a specific project phase. The average air residence time is the average volume being ventilated divided by the average ventilation rate for a project phase. For example, an increased repository volume would result in an increased average residence time as would a decrease in the ventilation flow rate.

Also considered were (1) the distribution of the measured values of the equilibrium fraction between radon-222 and the decay products in the underground facility; this value ranged from 0.0022 to 0.44, with a median of 0.14 (TRW 1999a, page 12); and (2) the number of hours an involved worker would be underground, exposed to airborne radon. Based on a typical amount of time spent underground (about 6.5 hours per workday) (Jessen 1999, all), the yearly exposure time for involved workers would range from 1,500 to 1,700 hours per year. The dose conversion factor for radon was taken from Publication 65 of the International Commission on Radiological Protection (ICRP 1994, page 24). This dose conversion factor, which is 0.5 rem per working-level month for inhalation of radon decay products by workers, corresponds to 0.029 millirem per picocurie per liter per hour for radon decay products in 100-percent equilibrium (equilibrium factor of 1.0) with the radon-222 parent (ICRP 1994, page 5). For radon products with a 0.14 equilibrium factor, the dose conversion factor would be 0.0041 millirem per picocurie per liter per hour.

The estimated baseline median dose to an involved worker in the Exploratory Studies Facility from inhalation of radon and radon decay products was estimated to be approximately 60 millirem per year. This estimate was used in calculating the worker dose estimates in this appendix. The estimated 5th-percentile dose is 2 millirem per year, and the 95th-percentile dose is 580 millirem per year. These estimates were made using a Monte Carlo uncertainty analysis.

Annual Dose for Subsurface Facility Worker from Ambient External Radiation in Drifts

Workers in the underground facility would also be exposed to external radiation from naturally occurring primordial radionuclides in the rock. Measured exposure rates for the underground facility ranged from 0.014 to 0.038 millirem per hour (TRW 1999a, page 12). As for inhalation dose estimates, an underground exposure time of 1,500 to 1,700 hours per year was considered. The estimated baseline median dose to an involved worker in the Exploratory Studies Facility from ambient external radiation would be approximately 40 millirem per year. This estimate was used in this appendix for calculating the worker dose estimates from ambient external radiation. The estimated 5th-percentile dose is 23 millirem per year, and the 95th-percentile dose is 56 millirem per year. Like the radon dose estimates, these estimates were made using a Monte Carlo uncertainty analysis.

F.1.2 EXPOSURE TO TOXIC OR HAZARDOUS MATERIALS

When certain natural or manmade materials or substances have harmful effects that are not random or do not occur solely at the site of contact, the materials or substances are described as toxic. Toxicology is the branch of science dealing with the toxic effects that chemicals or other substances might have on living organisms.

Chemicals can be toxic for many reasons, including their ability to cause cancer, to harm or destroy tissue or organs, or to harm body systems such as the reproductive, immune, blood-forming, or nervous systems. The following list provides examples of substances that can be toxic:

- Carcinogens, which are substances known to cause cancer in humans or in animals. If cancers have been observed in animals, they could occur in humans. Examples of generally accepted human carcinogens include asbestos, benzene, and vinyl chloride (Kamrin 1988, pages 37 and 38 and Chapter 6).

- Chemicals that controlled studies have shown to cause a harmful or fatal effect. Examples include metals such as cadmium, lead, and mercury; strong acids such as nitric acid and sulfuric acid; some welding fumes; coal dust; sulfur dioxide; and some solvents.

- Some biological materials, including various body fluids and tissues and infectious agents, are toxic.

Even though chemicals might be toxic, many factors influence whether or not a particular substance has a toxic effect on humans. These factors include (1) the amount of the substance with which the person comes in contact, (2) whether the person inhales or ingests a relatively large amount of the substance in a short time (acute exposure) or repeatedly ingests or inhales a relatively small amount over a longer time (chronic exposure), and (3) the period of time over which the exposure occurs.

Scientists determine a substance’s toxic effect (or toxicity) by performing controlled tests on animals. In addition to environmental and physical factors, these tests help establish three other important factors for measuring toxicity—dose-response relationship, threshold concept, and margin of safety. The dose-response relationship relates the percentage of test animals that experience observable toxic effects to the doses administered. After the administration of an initial dose, the dose is increased or decreased until, at the upper end, all animals are affected and, at the lower end, no animals are affected. Thus, there is a threshold concentration below which there is no effect. The margin of safety is an arbitrary separation between the highest concentration or exposure level that produces no adverse effect in a test animal species and the concentration or exposure level designated safe for humans. There is no universal margin of safety. For some chemicals, a small margin of safety is sufficient; others require a larger margin.

Two substances in the rock at Yucca Mountain, crystalline silica and erionite, are of potential concern as toxic or hazardous materials. Both of these naturally occurring compounds occur in the parent rock at the repository site, and excavation activities could encounter them. The following paragraphs contain additional information on these.

Crystalline Silica

Crystalline silica is a naturally occurring, highly structured form of silica (silicon dioxide, SiO_2). Because it can occur in several different forms, including quartz, cristobalite, and tridymite, it is called a *polymorph*. These three forms occur in the welded tuff parent rock at Yucca Mountain (DOE 1998b, page 25). Crystalline silica is a known causative agent for *silicosis*, a destructive lung condition caused by deposition of particulate matter in the lungs and characterized by scarring of lung tissue. It is contracted by prolonged exposure to high levels of respirable silica dust or an acute exposure to even higher levels of respirable silica dust (EPA 1996, Chapter 8). Accordingly, DOE considers worker inhalation of respirable crystalline silica dust particles to be hazardous to worker health. Current standards for crystalline silica have been established to prevent silicosis in workers.

Cristobalite has a lower exposure limit than does quartz. The limits for these forms of silica include the Permissible Exposure Limits established by the Occupational Safety and Health Administration and the Threshold Limit Value defined by the American Conference of Governmental Industrial Hygienists. The Occupational Safety and Health Administration Permissible Exposure Limit is 50 micrograms per cubic meter averaged over a 10-hour work shift. The American Conference of Governmental Industrial Hygienists Threshold Limit Value is also 50 micrograms per cubic meter, but it is averaged over an 8-hour work shift (NJDHSS 1996, all). Thus, the two limits are essentially the same. In accordance with DOE Order 440.1A (DOE 1998a, page 5), the more restrictive value provided by the American Conference of Governmental Industrial Hygienists will be applied. In addition, the National Institute for Occupational Safety and Health has established Immediately-Dangerous-to-Life-and-Health concentration limits at levels of 50,000 and 25,000 micrograms per cubic meter for quartz and cristobalite, respectively (NIOSH 1996, page 2). These limits are based on the maximum airborne concentrations an individual could tolerate for 30 minutes without suffering symptoms that could impair escape from the contaminated area or irreversible acute health effects.

There is also evidence that silica may be a carcinogen. The International Agency for Research on Cancer has classified crystalline silica and cristobalite as a Class I (known) carcinogen (IARC 1997, pages 205 to 210). The National Institute for Occupational Safety and Health considers crystalline silica to be a potential carcinogen, as defined by the Occupational Safety and Health Administration's carcinogen policy (29 CFR Part 1990). The National Institute for Occupational Safety and Health is reviewing data on carcinogenicity, which could result in a revised limit for crystalline silica. The Environmental Protection Agency has noted an increase in cancer risk to humans who have already developed the adverse noncancer effects of silicosis, but the cancer risk to otherwise healthy individuals is not clear (EPA 1996, pages 1 to 5).

Because there are no specific limits for exposure of members of the public to crystalline silica, this analysis used a comparative benchmark of 10 micrograms per cubic meter, based on a cumulative lifetime exposure limit of 1,000 micrograms per (cubic meter multiplied by years). At this level, an Environmental Protection Agency health assessment has stated that there is a less than 1 percent chance of silicosis (EPA 1996, Chapter 1, page 5, and Chapter 7, page 5). Over a 70-year lifetime, this cumulative exposure benchmark would correspond to an annual average exposure concentration of about 14 micrograms per cubic meter, which was rounded down to 10 micrograms per cubic meter to establish the benchmark. Appendix G, Section G.1 contains additional information on public exposure to crystalline silica.

Samples of the welded tuff parent rock from four boreholes at Yucca Mountain have an average quartz content of 15.7 percent, an average cristobalite content of 16.3 percent, and an average tridymite content of 3.5 percent (DOE 1998b, page I-1). Worker protection during excavation in the subsurface would be based on the more restrictive Threshold Limit Value for cristobalite. The analysis assumed that the parent rock and dust would have a cristobalite content of 28 percent, which is the higher end of the concentration range reported in TRW (1999b, page 4-81). Thus, the assumed percentage of cristobalite in dust probably will overestimate the airborne cristobalite concentration. Also, studies of both ambient and occupational airborne crystalline silica have shown that most of the airborne crystalline silica is coarse and not respirable (greater than 5 micrometers aerodynamic diameter), and the larger particles will deposit rapidly on the surface (EPA 1996, page 3-26).

Erionite

Erionite is a natural fibrous zeolite that occurs in the rock layers below the proposed repository level in the hollows of rhyolitic tuffs and in basalts. It might also occur in rock layers above the repository level but has not been found in those layers. Erionite is a rare tectosilicate zeolite with hexagonal symmetry that forms wool-like fibrous masses (with a maximum fiber length of about 50 microns, which is generally shorter than asbestos fibers). Erionite particles (ground to powder) resemble amphibole asbestos fibers. Erionite fibers have been detected in samples of road dust in Nevada, and residents of the Intermountain West could be exposed to fibrous erionite in ambient air (Technical Resources 1994, page 134).

There are no specific limits for exposure to erionite. Descriptive studies have shown very high mortality from cancer [malignant mesothelioma, mainly of the pleura (a lung membrane)] in the population of three Turkish villages in Cappadocia where erionite is mined. The International Agency for Research on Cancer has indicated that these studies demonstrate the carcinogenicity of erionite to humans. The Agency classifies erionite as a Group 1 (known) carcinogen (IARC 1987, all).

Erionite could become a potential hazard during excavation of access tunnels to the lower block and to offset Area 5 for the low and intermediate thermal load cases or during vertical boring operations necessary to excavate ventilation shafts. DOE does not expect to encounter erionite layers during the vertical boring operations, which would be through rock layers above known erionite layers, or during excavation of access tunnels to the lower block or offset Area 5, where any identified layers of erionite would likely be avoided (McKenzie 1998, all). In accordance with the Erionite Protocol (DOE 1995, all), a task-specific health and safety plan would be prepared before the start of boring operations to identify this material and prevent worker inhalation exposures from unconfined material.

The Los Alamos National Laboratory is studying the mineralogy and geochemistry of the deposition of erionite under authorization from the DOE Office of Energy Research. Laboratory researchers are applying geochemical modeling so they can understand the factors responsible for the formation of zeolite assemblages in volcanic tuffs. The results of this modeling will be used to predict the distribution of erionite at Yucca Mountain and to assist in the planning of excavation operations so erionite layers are avoided.

F.1.3 EXPOSURE PATHWAYS

Four conditions must exist for there to be a pathway from the source of released radiological or toxic material to a person or population (Maheras and Thorne 1993, page 1):

- A source term: The material released to the environment, including the amount of radioactivity (if any) or mass of material, the physical form (solid, liquid, gas), particle size distribution, and chemical form

- An environmental transport medium: Air, surface water, groundwater, or a food chain

- An exposure route: The method by which a person can come in contact with the material (for example, external exposure from contaminated ground, immersion in contaminated air or internal exposure from inhalation or ingestion of radioactive or toxic material)

- A human receptor: The person or persons potentially exposed; the level of exposure depends on such factors as location, duration of exposure, time spent outdoors, and dietary intake

These four elements define an exposure pathway. For example, one exposure scenario might involve release of contaminated gas from a stack (source term); transport via the airborne pathway (transport medium); external gamma exposure from the passing cloud (exposure route); and an onsite worker (human receptor). Another exposure scenario might involve a volatile organic compound as the source term, release to groundwater as the transport medium, ingestion of contaminated drinking water as the exposure route, and offsite members of the public as the human receptors. No matter which pathway the scenario involves, local factors such as water sources, agriculture, and weather patterns play roles in determining the importance of the pathway when assessing potential human health effects.

Worker exposure to crystalline silica (and possibly erionite) in the subsurface could occur from a rather unique exposure pathway. Mechanical drift excavation, shaft boring, and broken rock management activities could create airborne dust comprising a range of particles sizes. Dust particles smaller than 10 micrometers have little mass and inertia in comparison to their surface area; therefore, these small particles could remain suspended in dry air for long periods. Airborne dust concentrations could increase if the ventilation system recirculated the air or if airflow velocity in the subsurface facilities became high enough to entrain dust previously deposited on drift or equipment surfaces. As tunnel boring machines or road headers break the rock from the working face, water would be applied to wet both the working face and the broken rock to minimize airborne dust levels. Wet or dry dust scrubbers would capture dust that was not suppressed by the water sprays. To prevent air recirculation, which would lead to an increase of airborne dust loads, the fresh air intake and the exhaust air streams would be separated. Finally, the subsurface ventilation system would be designed and operated to control ambient air velocities to minimize dust reentrainment. If these engineering controls did not maintain dust concentrations below the Threshold Limit Value concentration, workers would have to wear respirators until engineering controls established habitable conditions.

F.2 Human Health and Safety Impact Analysis for the Proposed Action Inventory

This section discusses the methodologies and data used to estimate industrial and radiological health and safety impacts to workers that would result from the construction, operation and monitoring, and closure of the Yucca Mountain Repository, as well as the detailed results from the impact calculations. Section F.2.1 describes the methods used to estimate impacts, Section F.2.2 contains tabulations of the detailed data used in the impact calculations and references to the data sources, and Section F.2.3 contains a detailed tabulation of results.

For members of the public, the EIS uses the analysis methods in Appendix K, Section K.2, to estimate radiation dose from radon-222 and crystalline silica released in the subsurface ventilation system exhaust. The radiation dose estimates were converted to estimates of human health impacts using the dose conversion factors discussed in Section F.1.1.5. These impacts are expressed as the probability of a latent cancer fatality for a maximally exposed individual and as the number of latent cancer fatalities among members of the public within about 80 kilometers (50 miles) for the Proposed Action, the retrieval contingency, and the inventory modules. The results are listed in Chapter 4, Section 4.1.7.

Health and safety impacts to workers have been estimated for two worker groups: involved workers and noninvolved workers. Involved workers are craft and operations personnel who would be directly involved in activities related to facility construction and operations, including excavation activities; receipt, handling, packaging, and emplacement of spent nuclear fuel and high-level radioactive waste material; monitoring of conditions and performance of the waste packages; and those directly involved in closure activities. Noninvolved workers are managerial, technical, supervisory, and administrative personnel who would not be directly involved in construction, excavation, operations, monitoring, and closure activities. The analysis did not consider project workers who would not be located at the repository site.

F.2.1 METHODOLOGY FOR CALCULATING OCCUPATIONAL HEALTH AND SAFETY IMPACTS

To estimate the impacts to workers from industrial hazards common to the workplace, values for the full-time equivalent work years for each phase of the project were multiplied by the statistic (occurrence per 10,000 full-time equivalent work years) for the impact being considered. Values for the number of full-time equivalent workers for each phase of the project are listed in Section F.2.2.1. The statistics for industrial impacts for each of the phases are listed in Section F.2.2.2 for involved and noninvolved workers.

Two kinds of radiological health impacts to workers are provided in this EIS. The first is an estimate of the latent cancer fatalities to the worker group involved in a particular project phase. The second is the incremental increase in latent cancer fatalities attributable to occupational radiation for a maximally exposed individual in the worker population for each project phase.

To calculate the expected number of worker latent cancer fatalities during a phase of the project, the collective dose to the worker group, in person-rem, was multiplied by a standard factor for converting the collective worker dose to projected latent cancer fatalities (see Section F.1.1.5). As discussed in Section F.1.1.5, the value of this factor for radiation workers is 0.0004 excess latent cancer fatality per person-rem of dose.

The collective dose for a particular phase of the operation is calculated as the product of the number of full-time equivalent workers for the project phase (see Section F.2.2.1), the average dose over the exposure period, and the fraction of the working time that a worker is in an environment where there is a source of radiation exposure. Values for exposure rates for both involved and noninvolved workers are presented in Section F.2.2.3 as are the fractional occupancy factors. The calculation of collective dose to subsurface workers from exposure to the radiation emanating from the loaded waste packages is an exception. Collective worker doses from this source of exposure were calculated using the methodology described in TRW (1999b, Tables G-1 and G-2). For the calculation of exposures, the estimated annual radiation doses listed in TRW (1999b, Tables G-3, G-3a, G-4, and G-4a) for the various classes of involved subsurface workers were used. The exposure values were multiplied by the craft manpower distribution listed in TRW (1999b, Tables G-5, G-5a, G-5b, G-7, G-7a, and G-7b) for each of the involved labor classes for a project phase to obtain an overall annual exposure. The annual exposures for the labor classes were then summed to obtain the collective annual dose in person-rem to the involved subsurface workers for each of the subsurface operational phases. The total collective dose was then obtained by multiplying the annual collective dose by the length of the project phase.

To estimate the incremental increase in the likelihood of death from a latent cancer for the maximally exposed individual, the estimated dose to the maximally exposed worker was multiplied by the factor for converting radiation dose to latent cancers. The factor applied for workers was 0.0004 latent cancer fatality per rem, as discussed above and in Section F.1.1.5. Thus, if a person were to receive a dose of 1 rem, the incremental increase in the probability that person would suffer a latent cancer fatality is 1 in 2,500 or 0.0004.

To estimate the dose for a hypothetical maximally exposed individual, the analysis generally assumed that this individual would be exposed to the radiation fields (see Section F.2.2.3) over the entire duration of a project phase or for 50 years, whichever would be shorter. Other sources of exposure while working underground would be ambient radiation coming from the radionuclides in the drift walls and from inhalation of radon-222 and its decay products. The radiation from the waste package is usually the dominant component when these three dose contributors are added. Doses for the maximally exposed subsurface worker were estimated by adding the three dose components because they would occur simultaneously.

F.2.2 DATA SOURCES AND TABULATIONS

F.2.2.1 Work Hours for the Repository Phases

Table F-1 lists the number of workers involved in the various repository phases in terms of full-time equivalent work years. Each full-time equivalent work year represents 2,000 work hours (the number of hours assumed for a normal work year). The values were obtained from TRW (1999c, Section 6) and from TRW (1999b, Section 6) for surface and subsurface workers, respectively.

F.2.2.2 Workplace Health and Safety Statistics

The analysis selected health and safety statistics for three impact categories—total recordable cases, lost workday cases, and fatalities. Total recordable cases are occupational injuries or illnesses that result in:

- Fatalities, regardless of the time between the injury and death, or the length of the illness
- Lost workday cases, other than fatalities, that result in lost workdays
- Nonfatal cases without lost workdays that result in transfer to another job, termination of employment, medical treatment (other than first aid), loss of consciousness, or restriction of work or motion
- Diagnosed occupational illness cases that are reported to the employer but are not classified as fatalities or lost workday cases

Table F-1. Estimated full-time equivalent worker years for repository phases.

				High thermal load			Intermediate thermal load			Low thermal load		
Phase	Subphase or worker group	Source[a]	Length of phase	UC[b]	DISP[c]	DPC[d]	UC	DISP	DPC	UC	DISP	DPC
Construction	Surface	(1)	44 months									
	Involved			2,380	1,650	1,760	2,380	1,650	1,760	2,380	1,650	1,760
	Noninvolved			900	630	670	900	630	670	900	630	670
	Subsurface	(2)	5 years									
	Involved			2,300	2,300	2,300	2,460	2,460	2,460	2,460	2,460	2,460
	Noninvolved			600	600	600	600	600	600	600	600	600
	Construction subtotal			*6,180*	*5,180*	*5,330*	*6,340*	*5,340*	*5,490*	*6,340*	*5,340*	*5,490*
Operation and monitoring												
Operations	Surface handling	(3)	24 years									
	Involved			17,500	11,470	11,810	17,500	11,470	11,810	17,500	11,470	11,810
	Noninvolved			13,150	11,620	11,760	13,150	11,620	11,760	13,150	11,620	11,760
	Subsurface emplacement	(4)	24 years									
	Involved			1,780	1,780	1,780	1,780	1,780	1,780	1,780	1,780	1,780
	Noninvolved			380	380	380	380	380	380	380	380	380
	Subsurface development	(5)	(e)									
	Involved			6,230	6,230	6,230	6,230	6,230	6,230	6,530	6,530	6,530
	Noninvolved		22 years	1,670	1,670	1,670	1,670	1,670	1,670	1,670	1,670	1,670
	Operations subtotal			*40,710*	*33,150*	*33,630*	*40,710*	*33,150*	*33,630*	*41,010*	*33,450*	*33,930*
Monitoring	Surface	(6)	76 years									
	Involved			2,260	2,260	2,260	2,260	2,260	2,260	2,260	2,260	2,260
	Noninvolved			NA[f]	NA	NA	NA	NA	NA	NA	NA	NA
	Surface decontamination	(7)	3 years									
	Involved			4,060	2,950	3,070	4,060	2,950	3,070	4,060	2,950	3,070
	Noninvolved			NA	NA	NA	NA	NA	NA	NA	NA	NA
	Subsurface	(8)	76 years									
	Involved			5,240	5,240	5,240	5,240	5,240	5,240	5,780	5,780	5,780
	Noninvolved			990	990	990	990	990	990	990	990	990
	Monitoring subtotal			*12,550*	*11,440*	*11,560*	*12,550*	*11,440*	*11,560*	*13,090*	*11,980*	*12,100*
Operation and monitoring subtotal				*53,260*	*44,590*	*45,190*	*53,260*	*44,590*	*45,190*	*54,500*	*45,430*	*46,030*
Closure	Surface	(9)	6 years									
	Involved			1,580	1,110	1,200	1,580	1,110	1,210	1,580	1,110	1,200
	Noninvolved			600	420	460	600	420	460	600	420	460
	Subsurface	(10)	(g)									
	Involved			1,310	1,310	1,310	1,310	1,310	1,310	3,270	3,270	3,270
	Noninvolved			260	260	260	260	260	260	660	660	660
	Closure subtotal			*3,750*	*3,100*	*3,230*	*3,750*	*3,100*	*3,230*	*6,110*	*5,460*	*5,590*
Totals				***63,190***	***52,870***	***53,750***	***63,350***	***53,030***	***53,910***	***66,940***	***56,230***	***57,110***

a. Sources: (1) TRW (1999c, Table 6-1); (2) TRW (1999b, Table 6.1.1.1-1); (3) TRW (1999c Table 6-2); (4) TRW (1999b, Table 6.1.3.1-1); (5) TRW (1999b, Table 6.1.2.1-1); (6) TRW (1999c, Table 6-5); (7) TRW (1999c, Table 6-4); (8) TRW (1999b, Table 6.1.4.1-1); (9) TRW (1999c, Table 6-6); (10) TRW (1999b, Table 6.1.6.1-1).

b. UC = uncanistered packaging scenario.

c. DISP = disposable canister packaging scenario.

d. DPC = dual-purpose canister packaging scenario.

e. High thermal load and intermediate thermal load = 21 years; low thermal load = 22 years.

f. NA = not applicable.

g. High thermal load = 6 years; intermediate thermal load = 6 years; low thermal load = 15 years.

Lost workday cases, which are described above, include cases that result in the loss of more than half a workday. These statistical categories, which have been standardized by the U.S. Department of Labor and the Bureau of Labor Statistics, must be reported annually by employers with 11 or more employees. Table F-2 summarizes the health and safety impact statistics used for this analysis.

Table F-2. Health and safety statistics for estimating industrial safety impacts common to the workplace.[a]

Phase	Total recordable cases incidents per 100 FTEs[b]		Lost workday cases per 100 FTEs		Fatalities per 100,000 FTEs (involved and noninvolved)[c]	Data set for TRCs and LWCs[d]
	Involved	Noninvolved	Involved	Noninvolved		
Construction						
Surface	6.1	3.3	2.9	1.6	2.9	(1)
Subsurface	6.1	3.3	2.9	1.6	2.9	(1)
Operation and Monitoring						
Operation period						
Surface	3	3.3	1.2	1.6	2.9	(3)
Subsurface - emplacement	3	3.3	1.2	1.6	2.9	(3)
Subsurface - drift development	6.8	1.1	4.8	0.7	2.9	(2)
Monitoring period						
Surface	3	3.3	1.2	1.6	2.9	(3)
Subsurface	3	3.3	1.2	1.6	2.9	(3)
Closure						
Surface	6.1	3.3	2.9	1.6	2.9	(1)
Subsurface	6.1	3.3	2.9	1.6	2.9	(1)

a. See text below for source of data in Data Sets 1, 2, and 3.
b. FTEs = full-time equivalent work years.
c. See the discussion about Data Set 4 for source of fatality statistic for normal industrial activities.
d. TRCs = total recordable cases; LWCs = lost workday cases.

Table F-2 cites three sets of statistics that were used to estimate total recordable cases and lost workday cases for workers during activities at the Yucca Mountain site. In addition, there is a fourth statistic related to the occupational fatality projections for the Yucca Mountain site activities. The source of information from which the sets of impact statistics were derived is discussed below. All of the statistics are based on DOE experience for similar types of activities and were derived from the DOE CAIRS (Computerized Accident/Incident Reporting and Recordkeeping System) data base (DOE 1999, all).

Data Set 1, Construction and Construction-Like Activities

This set of statistics from the DOE CAIRS data base was applied to construction or construction-like activities. Specifically, it was used for both surface and subsurface workers during the construction phase and the closure phase (closure phase activities were deemed to be construction-like activities). The statistics were based on a 6.75-year period (1992 through the third quarter of 1998).

For involved workers the impact statistic numbers were derived from the totals for all of the DOE construction activities over the period. For noninvolved workers, the values were derived from the combined government and services contractor noninvolved groups for the same period. The noninvolved worker statistic, then, is representative of impacts for oversight personnel who would not be involved in the actual operation of equipment or resources. The basic statistics derived from the CAIRS data base for each of the groups include:

- Involved worker total recordable cases: 764 recordable cases for approximately 12,400 full-time equivalent work years

- Involved worker lost workday cases: 367 lost workday cases for approximately 12,400 full-time equivalent work years

- Noninvolved worker total recordable cases: 1,333 recordable cases for approximately 40,600 full-time equivalent work years

- Noninvolved worker lost workday cases: 657 lost workday cases for approximately 40,600 full-time equivalent work years

Data Set 2, Excavation Activities

This set of statistics was derived from experience at the Yucca Mountain Project over a 30-month period (fourth quarter of 1994 though the first quarter of 1997). DOE selected this period because it coincided with the exploratory tunnel boring machine operations at Yucca Mountain, reflecting a high level of worker activity during ongoing excavation activities. This statistic was applied for the Yucca Mountain Project subsurface development period, which principally involves drift development activities. The Yucca Mountain Project experience from which the statistic is derived is presented in Table F-3. Stewart (1998, all) contains the Yucca Mountain statistics, which were derived from the CAIRS data base (DOE 1999, all).

Table F-3. Yucca Mountain Project worker industrial safety loss experience.[a]

Factor	Value[b]	Basis
TRCs[c] per 100 FTEs[d]		
Involved worker	6.8	56 TRCs for 825 construction FTEs
Noninvolved worker	1.1	2.3 TRCs for 2,015 nonconstruction FTEs
LWCs[e] per 100 FTEs		
Involved worker	4.8	40 LWCs for 825 construction FTEs
Noninvolved worker	0.7	14 LWCs for 2,015 nonconstruction FTEs
Fatality rate occurrence per 100,000 FTEs		
Involved worker	0.0	No fatalities for 825 construction FTEs
Noninvolved worker	0.0	No fatalities for 2,015 nonconstruction FTEs

a. Fourth quarter 1994 through first quarter 1997.
b. Source: Adapted from the CAIRS data base (DOE 1999, all) by Stewart (1998, all) for the fourth quarter of 1994 through the first quarter of 1997.
c. TRCs = total recordable cases of injury and illness.
d. FTEs = full-time equivalent work years.
e. LWCs = lost workday cases.

Data Set 3, Activities Involving Work in a Radiological Environment

This set of statistics is from the DOE CAIRS data base (DOE 1999, all). In arriving at the statistics listed in Table F-2, information from the Savannah River Site, the Hanford Site, and the Idaho National Engineering and Environmental Laboratory was averaged individually for the 6.5 years from 1992 through the second quarter of 1998. The averages were then combined to produce an overall average. The reason these three sites were selected as the basis for this set of statistics is that the DOE Savannah River, Hanford, and Idaho National Engineering and Environmental Laboratory sites currently conduct most of the operations in the DOE complex involving handling, sorting, storing, and inspecting spent nuclear fuel and high-level radioactive waste materials, as well as similar activities for low-level radioactive waste materials. The Yucca Mountain Repository phases for which this set of statistics was applied included the receipt, handling, and packaging of spent nuclear fuel and high-level radioactive waste in the surface facilities; subsurface emplacement activities; and surface and subsurface monitoring activities, including decontamination of the surface facilities. These activities involve handling, storing, and inspecting spent nuclear fuel and high-level radioactive waste, so the worker activities at the Yucca Mountain site are expected to be similar to those cited above for the other sites in the DOE complex.

The basic statistics for the involved and noninvolved workers include:

- Involved worker total recordable cases: 1,246 for about 41,600 full-time equivalent work years
- Involved worker lost workday cases: 538 for about 41,600 full-time equivalent work years
- Noninvolved worker total recordable cases: 1,333 for about 40,600 full-time equivalent work years
- Noninvolved worker lost workday cases: 657 for about 40,600 full-time equivalent work years

Data Set 4, Statistics for Worker Fatalities from Industrial Hazards

There have been no reported fatalities as a result of workplace activities for the Yucca Mountain project. Similarly, there are no fatalities listed in the Mine Safety and Health Administration data base for stone mining workers (MSHA 1999, all). Because fatalities in industrial operations sometimes occur, the more extensive overall DOE data base was used to estimate a fatality rate for the activities at the Yucca Mountain site. Statistics for the DOE facility complex for the 10 years between 1988 and 1997 were used (DOE 1999, all). These fatality statistics are for both government and contractor personnel working in the DOE complex who were involved in the operation of equipment and resources (involved workers). The activities in the DOE complex covered by this statistic were governed by safety and administrative controls (under the DOE Order System) that are similar to the safety and administrative controls that would be applied for Yucca Mountain Repository work. These fatality statistics were also applied to the noninvolved worker population because they are the most inclusive statistics in the CAIRS data base. However, the statistics probably are conservatively high for the noninvolved worker group.

F.2.2.3 Estimates of Radiological Exposures

DOE considered the following potential sources of radiation exposure for assessing radiological health impacts to workers:

- Inhalation of gaseous radon-222 and its decay products. Subsurface workers could inhale the radon-222 present in the air in the repository drifts. Workers on the surface could inhale radon-222 released to the environment in the exhaust air from the subsurface ventilation system.

- External exposure of surface workers to radioactive gaseous fission products that could be released during handling and packaging of spent nuclear fuel with failed cladding for emplacement in the repository. Such impacts would be of most concern for the uncanistered shipping cask scenario.

- Direct external exposure of workers in the repository drifts as a result of naturally occurring radionuclides in the walls of the drifts (primarily potassium-40 and radionuclides of the naturally occurring uranium and thorium decay series).

- External exposure of workers to direct radiation emanating from the waste packages containing spent nuclear fuel and high-level radioactive waste either during handling and packaging (surface facility workers) or after it is placed within the waste package (largely subsurface workers).

Section F.1.1.6 describes the approach taken to estimate exposures to workers as a result of release of gaseous radon-222 from the drift walls to the subsurface atmosphere. For radon exposures to subsurface workers, the analysis assumed a subsurface occupancy factor of 1.0 for involved workers, an occupancy factor of 0.6 for noninvolved workers for construction and drift development activities, and an occupancy factor of 0.4 for noninvolved workers for emplacement, monitoring, and closure (Rasmussen 1998a, all; Rasmussen 1999, all; Jessen 1999, all).

As discussed in Section F.1.1.6, the average concentration of radon-222 in the subsurface atmosphere varies with the ventilation rate and repository volume. Table F-4 lists the correction factors (multipliers) applied to the average value for the concentration of radon-222 measured in the Exploratory Studies Facility for the Proposed Action.

Table F-4. Correction factors and annual exposures from radon-222 and its decay products for each of the project phases or periods under the Proposed Action.[a]

	Correction factor			Annual dose rate (millirem per year)		
	Thermal load scenario			Thermal load scenario		
Project phase or period	High	Intermediate	Low	High	Intermediate	Low
Construction	1.9	2.2	2.2	114	132	132
Drift development	0.6	0.6	0.6	36	36	36
Emplacement	1.1	1.5	2.9	66	90	174
Monitoring	3.2	4.1	4.4	192	246	264
Closure	3.2	4.1	4.4	192	246	264
Retrieval[b]	3.2	3.2	3.2	192	192	192

a. Based on the measured value of 60 rem per year corrected for repository volume and ventilation rate; see Section F.1.1.6 and Appendix G (Section G.2.3.1).

b. Multiplier for retrieval is not dependent on thermal load.

Appendix G, Section G.2.4.2 describes the approach taken to estimate source terms and associated doses to workers from the potential release of gaseous fission products from spent nuclear fuel with failed cladding.

Subsurface workers would also be exposed to background gamma radiation from naturally occurring radionuclides in the subsurface rock (largely from the uranium-238 decay series radionuclides and from potassium-40, both in the rock). DOE has based its projection of worker external gamma dose rates on the data obtained during Exploratory Studies Facility operations (Section F.1.1.6). The collective ambient radiation exposures for subsurface workers were calculated assuming occupancy factors cited in the previous paragraph for subsurface workers for emplacement and monitoring activities (Rasmussen 1998a, all; Rasmussen 1999, all; Jessen 1999, all).

Table F-5 lists dose rates in the fourth column for cases in which the annual full-time equivalent surface worker exposure values vary with the shipping package scenario. The table also lists the sources from which the data were obtained. The dose rates to subsurface workers from the radiation emitted from waste packages would vary with the thermal load, as indicated in the fourth column of Table F-5.

Table F-6 lists the annual exposures to subsurface workers from radiation emanating from the waste packages for the high, intermediate, and low thermal load scenarios, under the Proposed Action and Module 1 and 2 inventories. Section F.3 discusses Inventory Modules 1 and 2.

Table F-5. Radiological exposure data used to calculate worker radiological health impacts (page 1 of 2).

Phase and worker group	Exposure source[a]	Occupancy factor[b]	Annual dose (millirem, except where noted)	Annual full-time equivalent workers[c]			Data source[g]
				UC[d]	DISP[e]	DPC[f]	
Construction							
Surface							
Involved	Radon-222 inhalation	1.0	Small relative to subsurface worker exposures				(h)
Noninvolved	Radon-222 inhalation	1.0	Small relative to subsurface worker exposures				(h)
Subsurface							
Involved	Drift ambient	1.0	40				(1), (2)
	Radon-222 inhalation	1.0	Table F-4				(2), Table F-4
Noninvolved	Drift ambient	0.6	40				(1), (2)
	Radon-222 inhalation	0.6	Table F-4				(2), Table F-4
Operations and monitoring							
Surface handling and loading operations							
Involved	Receipt, handling and packaging of spent nuclear fuel and high-level radioactive waste	1.0	400	464	199	199	
			100	297	228	244	(3)
Noninvolved	Receipt, handling and packaging of spent nuclear fuel and high-level radioactive waste	1.0	25	175	150	149	(3)
			0	341	386	390	
Surface monitoring							
Involved only	Radon-222 inhalation	1.0	Small relative to subsurface workers				(i)
Surface decontamination (postemplacement, involved only)							
	External exposure	1.0	100	826	599	624	(4)
		1.0	25	528	383	399	(4)
Subsurface emplacement							
Involved	Waste package	Varies, see Table F-6	Varies, see Table F-6				Table F-6
	Drift ambient	1.0	40				(1), (2)
	Radon-222	1.0	Table F-4				(2), Table F-4
Noninvolved	Waste package	0.04	0.1 millirem per hour				(5)
	Drift ambient	0.4	40				(1), (2)
	Radon-222 inhalation	0.4	Table F-4				(2), Table F-4
Subsurface drift development							
Involved	Drift ambient	1.0	40				(1), (2)
	Radon-222 inhalation	1.0	Table F-4				(2), Table F-4
Noninvolved	Drift ambient	0.6	40				(1), (2)
	Radon-222 inhalation	0.6	Table F-4				(2), Table F-4
Monitoring							
Subsurface							
Involved	Waste package	Varies, see Table F-6	Varies, see Table F-6				Table F-6
	Drift ambient	1.0	40				(1), (2)
	Radon-222 inhalation	1.0	Table F-4				(2), Table F-4
Noninvolved	Waste package	0.04	0.1 millirem per hour				(5)
	Drift ambient	0.4	40				(1), (2), (6)
	Radon-222 inhalation	0.4	Table F-4				(2), (6), Table F-4

Table F-5. Radiological exposure data used to calculate worker radiological health impacts (page 2 of 2).

Phase and worker group	Exposure source[a]	Occupancy factor[b]	Annual dose (millirem per year except where noted)	Annual full-time equivalent workers[c] UC[d]	DISP[e]	DPC[f]	Data source[g]
Closure							
Surface							
Involved		1.0	Small relative to subsurface worker exposures				(j)
Noninvolved		1.0	Small relative to subsurface worker exposures				(j)
Subsurface							
Involved	Waste package	Varies, see Table F-6	Varies, see Table F-6				Table F-6
	Drift ambient	1.0	40				(1), (2)
	Radon-222 inhalation	1.0	Table F-4				(2), Table F-4
Noninvolved	Waste package	0.04	0.1 millirem per hour				(5)
	Drift ambient	0.4	40				(1), (2)
	Radon-22 inhalation	0.4	Table F-4				(2), Table F-4

a. Exposure sources include radiation from spent nuclear fuel and high-level radioactive waste packages to surface and subsurface workers, the ambient exposure to subsurface workers from naturally occurring radiation in the drift walls, and internal exposures from inhalation of radon-222 and its decay products in the drift atmosphere.
b. Fraction of 8-hour workday that workers are exposed.
c. Number of annual full-time equivalent workers for surface facility activities when number of workers would vary with shipping package scenario.
d. UC = uncanistered packaging scenario.
e. DISP = disposable canister packaging scenario.
f. DPC = dual-purpose canister packaging scenario.
g. Sources:
   (1) Section F.1.1.6.
   (2) Rasmussen (1998a, all).
   (3) TRW (1999c, Table 6-2).
   (4) Total employment for decontamination activities taken from TRW (1999c, Table 6-4). In Table 6-2 of TRW (1999c), the distribution of involved workers for surface facility receipt, handling, and packaging phase between the 400 millirem per year and 100 millirem per year cases is 61 percent and 39 percent, respectively. For decontamination operations it was assumed that 69 percent of the involved worker population would receive 100 millirem per year and 39 percent of the involved worker population would receive 25 millirem per year.
   (5) Rasmussen (1999, all).
   (6) Jessen (1999, all).
h. Comparison of information in Chapter 4, Table 4-2 (surface workers) and Table F-9 (subsurface workers).
i. Comparison of information in Chapter 4, Table 4-5 (surface workers) and Table F-27 (subsurface workers).
j. Comparison of information in Chapter 4, Table 4-7 (surface workers) and Table F-30 (subsurface workers).

Table F-6. Annual involved subsurface worker exposure rates from waste packages[a] (person-rem per year).

	Proposed Action			Inventory Modules		
Project phase	High	Intermediate	Low	High	Intermediate	Low
Emplacement	10.1	10.2	5.6	10.2	10.2	6.0
Monitoring	7.2	7.2	4.1	7.2	7.8	5.6
Closure	12.5	12.5	7.4	12.5	12.5	7.4

a. Sources: individual exposure values from TRW (1999b, Appendix G, Tables G-3, G-3a, G-4, and G-4a).
b. Calculated annual exposures, Rasmussen (1999, all).

F.2.3 COMPILATION OF DETAILED RESULTS FOR OCCUPATIONAL HEALTH AND SAFETY IMPACTS

F.2.3.1 Occupational Health and Safety Impacts During the Construction Phase

F.2.3.1.1 *Industrial Hazards to Workers*

Tables F-7 and F-8 list health and safety impacts from industrial hazards to surface and subsurface workers, respectively, for construction activities.

Table F-7. Industrial hazard health and safety impacts to surface facility workers during construction phase (44 months).[a]

	Waste packaging scenario		
Worker group	Uncanistered	Disposable canister	Dual-purpose canister
Involved			
Full-time equivalent work years[b]	2,380	1,650	1,760
Total recordable cases	150	100	110
Lost workday cases	70	50	50
Fatalities	0.07	0.05	0.05
Noninvolved			
Full-time equivalent work years	900	630	670
Total recordable cases	30	21	22
Lost workday cases	15	10	11
Fatalities	0.03	0.02	0.02
All workers (totals)[c]			
Full-time equivalent work years	3,280	2,280	2,420
Total recordable cases	180	120	130
Lost workday cases	85	59	63
Fatalities	0.10	0.07	0.07

a. Source: Impact rates from Table F-2.

b. Source: Table F-1.

c. Totals might differ from sums due to rounding.

Table F-8. Industrial hazard health and safety impacts to subsurface facility workers during construction phase (5 years).[a]

	Thermal load scenario		
Worker group	High	Intermediate	Low
Involved			
Full-time equivalent work years[b]	2,300	2,460	2,460
Total recordable cases	140	150	150
Lost workday cases	68	72	72
Fatalities	0.07	0.07	0.07
Noninvolved			
Full-time equivalent work years	600	600	600
Total recordable cases	20	20	20
Lost workday cases	10	10	10
Fatalities	0.02	0.02	0.02
All workers (totals)[c]			
Full-time equivalent work years	2,900	3,060	3,060
Total recordable cases	160	170	170
Lost workday cases	77	82	82
Fatalities	0.08	0.09	0.09

a. Source: Impact rates from Table F-2.

b. Source: Table F-1.

c. Totals might differ from sums due to rounding.

F.2.3.1.2 *Radiological Health Impacts to Workers*

Tables F-9 and F-10 list subsurface worker health impacts from inhalation of radon-222 in the subsurface atmosphere and from ambient radiation exposure from radionuclides in the rock of the drift walls, respectively. The radiological health impacts to surface workers from inhalation of radon-222 would be small in comparison to those for subsurface workers; therefore, they were not tabulated in this appendix (see Table F-5, Footnote h, for sources of exposure).

Table F-9. Radiological health impacts to subsurface facility workers from radon exposure during construction phase.[a]

Worker group	Thermal load scenario		
	High	Intermediate	Low
Involved			
Full-time equivalent work years[b]	2,300	2,460	2,460
Maximally exposed individual (MEI) worker dose (millirem)	570	660	660
Latent cancer fatality probability for MEI	0.0002	0.0003	0.0003
Collective dose (person-rem)	260	320	320
Latent cancer fatality incidence	0.10	0.13	0.13
Noninvolved			
Full-time equivalent work years	600	600	600
Maximally exposed individual (MEI) worker dose (millirem)	430	500	500
Latent cancer fatality probability for MEI	0.0002	0.0002	0.0002
Collective dose (person-rem)	52	60	60
Latent cancer fatality incidence	0.02	0.02	0.02
All workers (totals)[c]			
Full-time equivalent work years	2,900	3,060	3,060
Collective dose (person-rem)	310	380	380
Latent cancer fatality incidence	0.12	0.15	0.15

a. Source: Exposure data from Table F-5.
b. Source: Table F-1.
c. Totals might differ from sums due to rounding.

Table F-10. Radiological health impacts to subsurface facility workers from ambient radiation exposure during construction phase.[a]

Worker group	Thermal load scenario		
	High	Intermediate	Low
Involved			
Full-time equivalent work years[b]	2,300	2,460	2,460
Maximally exposed individual (MEI) worker dose (millirem)	200	200	200
Latent cancer fatality probability for MEI	0.00008	0.00008	0.00008
Collective dose (person-rem)	92	98	98
Latent cancer fatality incidence	0.04	0.04	0.04
Noninvolved			
Full-time equivalent work years	600	600	600
Maximally exposed individual (MEI) worker dose (millirem)	150	150	150
Latent cancer fatality probability for MEI	0.00006	0.00006	0.00006
Collective dose (person-rem)	18	18	18
Latent cancer fatality incidence	0.007	0.007	0.007
All workers (totals)[c]			
Full-time equivalent work years	2,900	3,060	3,060
Collective dose (person-rem)	110	120	120
Latent cancer fatality incidence	0.04	0.05	0.05

a. Source: Exposure data from Table F-5.
b. Source: Table F-1.
c. Totals might differ from sums due to rounding.

F.2.3.2 Occupational Health and Safety Impacts During the Operations Period

F.2.3.2.1 *Industrial Safety Hazards to Workers*

Tables F-11, F-12, and F-13 list estimated impacts for each worker group during waste receipt and packaging, drift development, and emplacement activities during the operations period.

Table F-11. Industrial hazard health and safety impacts to surface facility workers during waste receipt and packaging period (24 years).[a]

Worker group	Waste packaging option		
	Uncanistered	Disposable canister	Dual-purpose canister
Involved			
Full-time equivalent work years[b]	17,500	11,470	11,810
Total recordable cases of injury and illness	520	340	350
Lost workday cases	210	140	140
Fatalities	0.51	0.33	0.34
Noninvolved			
Full-time equivalent work years	13,150	11,620	11,760
Total recordable cases of injury and illness	430	380	390
Lost workday cases	210	190	190
Fatalities	0.38	0.34	0.34
All workers (totals)[c]			
Full-time equivalent work years	30,650	23,090	23,570
Total recordable cases of injury and illness	960	730	740
Lost workday cases	440	340	340
Fatalities	0.89	0.67	0.68

a. Source: Impact rates from Table F-2.
b. Source: Table F-1.
c. Totals might differ from sums due to rounding.

Table F-12. Industrial hazard health and safety impacts to subsurface facility workers during drift development period.[a]

Worker group	Thermal load scenario		
	High (21 years)	Intermediate (21 years)	Low (22 years)
Involved			
Full-time equivalent work years[b]	6,230	6,230	6,530
Total recordable cases of injury and illness	420	420	440
Lost workday cases	300	300	310
Fatalities	0.18	0.18	0.19
Noninvolved			
Full-time equivalent work years	1,670	1,670	1,670
Total recordable cases of injury and illness	19	19	19
Lost workday cases	12	12	12
Fatalities	0.05	0.05	0.05
All workers (totals)[c]			
Full-time equivalent work years	7,900	7,900	8,210
Total recordable cases of injury and illness	440	440	460
Lost workday cases	310	310	330
Fatalities	0.23	0.23	0.24

a. Source: Impact rates from Tables F-2 and F-3.
b. Source: Table F-1.
c. Totals might differ from sums due to rounding.

F.2.3.2.2 *Radiological Health Impacts to Workers*

Radiological health impacts to surface and subsurface facility workers for the operations period are the sum of the estimates of impacts to surface facility workers and subsurface facility workers during operation and monitoring (see Section F.2.3.3.2 for monitoring period).

- Table F-14 lists radiation dose to subsurface facility workers from radiation emanating from waste packages during emplacement operations.

Table F-13. Industrial hazard health and safety impacts to subsurface facility workers during emplacement period.[a]

Worker group	For all thermal load scenarios
Involved	
Full-time equivalent work years[b]	1,780
Total recordable cases of injury and illness	53
Lost workday cases	21
Fatalities	0.05
Noninvolved	
Full-time equivalent work years	380
Total recordable cases of injury and illness	13
Lost workday cases	6
Fatalities	0.01
All workers (totals)[c]	
Full-time equivalent work years	2,160
Total recordable cases of injury and illness	66
Lost workday cases	29
Fatalities	0.06

a. Source: Impact rates from Table F-2.
b. Source: Table F-1.
c. Totals might differ from sums due to rounding.

Table F-14. Radiological health impacts to subsurface facility workers from waste packages during emplacement period (24 years).[a]

	Thermal load scenario		
Worker group	High	Intermediate	Low
Involved			
Full-time equivalent work years[b]	1,780	1,780	1,780
Dose to maximally exposed individual worker (millirem)	4,460	4,510	2,490
Latent cancer fatality probability for MEI[c]	0.002	0.002	0.001
Collective dose (person-rem)	240	240	140
Latent cancer fatality incidence	0.10	0.10	0.05
Noninvolved			
Full-time equivalent work years	380	380	380
Dose to maximally exposed individual worker (millirem)	190	190	190
Latent cancer fatality probability for MEI	0.00008	0.00008	0.00008
Collective dose (person-rem)	3	3	3
Latent cancer fatality incidence	0.001	0.001	0.001
All workers (totals)[d]			
Full-time equivalent work years	2,160	2,160	2,160
Collective dose (person-rem)	240	250	140
Latent cancer fatality incidence	0.10	0.10	0.06

a. Source: Exposure data from Table F-5.
b. Source: Table F-1.
c. MEI = maximally exposed individual.
d. Totals might differ from sums due to rounding.

- Table F-15 lists radiation dose to subsurface workers from the ambient radiation in the drifts during emplacement operations. Table F-16 lists radiation doses to subsurface facility workers from ambient radiation during the drift development period.

- Table F-17 lists radiation dose to subsurface workers from inhalation of airborne radon-222 in the drift atmosphere during emplacement operations. Table F-18 lists radiation dose to subsurface workers from inhalation of airborne radon-222 during drift development operations.

Table F-15. Radiological health impacts to subsurface facility workers from ambient radiation during emplacement period.[a]

Worker group	Values are independent of thermal load scenario
Involved	
Full-time equivalent work years[b]	1,780
Dose to maximally exposed individual worker (millirem)	960
Latent cancer fatality probability for MEI[c]	0.0004
Collective dose (person-rem)	71
Latent cancer fatality incidence	0.03
Noninvolved	
Full-time equivalent work years	380
Dose to maximally exposed individual worker (millirem)	480
Latent cancer fatality probability for MEI	0.0002
Collective dose (person-rem)	8
Latent cancer fatality incidence	0.003
All workers (totals)[d]	
Full-time equivalent work years	2,160
Collective dose (person-rem)	79
Latent cancer fatality incidence	0.03

a. Source: Exposure data from Table F-5.
b. Source: Table F-1.
c. MEI = maximally exposed individual.
d. Totals might differ from sums due to rounding.

Table F-16. Radiological health impacts to subsurface facility workers from ambient radiation during drift development period.[a]

	Thermal load scenario		
Worker group	High (21 years)	Intermediate (21 years)	Low (22 years)
Involved			
Full-time equivalent work years[b]	6,230	6,230	6,530
Dose to maximally exposed individual worker (millirem)	880	880	880
Latent cancer fatality probability for MEI[c]	0.0004	0.0004	0.0004
Collective dose (person-rem)	250	250	260
Latent cancer fatality incidence	0.10	0.10	0.10
Noninvolved			
Full-time equivalent work years	1,670	1,670	1,670
Dose to maximally exposed individual worker (millirem)	660	660	660
Latent cancer fatality probability for MEI	0.0003	0.0003	0.0003
Collective dose (person-rem)	50	50	50
Latent cancer fatality incidence	0.02	0.02	0.02
All workers (totals)[d]			
Full-time equivalent work years	7,900	7,900	8,210
Collective dose (person-rem)	300	300	310
Latent cancer fatality incidence	0.12	0.12	0.12

a. Source: Exposure data from Table F-5.
b. Source: Table F-1.
c. MEI = maximally exposed individual.
d. Totals might differ from sums due to rounding.

Table F-17. Radiological health impacts to subsurface facility workers from airborne radon-222 during emplacement period.[a]

	Thermal load scenario		
Worker group	High	Intermediate	Low
Involved			
Full-time equivalent work years[b]	1,780	1,780	1,780
Dose to maximally exposed individual worker (millirem)	1,580	2,160	4,180
Latent cancer fatality probability for MEI[c]	0.0006	0.0008	0.002
Collective dose (person-rem)	120	160	310
Latent cancer fatality incidence	0.05	0.06	0.12
Noninvolved			
Full-time equivalent work years	380	380	380
Dose to maximally exposed individual worker (millirem)	790	1,080	2,090
Latent cancer fatality probability for MEI	0.0003	0.0004	0.0008
Collective dose (person-rem)	13	17	33
Latent cancer fatality incidence	0.005	0.007	0.01
All workers (totals)[d]			
Full-time equivalent work years	2,160	2,160	2,160
Collective dose (person-rem)	130	180	340
Latent cancer fatality incidence	0.05	0.07	0.14

a. Source: Exposure data from Table F-5.
b. Source: Table F-1.
c. MEI = maximally exposed individual.
d. Totals might differ from sums due to rounding.

Table F-18. Radiological health impacts to subsurface facility workers from airborne radon-222 during development period.[a]

	Thermal load scenario		
Worker group	High (21 years)	Intermediate (21 years)	Low (22 years)
Involved			
Full-time equivalent work years[b]	6,230	6,230	6,530
Dose to maximally exposed individual worker (millirem)	790	790	790
Latent cancer fatality probability for MEI[c]	0.0003	0.0003	0.0003
Collective dose (person-rem)	220	220	240
Latent cancer fatality incidence	0.09	0.09	0.09
Noninvolved			
Full-time equivalent work years	1,670	1,670	1,670
Dose to maximally exposed individual worker (millirem)	590	590	590
Latent cancer fatality probability for MEI	0.0002	0.0002	0.0002
Collective dose (person-rem)	45	45	45
Latent cancer fatality incidence	0.02	0.02	0.02
All workers (totals)[d]			
Full-time equivalent work years	7,900	7,900	8,210
Collective dose (person-rem)	270	270	280
Latent cancer fatality incidence	0.11	0.11	0.11

a. Source: Exposure data from Table F-5.
b. Source: Table F-1.
c. MEI = maximally exposed individual.
d. Totals might differ from sums due to rounding.

F.2.3.3 Occupational Health and Safety Impacts to Workers During the Monitoring Period

F.2.3.3.1 *Health and Safety Impacts to Workers from Workplace Industrial Hazards*

Health and safety impacts from industrial hazards common to the workplace for the monitoring period consist of the following:

- Impacts to surface facility workers for the 3-year surface facility decontamination period (Table F-19)
- Impacts to surface facility workers for monitoring support activities (Table F-20)
- Impacts to subsurface facility workers for monitoring and maintenance activities (Table F-21)

Table F-19. Industrial hazard health and safety impacts to surface facility workers during decontamination period.[a]

Impact	Uncanistered	Disposable canister	Dual-purpose canister
Full-time equivalent work years[b]	4,060	2,950	3,070
Total recordable cases of injury and illness	120	88	92
Lost workday cases	49	35	37
Fatalities	0.13	0.08	0.11

a. Source: Incident rate data from Table F-2.
b. Source: Table F-1.

Table F-20. Industrial hazard health and safety impacts to surface facility workers during monitoring period.[a]

Worker group	Phase	Annual
Full-time equivalent work years[b]	2,660	35
Total recordable cases of injury and illness	80	1.1
Lost workday cases	32	0.42
Fatalities	0.08	0.001

a. Source: Impacts rates from Table F-2.
b. Source: Table F-1.

Table F-21. Industrial hazard health and safety impacts for subsurface facility workers during monitoring period.[a]

	Thermal load scenario		
Worker group	High	Intermediate	Low
Involved			
Full-time equivalent work years[b]	5,240	5,240	5,780
Total recordable cases of injury and illness	160	160	170
Lost workday cases	63	63	69
Fatalities	0.15	0.15	0.17
Noninvolved			
Full-time equivalent work years	990	990	990
Total recordable cases of injury and illness	32	32	32
Lost workday cases	16	16	16
Fatalities	0.03	0.03	0.03
All workers (totals)[c]			
Full-time equivalent work years	6,230	6,230	6,760
Total recordable cases of injury and illness	190	190	210
Lost workday cases	84	84	91
Fatalities	0.18	0.18	0.20

a. Source: Impacts rates from Table F-2.
b. Source: Table F-1.
c. Totals may differ from sums due to rounding.

For surface monitoring support activities, annual impact values are listed to facilitate the extrapolation of the data for longer and shorter monitoring periods.

F.2.3.3.2 *Radiological Health Impacts to Workers*

F.2.3.3.2.1 Surface Facility Workers. During monitoring, surface workers would be involved in two types of activities—decontamination for 3 years after the completion of emplacement and support of subsurface monitoring for 76 years (starting at the end of emplacement). Surface workers providing support to the subsurface activities would receive very little radiological dose in comparison to their counterparts involved in subsurface monitoring activities. Therefore, radiological dose impacts were not included for this group; they are estimated in Appendix G, Section G.2. Radiological health impact estimates for the surface facilities decontamination activities are listed in Table F-22.

Table F-22. Radiological health impacts to surface facility workers during decontamination period.[a]

Worker group	Uncanistered	Disposable canister	Dual-purpose canister
Full-time equivalent work years[b]	4,060	2,950	3,070
Maximally exposed individual worker (millirem)[c]	300	300	300
Latent cancer fatality probability for MEI[d]	0.0001	0.0001	0.0001
Collective dose (person-rem)	290	210	220
Latent cancer fatality incidence	0.11	0.08	0.09

a. Source: Dose rate data from Table F-5.
b. Source: Table F-1.
c. Source: Based on Table F-4, maximum dose of 100 millirem per year for 3 years.
d. MEI = maximally exposed individual.

F.2.3.3.2.2 Subsurface Facility Workers. Radiological health impacts to subsurface facility workers during monitoring are listed in Table F-23. Maximum worker dose values in the table were based on a maximum work period of 50 years on a monitoring assignment rather than a 76-year monitoring period.

Table F-23. Radiological health impacts to subsurface facility workers during a 50-year work period during a 76-year monitoring period.[a]

	Thermal load scenario		
Worker group	High	Intermediate	Low
Involved			
Full-time equivalent work years[b]	5,240	5,240	5,780
Dose to maximally exposed individual worker (millirem)	16,240	18,940	17,610
Latent cancer fatality probability for MEI[c]	0.006	0.008	0.007
Collective dose (person-rem)	1,760	2,050	2,060
Latent cancer fatality incidence	0.71	0.82	0.83
Noninvolved			
Full-time equivalent work years	990	990	990
Dose to maximally exposed individual worker (millirem)	6,200	7,550	8,000
Latent cancer fatality probability for MEI	0.003	0.003	0.003
Collective dose (person-rem)	120	150	160
Latent cancer fatality incidence	0.05	0.06	0.06
All workers (totals)[d]			
Full-time equivalent work years	6,230	6,230	6,760
Collective dose (person-rem)	1,880	2,200	2,220
Latent cancer fatality incidence	0.75	0.88	0.89

a. Source: Exposure data from Table F-4.
b. Source: Table F-1.
c. MEI = maximally exposed individual.
d. Totals might differ from sums due to rounding.

In addition, DOE considered monitoring periods as short as 26 years and as long as 276 years. Radiological health impacts for both of these monitoring periods were evaluated; the radiological health impact estimates are listed in Table F-24. Doses to the maximally exposed worker were based on a 50-year employment period rather than the 276-year monitoring period.

Table F-24. Radiological health impacts to workers during a 26-year and a 276-year monitoring period, dual-purpose canister packaging scenario.[a]

Group	26 years			276 years		
	High thermal load	Intermediate thermal load	Low thermal load	High thermal load	Intermediate thermal load	Low thermal load
Involved						
Full-time equivalent work years	1,790	1,790	1,980	19,040	19,040	20,980
Dose to maximally exposed individual worker (millirem)	8,440	9,850	9,160	16,240	18,940	17,610
Latent cancer fatality probability for MEI[b]	0.003	0.004	0.004	0.006	0.008	0.007
Collective dose (person-rem)	600	700	710	6,400	7,430	7,500
Latent cancer fatality incidence	0.24	0.28	0.28	2.6	3.0	3.0
Noninvolved						
Full-time equivalent work years	340	340	340	3,590	3,590	3,590
Dose to maximally exposed individual worker (millirem)	3,220	3,930	4,160	6,200	7,550	8,000
Latent cancer fatality probability for MEI	0.001	0.002	0.002	0.002	0.003	0.003
Collective dose (person-rem)	42	51	54	450	540	570
Latent cancer fatality incidence	0.02	0.02	0.02	0.18	0.22	0.23
All workers (totals)						
Full-time equivalent work years	2,130	2,130	2,320	22,630	22,630	24,570
Collective dose (person-rem)	640	750	760	6,850	7,970	8,073
Latent cancer fatality incidence	0.26	0.30	0.30	2.7	3.2	3.2

a. Sources: Tables F-1, F-4, and F-23.

b. MEI = maximally exposed individual.

F.2.3.4 Occupational Health and Safety Impacts During the Closure Phase

F.2.3.4.1 *Health and Safety Impacts to Workers from Workplace Industrial Hazards*

Health and safety impacts to workers from industrial hazards common to the workplace for closure are listed in Table F-25 for surface facility workers and Table F-26 for subsurface facility workers.

F.2.3.4.2 *Radiological Health Impacts to Workers*

Radiological health impact to workers from closure activities are the sum of the following components:

- Radiological health impacts to subsurface workers from radiation emanating from the waste packages during the closure phase (Table F-27)

- Radiological impacts to subsurface workers from the ambient radiation field in the drifts during the closure phase (Table F-28)

- Radiological impacts to subsurface workers from inhalation of radon-222 in the drift atmosphere during the closure phase (Table F-29)

Table F-25. Industrial hazard health and safety impacts to surface facility workers during closure phase.[a]

	Waste packaging option		
Worker group	Uncanistered	Disposable canister	Dual-purpose canister
Involved			
Full-time equivalent work years[b]	1,580	1,110	1,200
Total recordable cases of injury and illness	97	68	73
Lost workday cases	46	33	35
Fatalities	0.04	0.03	0.03
Noninvolved			
Full-time equivalent work years	600	420	460
Total recordable cases of injury and illness	20	14	15
Lost workday cases	10	7	7
Fatalities	0.02	0.01	0.01
All workers (totals)[c]			
Full-time equivalent work years	2,180	1,540	1,650
Total recordable cases of injury and illness	120	82	88
Lost workday cases	56	40	43
Fatalities	0.06	0.04	0.04

a. Source: Impact rates from Table F-2.
b. Source: Table F-1.
c. Totals might differ from sums due to rounding.

Table F-26. Industrial hazard health and safety impacts to subsurface facility workers during closure phase.[a]

	Thermal load scenario		
Worker group	High (6 years)	Intermediate (6 years)	Low (15 years)
Involved			
Full-time equivalent work years[b]	1,310	1,310	3,270
Total recordable cases of injury and illness	80	80	200
Lost workday cases	39	39	96
Fatalities	0.04	0.04	0.09
Noninvolved			
Full-time equivalent work years	260	260	660
Total recordable cases of injury and illness	9	9	22
Lost workday cases	4	4	11
Fatalities	0.01	0.01	0.02
All workers (totals)[c]			
Full-time equivalent work years	1,570	1,570	3,930
Total recordable cases of injury and illness	89	89	220
Lost workday cases	43	43	110
Fatalities	0.05	0.05	0.11

a. Source: Impact rates from Table F-2.
b. Source: Table F-1.
c. Totals might differ from sums due to rounding.

Because the surface facilities would be largely decontaminated at the beginning of the monitoring period (the exception would be a small facility retained to handle an operations emergency), radiological health impacts to surface facility workers during closure would be small in comparison to those to the subsurface facility workers and so are not included here.

Table F-27. Radiological health impacts to subsurface facility workers from waste package radiation exposures during closure phase.[a]

	Thermal load scenario		
Worker group	High (5 years)	Intermediate (6 years)	Low (15 years)
Involved			
Full-time equivalent work years[b]	1,310	1,310	3,270
Dose to maximally exposed individual worker (millirem)	650	650	960
Latent cancer fatality probability for MEI[c]	0.0003	0.0003	0.0004
Collective dose (person-rem)	75	75	110
Latent cancer fatality incidence	0.03	0.03	0.04
Noninvolved			
Full-time equivalent work years	260	260	660
Dose to maximally exposed individual worker (millirem)	48	48	120
Latent cancer fatality probability for MEI	0.00002	0.00002	0.00005
Collective dose (person-rem)	2	2	5
Latent cancer fatality incidence	0.0008	0.0008	0.002
All workers (totals)[d]			
Full-time equivalent work years	1,570	1,570	3,930
Collective dose (person-rem)	77	77	115
Latent cancer fatality incidence	0.03	0.03	0.05

a. Source: Exposure data from Table F-5.

b. Source: Table F-1.

c. MEI = maximally exposed individual.

d. Totals might differ from sums due to rounding.

Table F-28. Radiological health impacts to subsurface facility workers from ambient radiation exposures during closure phase.[a]

	Thermal load scenario		
Worker group	High (5 years)	Intermediate (6 years)	Low (15 years)
Involved			
Full-time equivalent work years[b]	1,310	1,310	3,270
Dose to maximally exposed individual worker (millirem)	240	240	600
Latent cancer fatality probability for MEI[c]	0.0001	0.0001	0.0002
Collective dose (person-rem)	52	52	130
Latent cancer fatality incidence	0.02	0.02	0.05
Noninvolved			
Full-time equivalent work years	260	260	660
Dose to maximally exposed individual worker (millirem)	180	180	450
Latent cancer fatality probability for MEI	0.00006	0.00007	0.00018
Collective dose (person-rem)	8	8	20
Latent cancer fatality incidence	0.003	0.003	0.008
All workers (totals)[d]			
Full-time equivalent work years	1,570	1,570	3,930
Collective dose (person-rem)	60	60	150
Latent cancer fatality incidence	0.02	0.02	0.06

a. Source: Exposure data from Table F-5.

b. Source: Table F-1.

c. MEI = maximally exposed individual.

d. Totals might differ from sums due to rounding.

Table F-29. Radiological health impacts to subsurface facility workers from radon-222 exposure during closure phase.[a]

Worker group	Thermal load scenario: High (5 years)	Intermediate (6 years)	Low (15 years)
Involved			
Full-time equivalent work years[b]	1,310	1,310	3,270
Dose to maximally exposed individual worker (millirem)	1,150	1,480	3,960
Latent cancer fatality probability for MEI[c]	0.0005	0.0006	0.002
Collective dose (person-rem)	250	320	860
Latent cancer fatality incidence	0.10	0.13	0.35
Noninvolved			
Full-time equivalent work years	260	260	660
Dose to maximally exposed individual worker (millirem)	860	1,110	2,970
Latent cancer fatality probability for MEI	0.0003	0.0004	0.001
Collective dose (person-rem)	38	49	130
Latent cancer fatality incidence	0.02	0.02	0.05
All workers (totals)[d]			
Full-time equivalent work years	1,570	1,570	3,930
Collective dose (person-rem)	290	370	990
Latent cancer fatality incidence	0.12	0.15	0.40

a. Source: Exposure data from Table F-5.
b. Source: Table F-1.
c. MEI = maximally exposed individual.
d. Totals might differ from sums due to rounding.

F.3 Human Health and Safety Impact Analysis for Inventory Modules 1 and 2

DOE performed an analysis to estimate the occupational and public health and safety impacts from the emplacement of Inventory Module 1 or 2. Module 1 would involve the emplacement of additional spent nuclear fuel and high-level radioactive waste in the repository; Inventory Module 2 would emplace commercial Greater-Than-Class-C waste and DOE Special-Performance-Assessment-Required waste, which is equivalent to commercial Greater-Than-Class-C waste, in addition to the inventory from Module 1. The volumes of Greater-Than-Class-C and Special-Performance-Assessment-Required waste would be less than that for spent nuclear fuel and high-level radioactive waste (TRW 1999c, Table 3.1). Waste packages containing these materials would be placed between the waste packages containing spent nuclear fuel and high-level radioactive waste (see Chapter 8, Section 8.1.2.1).

With regard to estimating heath and safety impacts for the inventory modules, the characteristics of the spent nuclear fuel and high-level radioactive waste were taken to be the same as those for the Proposed Action, but there would be more material to emplace (see Appendix A, Section A.2). As described in Appendix A, the radiological content of the Greater-Than-Class-C waste and Special-Performance-Assessment-Required waste, which is the additional material in Module 2, is much less than that for spent nuclear fuel and high-level radioactive waste. Therefore, the emplacement of the Module 2 material would not meaningfully increase radiological impacts to workers over those estimated for the Module 1 inventory. Further, the facility design parameters, on which the impact estimates are based, are extrapolations from existing designs and have some uncertainty associated with them [see, for example, TRW (1999c), Section 6.2, first paragraph]. Therefore, separate occupational and public health and safety impact analyses were not performed for Module 2 because the impacts for Inventory Modules 1 and 2 would not differ meaningfully.

The calculation of health and safety impacts to workers assumed that the throughput rate of materials for the facility would remain the same as that assumed for the Proposed Action during repository operations (that is, the 70,000-MTHM case). In addition, for the inventory modules the period of operations would be extended to accommodate the additional materials, and the monitoring period would be reduced such that the Yucca Mountain repository operations and monitoring activities would still occur in a 100-year period. Table F-30 summarizes the expected lengths of the phases for Yucca Mountain Repository activities for the inventory modules. These periods were used in the occupational and public health and safety impact calculations.

Table F-30. Expected durations (years) of the Proposed Action and Inventory Modules 1 and 2.[a]

Inventory	Construction phase (2005-2010)	Operation and monitoring phase (2010-2110)				Closure phase (starts in 2110)
		Development[b]	Emplacement	Monitoring	Total	
Proposed Action	5	22	24	76	100[c]	6-15[d]
Module 1 or 2	5	36	38	62	100	13-27[e]

a. Sources: TRW (1999b, all); TRW (1999c, all); Jessen (1999, all).
b. Continuing subsurface construction (development) activities are concurrent with emplacement activities.
c. Closure is assumed to begin 100 years following initial emplacement for the Proposed Action and Module 1 or 2 for the evaluation of cumulative impacts.
d. 6, 6, and 15 years for the high, intermediate, and low thermal load scenarios, respectively.
e. 13, 17, and 27 years for the high, intermediate, and low thermal load scenarios, respectively.

This section discusses the methodologies and data used to estimate occupational radiological health and safety impacts resulting from construction, operation and monitoring, and closure of the Yucca Mountain Repository for Inventory Modules 1 and 2, and presents the detailed results. Section F.3.1 describes the methods DOE used to estimate impacts. Section F.3.2 contains tabulations of the detailed data used in the impact calculations and references to the data sources. Section F.3.3 contains detailed tabulations of results.

F.3.1 METHODOLOGY FOR CALCULATING HUMAN HEALTH AND SAFETY IMPACTS

DOE used the methodology described in Section F.2.1 to estimate health and safety impacts for the inventory modules. This methodology involved assembling data for the number of full-time equivalent workers for each repository phase. These numbers were used with statistics for the likelihood of an impact (industrial hazards) or the expected dose rate in the worker environment to calculate health and safety impacts. The way in which the input data was combined in the calculation of health and safety impacts is described in more detail in Section F.2.1. Some of the input data for the calculations for the inventory modules are different from those for the Proposed Action, as discussed in the next section.

F.3.2 DATA SOURCES AND TABULATIONS

F.3.2.1 Full-Time Equivalent Worker-Year Estimates for the Repository Phases for Inventory Modules 1 and 2

The full-time equivalent work-year estimates for the inventory modules are different from those for the Proposed Action. Table F-31 lists the number of full-time equivalent work years for the various repository phases for the inventory modules. Each full-time equivalent work year represents 2,000 work hours, the hours assumed to be worked in a normal work year.

This analysis divides the repository workforce into two groups—involved and noninvolved workers (see Section F.2 for definitions of involved and noninvolved workers). It did not consider workers whose place of employment would be other than at the repository site.

Table F-31. Full-time equivalent work years for various repository periods for Inventory Modules 1 and 2.

			High thermal load			Intermediate thermal load			Low thermal load		
Phase	Period	Sources[a]	UC[b]	DISP[c]	DPC[d]	UC	DISP	DPC	UC	DISP	DPC
Construction											
Surface	44 months	(1)									
Involved worker			2,380	1,650	1,760	2,380	1,650	1,760	2,380	1,650	1,760
Noninvolved worker			900	630	670	900	630	670	900	670	680
Subsurface	5 years	(2)									
Involved worker			2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460	2,460
Noninvolved worker			600	600	600	600	600	600	600	600	600
Subtotal			*6,340*	*5,340*	*5,480*	*6,340*	*5,340*	*5,480*	*6,340*	*5,380*	*5,480*
Operation and monitoring											
Operation											
Subsurface drift development	36 years	(5)									
Involved worker			9,110	9,110	9,110	9,540	9,540	9,540	10,370	10,370	10,370
Noninvolved worker			2,450	2,450	2,450	2,450	2,450	2,450	2,740	2,740	2,740
Subsurface emplacement	38 years	(4)									
Involved worker			2,810	2,810	2,810	2,810	2,810	2,810	3,000	3,000	3,000
Noninvolved worker			610	610	610	610	610	610	650	650	650
Surface handling	38 years	(3)									
Involved worker			27,700	18,160	18,700	27,700	18,160	18,700	27,700	18,160	18,700
Noninvolved worker			20,820	18,390	18,620	20,820	18,390	18,620	20,820	18,390	18,620
Subtotal operation			*63,500*	*51,530*	*52,290*	*63,930*	*51,960*	*52,720*	*65,270*	*53,310*	*54,070*
Monitoring											
Surface support	62 years	(6)									
Involved worker			2,170	2,170	2,170	2,170	2,170	2,170	2,170	2,170	2,170
Noninvolved worker			NA[e]	NA	NA	NA	NA	NA	NA	NA	NA
Surface facility decontamination	3 years	(7)									
Involved worker			4,060	2,950	3,070	4,060	2,950	3,070	4,060	2,950	3,070
Noninvolved worker			NA	NA	NA	NA	NA	NA	NA	NA	NA
Subsurface monitoring	62 years	(8)									
Involved worker			4,280	4,280	4,280	4,710	4,710	4,710	5,950	5,950	5,950
Noninvolved worker			810	810	810	810	810	810	1,610	1,610	1,610
Subtotal monitoring			*11,320*	*10,200*	*10,320*	*11,750*	*10,640*	*10,760*	*13,800*	*12,680*	*12,800*
Subtotal operation and monitoring			*74,820*	*61,730*	*62,610*	*75,680*	*62,600*	*63,480*	*79,070*	*65,990*	*66,870*
Closure											
Surface	6 years	(9)									
Involved worker			1,580	1,110	1,200	1,580	1,110	1,200	1,580	1,110	1,200
Noninvolved worker			600	420	460	600	420	460	600	420	460
Subsurface	(f)	(10)									
Involved worker			2,830	2,830	2,830	3,710	3,710	3,710	5,890	5,890	5,890
Noninvolved worker			570	570	570	750	750	750	1,190	1,190	1,190
Subtotal closure			*5,580*	*4,940*	*5,060*	*6,630*	*5,940*	*6,100*	*9,250*	*8,610*	*8,720*
Totals[d]			***86,740***	***72,020***	***73,150***	***88,660***	***73,930***	***75,070***	***94,670***	***79,980***	***81,080***

a. Sources: (1) TRW (1999c, Table 6-1); (2) TRW (1999b, Table 6.2.1.1-1); (3) TRW (1999c, Table 6-2; (4) TRW (1999b, Table 6.2.3.1-1); (5) TRW (1999b, Table 6.2.3.1-1); (6) TRW (1999c, Table 6-5); (7) TRW (1999c, Table 6-4); (8) TRW (1999b, Table 6.2.4.1-1); (9) TRW (1999c, Table 6-6); (10) TRW (1999b, Table 6.2.6.1-1).

b. UC = uncanistered packaging scenario.

c. DISP = disposable canister packaging scenario.

d. DPC = dual-purpose canister packaging scenario.

e. NA = not applicable, all workers assumed to be involved.

f. High thermal load, 13 years; intermediate thermal load, 17 years; low thermal load, 27 years.

g. Totals might differ from sums due to rounding.

F.3.2.2 Statistics on Health and Safety Impacts from Industrial Hazards in the Workplace

DOE used the same statistics for health and safety impacts from industrial hazards common to the workplace that were used for the Proposed Action (70,000 MTHM) for analyzing the inventory module impacts (see Table F-2).

F.3.2.3 Estimates of Radiological Exposure Rates and Times for Inventory Modules 1 and 2

DOE used the values in Table F-5 (Proposed Action) for exposure rates, occupancy times, and the fraction of the workforce that would be exposed to estimate radiological health impacts for the inventory module cases, except for doses from the waste packages and from radon-222 inhalation for the subsurface emplacement, monitoring, and closure phases. Annual exposures to subsurface workers for Inventory Modules 1 and 2 from radiation emanating from the waste packages are listed as part of Table F-6. Table F-32 lists annual dose rates from inhalation of radon-222 and its decay products. Section F.1.1.6 discusses the basis for the values in Table F-32.

Table F-32. Correction factors and annual exposures from radon-222 and its decay products for the project phases or periods for Inventory Modules 1 and 2.[a]

	Correction factor			Annual dose rate (millirem per year)		
Subsurface project period	High	Intermediate	Low	High	Intermediate	Low
Construction	2.1	2.1	2.1	126	126	126
Drift development	0.6	0.6	0.6	36	36	36
Emplacement	2.0	1.7	3.5	120	120	210
Monitoring	4.2	2.7	4.1	252	160	246
Closure	4.2	2.7	4.1	252	160	246

a. Based on measured value of 60 millirem per year corrected for repository volume and ventilation rate; see the discussions in Section F.1.1.6 and Appendix G (Section G.2.3.1).

F.3.3 DETAILED HUMAN HEALTH AND SAFETY IMPACTS TO WORKERS – INVENTORY MODULES 1 AND 2

F.3.3.1 Construction Phase

F.3.3.1.1 *Industrial Hazards to Workers*

This section details health and safety impacts to workers from industrial hazards common to the workplace for the construction phase. Impact values for surface workers are the same as those presented for the Proposed Action in Table F-7. Impact values for subsurface workers are presented in Table F-33. The subsurface impacts are independent of thermal load or packaging scenarios.

F.3.3.1.2 *Radiological Health Impacts to Workers*

Table F-34 lists subsurface worker health impacts from inhalation of radon-222 and its decay products in the subsurface atmosphere and from exposure to natural radiation from radionuclides in the drift walls. The radiological health impacts to surface workers from inhalation of radon-222 and its decay products would be small in comparison to those for subsurface workers; therefore, they are not tabulated here (see Table F-5, Footnote h).

Table F-33. Industrial hazard health and safety impacts to subsurface facility workers during construction phase – Inventory Module 1 or 2.[a]

Worker group	Impacts
Involved	
Full-time equivalent work years[b]	2,460
Total recordable cases of injury and illness	150
Lost workday cases	72
Fatalities	0.07
Noninvolved	
Full-time equivalent work years	600
Total recordable cases of injury and illness	20
Lost workday cases	10
Fatalities	0.02
All workers (totals)[c]	
Full-time equivalent work years	3,060
Total recordable cases of injury and illness	170
Lost workday cases	82
Fatalities	0.09

a. Source: Impact rates from Table F-2.
b. Source: Table F-31.
c. Totals might differ from sums due to rounding.

Table F-34. Radiological health impacts to subsurface facility workers from radon inhalation and natural exposure for the construction phase – Inventory Modules 1 and 2.[a]

Worker group	Radon inhalation exposure	Subsurface ambient exposure
Involved		
Full-time equivalent work years[c]	2,460	2,460
Dose to maximally exposed individual worker (millirem)	630	200
Latent cancer fatality probability for MEI[c]	0.0002	0.00008
Collective dose (person-rem)	310	98
Latent cancer fatality incidence	0.12	0.04
Noninvolved		
Full-time equivalent work years	600	600
Dose to maximally exposed individual worker (millirem)	470	150
Latent cancer fatality probability for MEI	0.0002	0.00006
Collective dose (person-rem)	57	18
Latent cancer fatality incidence	0.02	0.007
All workers (totals)[d]		
Full-time equivalent work years	3,060	3,060
Collective dose (person-rem)	370	120
Latent cancer fatality incidence	0.15	0.05

a. Sources: Table F-5 (ambient exposure); Table F-32 (exposure from radon inhalation).
b. Source: Table F-31.
c. MEI = maximally exposed individual.
d. Totals might differ from sums due to rounding.

F.3.3.2 Operation and Monitoring Phase

F.3.3.2.1 *Health and Safety Impacts to Workers from Industrial Hazards*

This section details health and safety impacts to workers from industrial hazards common to the workplace for the operation and monitoring phase. These impacts would consist of four components:

- Health and safety impacts to surface workers for operations (Table F-35)
- Health and safety impacts to subsurface workers for emplacement and for drift development (Table F-36)
- Health and safety impacts to subsurface workers for the monitoring period (Table F-37)
- Health and safety impacts to surface workers for surface facility decontamination and monitoring support (Table F-38)

Table F-35. Industrial hazard health and safety impacts for surface facility workers during a 38-year operations period by packaging option – Inventory Module 1 or 2.[a]

Worker group	Uncanistered	Disposable canister	Dual-purpose canister
Involved			
Full-time equivalent work years[b]	27,700	18,160	18,700
Total recordable cases of injury and illness	830	540	560
Lost workday cases	360	240	240
Fatalities	0.80	0.53	0.55
Noninvolved			
Full-time equivalent work years	20,820	18,390	18,620
Total recordable cases of injury and illness	680	600	610
Lost workday cases	340	300	300
Fatalities	0.60	0.53	0.54
All workers (totals)[c]			
Full-time equivalent work years	48,530	36,560	37,320
Total recordable cases of injury and illness	1,520	1,150	1,170
Lost workday cases	700	530	540
Fatalities	1.4	1.1	1.1

a. Source: Impact rates from Table F-2.
b. Source: Table F-31.
c. Totals might differ from sums due to rounding.

F.3.3.2.2 *Radiological Health Impacts to Workers*

This section details radiological health impacts to workers during the operation and monitoring phase for the inventory modules. These impacts consist of four components:

- Radiological health impacts to surface workers during operations (Table F-39)
- Radiological health impacts to subsurface workers during operations (emplacement and drift development) (Table F-40)
- Radiological health impacts to workers during surface facility decontamination and monitoring support (Table F-41)
- Radiological health impacts to subsurface workers for the monitoring period (Table F-42)

Table F-36. Industrial hazard health and safety impacts for subsurface facility workers for development and emplacement period – Inventory Module 1 or 2.[a]

Worker group	High thermal load	Intermediate thermal load	Low thermal load
Involved			
Full-time equivalent work years[b]	11,920	12,350	13,370
Total recordable cases of injury and illness	700	730	790
Lost workday cases	480	500	540
Fatalities	0.35	0.36	0.39
Noninvolved			
Full-time equivalent work years	3,060	3,060	3,380
Total recordable cases of injury and illness	48	48	52
Lost workday cases	27	27	29
Fatalities	0.09	0.09	0.10
All workers (totals)[c]			
Full-time equivalent work years	14,980	15,410	16,750
Total recordable cases of injury and illness	750	780	850
Lost workday cases	500	530	570
Fatalities	0.42	0.45	0.49

a. Source: Impact rates from Tables F-2 and F-3.
b. Source: Table F-31.
c. Totals might differ from sums due to rounding.

Table F-37. Industrial hazard health and safety impacts for subsurface facility workers during monitoring period – Inventory Module 1 or 2.[a]

Worker group	High thermal load	Intermediate thermal load	Low thermal load
Involved			
Full-time equivalent work years[b]	4,280	4,710	5,950
Total recordable cases of injury and illness	130	140	180
Lost workday cases	55	61	77
Fatalities	0.12	0.14	0.17
Noninvolved			
Full-time equivalent work years	810	810	1610
Total recordable cases of injury and illness	26	26	53
Lost workday cases	13	13	26
Fatalities	0.02	0.02	0.05
All workers (totals)[c]			
Full-time equivalent work years	5,080	5,520	7,560
Total recordable cases of injury and illness	160	170	230
Lost workday cases	68	74	100
Fatalities	0.15	0.16	0.22

a. Source: Impact rates from Table F-2.
b. Source: Table F-31.
c. Totals might differ from sums due to rounding.

Table F-38. Industrial hazard health and safety impacts by packaging option to workers during surface facility decontamination and monitoring period – Inventory Module 1 or 2.[a]

Involved workers	Uncanistered	Disposable canister	Dual-purpose canister
Full-time equivalent work years[b]	6,230	5,120	5,240
Total recordable cases of injury and illness	190	150	160
Lost workday cases	80	70	70
Fatalities	0.18	0.15	0.15

a. Source: Impact rates from Table F-2.
b. Source: Table F-31.

Table F-39. Radiological health impacts to surface facility workers for a 38-year operations period – Inventory Module 1 or 2.[a]

Worker group	Uncanistered	Disposable canister	Dual-purpose canister
Involved			
Full-time equivalent work years[b]	27,700	18,160	18,700
Dose to maximally exposed individual worker (millirem)	15,200	15,200	15,200
Latent cancer fatality probability for maximally exposed individual	0.006	0.006	0.006
Collective dose (person-rem)	8,180	3,890	3,950
Latent cancer fatality incidence	3.3	1.6	1.6
Noninvolved			
Full-time equivalent work years	20,820	18,390	18,620
Dose to maximally exposed individual worker (millirem)	950	950	950
Latent cancer fatality probability for maximally exposed individual	0.0004	0.0004	0.0004
Collective dose (person-rem)	170	140	140
Latent cancer fatality incidence	0.07	0.06	0.06
All workers (totals)[c]			
Full-time equivalent work years	48,530	36,560	37,320
Collective dose (person-rem)	8,350	4,030	4,090
Latent cancer fatality incidence	3.3	1.6	1.6

a. Source: Exposure data from Table F-5.
b. Source: Table F-31.
c. Totals might differ from sums due to rounding.

Table F-40. Radiological health impacts to subsurface workers for emplacement and drift development during operations period – Inventory Module 1 or 2.[a]

Worker group	High thermal load	Intermediate thermal load	Low thermal load
Involved			
Full-time equivalent work years[b]	11,900	12,350	13,370
Dose to maximally exposed individual worker (millirem)	13,220	12,530	13,460
Latent cancer fatality probability for maximally exposed individual	0.005	0.005	0.005
Collective dose (person-rem)	1,530	1,510	1,770
Latent cancer fatality incidence	0.61	0.60	0.71
Noninvolved			
Full-time equivalent work years	3,060	3,060	3,380
Dose to maximally exposed individual worker (millirem)	2,280	2,240	4,290
Latent cancer fatality probability for maximally exposed individual	0.0009	0.0009	0.002
Collective dose (person-rem)	190	190	240
Latent cancer fatality incidence	0.08	0.08	0.10
All workers (totals)[c]			
Full-time equivalent work years	14,980	15,410	16,750
Collective dose (person-rem)	1,720	1,700	2,010
Latent cancer fatality incidence	0.69	0.68	0.80

a. Source: Exposure data from Table F-4 except waste package exposures, which are from Table F-6.
b. Source: Table F-31.
c. Totals might differ from sums due to rounding.

Table F-41. Radiological health impacts to surface facility workers for decontamination and monitoring support – Inventory Module 1 or 2.[a]

Involved workers	Uncanistered	Disposable canister	Dual-purpose canister
Full-time equivalent work years[b]	6,230	5,120	5,240
Dose to maximally exposed individual worker (millirem)	300	300	300
Latent cancer fatality probability for maximally exposed individual	0.0001	0.0001	0.0001
Collective dose (person-rem)	290	210	220
Latent cancer fatality incidence	0.11	0.08	0.09

a. Source: Exposure data from Table F-4.
b. Source: Table F-31.

Table F-42. Radiological health impacts to subsurface facility workers for a 62-year monitoring period – Inventory Module 1 or 2.[a]

Worker group	High thermal load	Intermediate thermal load	Low thermal load
Involved			
Full-time equivalent work years[b]	4,280	4,710	5,950
Dose to maximally exposed individual worker (millirem)	19,240	14,740	16,710
Latent cancer fatality probability for maximally exposed individual	0.008	0.006	0.007
Collective dose (person-rem)	1,700	1,440	2,050
Latent cancer fatality incidence	0.68	0.58	0.82
Noninvolved			
Full-time equivalent work years	810	810	1,610
Dose to maximally exposed individual worker (millirem)	7,700	5,450	7,550
Latent cancer fatality probability for maximally exposed individual	0.003	0.002	0.003
Collective dose (person-rem)	120	88	240
Latent cancer fatality incidence	0.05	0.04	0.10
All workers (totals)[c]			
Full-time equivalent work years	5,080	5,520	7,560
Collective dose (person-rem)	2,300	2,050	2,470
Latent cancer fatality incidence	0.92	0.82	3.0

a. Source: Exposure data from Table F-5 except for exposure from waste packages, which is from Table F-6.
b. Source: Table F-31.
c. Totals might differ from sums due to rounding.

F.3.3.3 Closure Phase

F.3.3.3.1 *Health and Safety Impacts to Workers from Industrial Hazards*

This section details health and safety impacts to workers from industrial hazards common to the workplace for the closure phase. The impacts would consist of two components—impacts to surface workers supporting the closure operations, and impacts to subsurface workers during the closure phase. These impacts are listed in Tables F-43 and F-44, respectively.

Table F-43. Industrial hazard health and safety impacts to surface workers during the closure phase – Inventory Module 1 or 2.[a]

Worker group	Uncanistered	Disposable canister	Dual-purpose canister
Involved			
Full-time equivalent work years[b]	1,580	1,110	1,200
Total recordable cases of injury and illness	97	68	73
Lost workday cases	46	33	35
Fatalities	0.05	0.03	0.04
Noninvolved			
Full-time equivalent work years	600	420	460
Total recordable cases of injury and illness	20	14	15
Lost workday cases	10	7	7
Fatalities	0.02	0.01	0.01
All workers (totals)[c]			
Full-time equivalent work years	2,180	1,540	1,650
Total recordable cases of injury and illness	116	82	88
Lost workday cases	56	40	43
Fatalities	0.06	0.04	0.05

a. Source: Impact rates from Table F-2.
b. Source: Table F-31.
c. Totals might differ from sums due to rounding.

Table F-44. Health and safety impacts to subsurface facility workers from industrial hazards during the closure phase – Inventory Module 1 or 2.[a]

Worker group	High thermal load	Intermediate thermal load	Low thermal load
Involved			
Full-time equivalent work years[b]	2,830	3,710	5,890
Total recordable cases of injury and illness	170	230	360
Lost workday cases	84	110	170
Fatalities	0.08	0.11	0.17
Noninvolved			
Full-time equivalent work years	570	750	1,190
Total recordable cases of injury and illness	19	25	39
Lost workday cases	9	12	19
Fatalities	0.02	0.02	0.03
All workers (totals)[c]			
Full-time equivalent work years	3,410	4,450	7,070
Total recordable cases of injury and illness	193	250	400
Lost workday cases	93	120	190
Fatalities	0.10	0.13	0.21

a. Source: Impact rates from Table F-2.
b. Source: Table F-31.
c. Totals might differ from sums due to rounding.

F.4 Human Health and Safety Impact Analysis for the Retrieval Contingency

Nuclear Regulatory Commission regulations state that the period for which DOE must maintain the ability to retrieve waste is at least 50 years after the start of emplacement operations [10 CFR 60.111(b)]. Although DOE does not anticipate retrieval and it is not part of the Proposed Action, the Department would maintain the ability to retrieve the waste for at least 100 years and possibly for as long as 300 years after the start of emplacement. Factors that could lead to a decision to retrieve the waste would be (1) to protect the public health and safety or the environment or (2) to recover resources from spent nuclear fuel. This EIS evaluates retrieval as a contingency action and describes potential impacts should it occur. The analysis assumes that under this contingency DOE would retrieve all the waste associated with the Proposed Action and would place it on surface storage pads pending future decisions about its ultimate disposition.

The analysis of health and safety impacts to workers divided the retrieval period into two subperiods, as follows:

- First, a construction subperiod in which DOE would (1) build the surface facilities necessary to handle and enclose retrieved waste packages in concrete storage units in preparation for placement on concrete storage pads, and (2) construct the concrete storage pads.

  No radioactive materials would be involved in the construction subperiod, so health and safety impacts would be limited to those associated with industrial hazards in the workplace. DOE expects this subperiod would last 2 to 3 years, although construction of the concrete storage pads probably would continue on an as-needed basis during most of the operations subperiod. The analysis assumed a 3-year period.

- Second, an operations subperiod during which the waste packages would be retrieved and moved to the Waste Retrieval Transfer Building. Surface facility workers would unload the waste package from the transfer vehicle and place it on a concrete base. The package and concrete base would then be enclosed in a concrete storage unit that would be placed on the concrete storage pad. The analysis assumed an 11-year period.

This section discusses the methodologies and data used to estimate human health and safety impacts resulting from the retrieval contingency. Section F.4.1 describes the methods DOE used to estimate impacts. Section F.4.2 contains tabulations of the detailed data used in the impact calculations and references to the data sources. Section F.4.3 contains detailed tabulations of the results.

F.4.1 METHODOLOGY FOR CALCULATING HUMAN HEALTH AND SAFETY IMPACTS

DOE used the methodology summarized in Section F.2.1 to estimate health and safety impacts for the retrieval contingency. This involved assembling data for the number of full-time equivalent workers for each retrieval activity. These numbers were used with statistics on the likelihood of an impact (industrial hazards), or the estimated radiological dose rate in the worker environment, to calculate health and safety impacts. The way in which the input data were combined to calculate health and safety impacts is described in more detail in Section F.2.1. Some of the input data in the retrieval impact calculations are different from those for the Proposed Action, as described in the next section.

F.4.2 DATA SOURCES AND TABULATIONS

F.4.2.1 Full-Time Equivalent Work-Year Estimates for the Retrieval Contingency

This analysis divides the repository workforce into two groups—involved and noninvolved workers (see Section F.2 for definitions of involved and noninvolved workers).

Table F-45 lists the number of workers involved in the two subperiods of the retrieval operation and the sources of the numbers. They are tabulated as full-time equivalent work years. Each full-time equivalent

Table F-45. Full-time equivalent work-year estimates for retrieval.

Subperiod and worker group	Length of subperiod (years)	Full-time equivalent work years
Surface facilities, construction[a]	3	
Involved		1,130
Noninvolved		430
Surface facilities, retrieval support[b]	11	
Involved		320
Noninvolved		870
Subsurface facility retrieval operations[c]	11	
Involved		810
Noninvolved		180
Total		***3,740***

a. Source: TRW (1999c, Table I-2).

b. Source: TRW (1999c, Table I-3).

c. Source: TRW (1999b, Table 6.1.5.1-1).

work year represents 2,000 work hours, the hours assumed to be worked in a normal work year. The full-time equivalent work year estimates are independent of thermal load.

F.4.2.2 Statistics on Health and Safety Impacts from Industrial Hazards in the Workplace

For the retrieval contingency, DOE used the same set of statistics on health and safety impacts from industrial hazards common to the workplace that were used for the Proposed Action (70,000 MTHM) (see Table F-2). The specific statistics that were applied to the retrieval contingency subphases are listed in Table F-46.

Table F-46. Statistics for industrial hazard impacts for retrieval.

Subperiod and worker group	Total recordable incidents (rate per 100 FTEs)[a]	Lost workday cases (rate per 100 FTEs)	Fatalities (rate per 100,000 FTEs)[b]
Construction, surface workers[c]			2.9
Involved	6.1	2.9	
Noninvolved	3.3	1.6	
Retrieval, surface workers[d]			2.9
Involved	3.0	1.2	
Noninvolved	3.3	1.6	
Retrieval, subsurface workers[d]			2.9
Involved	3.0	1.2	
Noninvolved	3.3	1.6	

a. FTE = full-time equivalent work years.

b. Source: Data Set 4, Section F.2.2.

c. Source: Data Set 1, Section F.2.2.

d. Source: Data Set 3, Section F.2.2.

F.4.2.3 Estimated Radiological Exposure Rates and Times for the Retrieval Contingency

DOE used the same set of worker exposure rates and exposure times as those used for evaluating radiological worker impacts for the Proposed Action. Table F-47 presents the specific application of this data to the retrieval contingency subphases. The source of the information is also referenced. The rates used in the analysis did not take into account radioactive decay for the period between emplacement and retrieval.

Table F-47. Radiological doses and exposure data used to calculate worker exposures during retrieval.[a]

Subperiod and worker group	Source of exposure	Occupancy factor for exposure rate (fraction of 8-hour workday)	Annual dose (millirem, except where noted)	Full-time equivalent workers[b]	Source[c]
Construction					
Surface					
Involved	None				
Noninvolved	None				
Operations					
Surface					
Involved	Waste package	1.0	400	13	(1)
	Radiation		100	16	(1)
Noninvolved		1.0	25	22	(2)
			0	57	(2)
Subsurface					
Involved	Waste package	1.0	Variable	--	(3)
	Radon-222	1.0	Table F-4		(5), Table F-4
	Drift ambient	1.0	40		(4), (5)
Noninvolved	Waste package	0.04 (0.4 for 10% of workers)	0.1 millirem per hour		(7)
	Radon-222	0.4	Table F-4		(6), Table F-4
	Drift ambient	0.4	40		(4), (6)

a. External exposures include radiation from spent nuclear fuel and high-level radioactive waste packages to surface and subsurface workers, the ambient exposure to subsurface workers from naturally occurring radiation in the drift walls, and subsurface worker exposure from inhalation of radon-222.

b. Number of full-time equivalent workers by dose category for surface facility activities.

c. Sources:
   (1) Adapted from TRW (1999c, Table 6.2) for waste receipt, handling, and packaging operations. Values are based on dose rate distribution (fractions) from TRW (1999c, Table 6.2) for involved workers for dual-purpose canister scenario adjusted for fewer workers for retrieval. Forty-five percent of 29 involved workers would be in the 400-millirem-per-year category and 55 percent would be in the 100-millirem-per-year category.
   (2) Adapted from TRW (1999c, Table 6.2) for waste receipt, handling, and packaging operations. Values based on dose rate distribution (fractions) from TRW (1999c, Table 6.2) for noninvolved workers for dual-purpose canister scenario adjusted for fewer workers for retrieval. Twenty-eight percent of the 79 workers would be in the 25-millirem-per-year category and 72 percent would be in the 0-rem-per-year category.
   (3) Table F-4.
   (4) Section F.1.1.6.
   (5) Rasmussen (1998a, all).
   (6) Rasmussen (1999, all).
   (7) Rasmussen (1998b, all).

F.4.3 DETAILED RESULTS FOR THE RETRIEVAL CONTINGENCY

F.4.3.1 Construction Phase

F.4.3.1.1 *Human Health and Safety Impacts to Workers from Industrial Hazards*

The construction phase would entail only surface-facility activities. Table F-48 summarizes health and safety impacts to workers from industrial hazards during construction. There would be no radiological sources present during surface facility construction activities for retrieval and, hence, no radiological health and safety impacts to workers.

F.4.3.2 Operations Period

F.4.3.2.1 *Health and Safety Impacts to Workers from Industrial Hazards*

Chapter 4, Table 4-47, summarizes health and safety impacts to workers from industrial hazards common to the workplace for the retrieval operations period. The impacts in that table consist of two

Table F-48. Industrial hazard health and safety impacts to workers during construction.[a]

Worker group	Impacts
Involved	
Full-time equivalent work years[b]	1,130
Total recordable cases of injury and illness	69
Lost workday cases	33
Fatalities	0.03
Noninvolved	
Full-time equivalent work years	430
Total recordable cases of injury and illness	14
Lost workday cases	7
Fatalities	0.01
All workers (totals)[b]	
Full-time equivalent work years	1,560
Total recordable cases of injury and illness	83
Lost workday cases	40
Fatalities	0.05

a. Source: Impact rates from Table F-46.
b. Source: Table F-45.

components—health impacts to surface workers and health impacts to subsurface workers. Tables F-49 and F-50 list health impacts from industrial hazards during retrieval operations for surface and subsurface workers, respectively.

Table F-49. Industrial hazard health and safety impacts to surface facility workers during retrieval.[a]

Worker group	Impacts
Involved	
Full-time equivalent work years[b]	320
Total recordable cases of injury and illness	10
Lost workday cases	4
Fatalities	0.009
Noninvolved	
Full-time equivalent work years	870
Total recordable cases of injury and illness	29
Lost workday cases	14
Fatalities	0.03
All workers (totals)[c]	
Full-time equivalent work years	1,190
Total recordable cases of injury and illness	37
Lost workday cases	18
Fatalities	0.03

a. Source: Impact rates from Table F-46.
b. Source: Table F-45.
c. Totals might differ from sums due to rounding.

F.4.3.2.2 *Radiological Health and Safety Impacts to Workers*

Potential radiological health impacts to workers during the operations period of retrieval consist of the following components:

- Impacts to surface facility workers involved in handling the waste packages and placing them in concrete storage units

Table F-50. Industrial hazard health and safety impacts to subsurface facility workers during retrieval.[a]

Worker group	Impacts
Involved	
Full-time equivalent work years[b]	810
Total recordable cases of injury and illness	24
Lost workday cases	11
Fatalities	0.02
Noninvolved	
Full-time equivalent work years	180
Total recordable cases of injury and illness	6
Lost workday cases	3
Fatalities	0.01
All workers (totals)[b]	
Full-time equivalent work years	990
Total recordable cases of injury and illness	30
Lost workday cases	13
Fatalities	0.03

a. Source: Impact rates from Table F-46.
b. Source: Table F-45.
c. Totals might differ from sums due to rounding.

- Impacts to subsurface facilities workers from direct radiation emanating from the waste packages
- Impacts to subsurface workers from inhalation of radon-222 in the atmosphere of the drifts
- Impacts to subsurface workers from ambient radiation from naturally occurring radionuclides in the drift walls

Tables F-51 and F-52 list potential radiological health impacts for each of these component parts. The impacts to subsurface workers only vary slightly (less than 2 percent) with thermal load and are highest for the low thermal load. Thus, the values in Table F-52 for the low thermal load case, would produce the largest impacts.

Table F-51. Radiological health impacts to surface facility workers from waste handling during retrieval.[a]

Worker group	Impacts
Involved	
Full-time equivalent work years[b]	320
Maximally exposed individual dose (millirem)	4,400
Latent cancer fatality probability for maximally exposed individual	0.002
Collective dose (person-rem)	75
Latent cancer fatality incidence for overall worker group	0.03
Noninvolved	
Full-time equivalent work years	870
Maximally exposed individual dose (millirem)	280
Latent cancer fatality probability for maximally exposed individual	0.0001
Collective dose (person-rem)	6
Latent cancer fatality incidence for overall worker group	0.002
All workers (totals)[c]	
Full-time equivalent work years	1,190
Collective dose (person-rem)	81
Latent cancer fatality	0.03

a. Source: Exposure rate data from Table F-47.
b. Source: Table F-45.
c. Totals might differ from sums due to rounding.

Table F-52. Components of radiological health impacts to subsurface workers during retrieval for the low thermal load scenario.[a,b]

	Source of exposure			
Group	Waste packages	Ambient	Radon-222 inhalation	Total[c]
Involved				
Full-time equivalent work years[d]	840	840	840	840
Maximally exposed individual dose (millirem)	4,400	440	2,110	6,950
Latent cancer fatality probability for maximally exposed individual	0.002	0.0002	0.0008	0.003
Collective dose (person-rem)	200	33	160	390
Latent cancer fatality incidence for overall worker group	0.08	0.01	0.06	0.16
Noninvolved				
Full-time equivalent work years	180	180	180	180
Maximally exposed individual dose (millirem)	88	220	1,060	1,370
Latent cancer fatality probability for maximally exposed individual	0.00004	0.00009	0.0004	0.000 5
Collective dose (person-rem)	1	4	17	22
Latent cancer fatality incidence for overall worker group	0.0004	0.001	0.007	0.009
All workers (totals)[c]				
Full-time equivalent work years	1,010	1,010	1,010	1,010
Collective dose (person-rem)	200	37	180	420
Latent cancer fatality incidence for overall worker group	0.08	0.01	0.07	0.17

a. Source: Exposure data from Table F-47.

b. The variation in values among the thermal load scenarios was small. Therefore, only the largest values (for the low thermal load) are listed.

c. Totals might differ from sums due to rounding.

d. Source: Table F-45.

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Appendix G

Air Quality

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APPENDIX G. AIR QUALITY

Potential releases of nonradiological and radiological pollutants associated with the construction, operation and monitoring, and closure of the proposed Yucca Mountain Repository could affect the air quality in the surrounding region. This appendix discusses the methods and additional data and intermediate results that the U.S. Department of Energy (DOE) used to estimate impacts from potential releases to air. Final results are presented in Chapter 4, Section 4.1.2, and Chapter 8, Section 8.2.2.

Nonradiological pollutants can be categorized as hazardous and toxic air pollutants, criteria pollutants, or other substances of particular interest. Repository activities would cause the release of no or very small quantities of hazardous and toxic pollutants; therefore, these pollutants were not considered in the analysis. Concentrations of six criteria pollutants are regulated under the National Ambient Air Quality Standards (40 CFR Part 50) established by the Clean Air Act. This analysis evaluated releases and potential impacts of four of these pollutants—carbon monoxide, nitrogen dioxide, sulfur dioxide, and particulate matter with an aerodynamic diameter of 10 micrometers or less (PM_{10})—quantitatively. It addresses the other two criteria pollutants—lead and ozone—and the concentration of particulate matter with an aerodynamic diameter of 2.5 micrometers or less ($PM_{2.5}$), qualitatively. In addition, this analysis considers potential releases to air of cristobalite, a form of crystalline silica that can cause silicosis and is a potential carcinogen. These pollutants could be released during all project phases. Section G.1 describes the methods DOE used to calculate impacts from releases of criteria pollutants and cristobalite.

Radionuclides that repository-related activities could release to the atmosphere include the noble gas krypton-85 from spent nuclear fuel handling during the operation and monitoring phase, and naturally occurring radon-222 and its decay products from ventilation of the subsurface facility during all project phases. Other radionuclides would not be released or would be released in such small quantities they would result in very small impacts to air quality. Such radionuclides are not discussed further in this appendix. Section G.2 describes the methods DOE used to calculate impacts of radionuclide releases.

G.1 Nonradiological Air Quality

This section describes the methods DOE used to analyze potential impacts to air quality at the proposed Yucca Mountain Repository from releases of nonradiological air pollutants during the construction, operation and monitoring, and closure phases, and a retrieval scenario. It also describes intermediate results for various repository activities. Table G-1 lists the six criteria pollutants regulated under the National Ambient Air Quality Standards or the Nevada Administrative Code along with their regulatory limits and the periods over which pollutant concentrations are averaged. The criteria pollutants addressed quantitatively in this section are nitrogen dioxide, sulfur dioxide, particulate matter 10 micrometers or less in aerodynamic diameter (PM_{10}), and carbon monoxide. Lead was not considered further in this analysis because there would be no airborne sources at the repository. Particulate matter 2.5 micrometers or less in aerodynamic diameter ($PM_{2.5}$) and ozone are discussed below, as is cristobalite, a mineral occurring naturally in the subsurface rock at Yucca Mountain.

The U.S. Environmental Protection Agency revised the primary and secondary standards for particulate matter in 1997 (62 *FR* 38652, July 18, 1997), establishing annual and 24-hour $PM_{2.5}$ standards at 15 micrograms per cubic meter and 65 micrograms per cubic meter, respectively. Primary standards set limits to protect public health, including the health of "sensitive" populations. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. Because the new particulate standard will regulate $PM_{2.5}$ for the first time, the agency has allowed 5 years for the creation of a national monitoring network and the analysis of collected data to help develop state implementation plans. The new $PM_{2.5}$ standards have not been implemented and the imposition of local area controls will not be required until 2005. By definition, $PM_{2.5}$ levels can be no more than, and in the real world are always substantially less than, PM_{10} levels. In

Table G-1. Criteria pollutants and regulatory limits.

Pollutant	Period	Regulatory limit[a] Parts per million	 Micrograms per cubic meter
Nitrogen dioxide	Annual	0.053	100
Sulfur dioxide	Annual	0.03	80
	24-hour	0.14	365
	3-hour	0.50	1,300
Carbon monoxide	8-hour	9	10,000
	1-hour	35	40,000
PM_{10}	Annual		50
	24-hour		150
$PM_{2.5}$[b]	Annual		15
	24-hour		65
Ozone	8-hour	0.08	157
	1-hour	0.12[c]	235
Lead	Quarterly		1.5

a. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

b. Standard not yet implemented.

c. The 1-hour standard does not apply to Nevada because the State was in attainment when the 8-hour standard was adopted in July 1997.

general, $PM_{2.5}$ levels would be approximately one-third of the PM_{10} levels. As the analysis for PM_{10} shows, even the maximum PM_{10} levels that could be generated by the Proposed Action are substantially below the $PM_{2.5}$ standards. Thus, although no detailed $PM_{2.5}$ analysis has been conducted, the PM_{10} analysis can be regarded as a surrogate for a $PM_{2.5}$ analysis and illustrates that potential $PM_{2.5}$ levels would be well below applicable regulatory standards.

The purpose of the ozone standard is to control the ambient concentration of ground-level ozone, not naturally occurring ozone in the upper atmosphere. Ozone is not emitted directly into the air; rather, it is formed when volatile organic compounds react in the presence of sunlight. Nitrogen dioxides are also important precursors to ozone. Small quantities of volatile organic compounds would be released from repository activities; the peak annual release would be about 540 kilograms (1,200 pounds) (TRW 1999a, Table 6-2, page 75). Because Yucca Mountain is in an attainment area for ozone, the analysis compared the estimated annual release to the Prevention of Significant Deterioration of Air Quality emission threshold for volatile organic compounds from stationary sources (40 CFR 52.21). The volatile organic compound emission threshold is 35,000 kilograms (77,000 pounds) per year, so the peak annual release from the repository would be well below this level. Accordingly, the analysis did not address volatile organic compounds and ozone further, although this does not preclude future, more detailed analyses if estimates of volatile organic compound emissions change.

Cristobalite, one of several naturally occurring crystalline forms of silica (silicon dioxide), is a major mineral constituent of Yucca Mountain tuffs (TRW 1999b, page 4-81). Prolonged high exposure to crystalline silica can cause silicosis, a disease characterized by scarring of lung tissue. An increased cancer risk to humans who already have developed adverse noncancer effects from silicosis has been shown, but the cancer risk to otherwise healthy individuals is not clear (EPA 1996, page 1-5). Cristobalite is principally a concern for involved workers because it could be inhaled during subsurface excavation operations. Appendix F, Section F.1, contains additional information on crystalline silica.

While there are no limits for exposure of the general public to cristobalite, there are limits to workers for exposure (29 CFR 1000.1910). Therefore, this analysis used a comparative benchmark of 10 micrograms per cubic meter, based on a cumulative lifetime exposure of 1,000 micrograms per cubic meter multiplied by years (that is, the average annual exposure concentration times the number of years exposed). At this level, an Environmental Protection Agency health assessment (EPA 1996, pages 1-5 and 7-5) states that there is a less than 1 percent chance of silicosis. Over a 70-year lifetime, this cumulative exposure benchmark would correspond to an annual average exposure concentration of about 14 micrograms per cubic meter, which was rounded down to 10 micrograms per cubic meter to establish the benchmark.

Cristobalite would be emitted from the subsurface in exhaust ventilation air during excavation operations and would be released as fugitive dust from the excavated rock pile, so members of the public and noninvolved workers could be exposed. Fugitive dust from the excavated rock pile would be the largest potential source of cristobalite exposure to the public. The analysis assumed that 28 percent of the fugitive dust released from this rock pile and from subsurface excavation would be cristobalite, reflecting the cristobalite content of the parent rock, which ranges from 18 to 28 percent (TRW 1999b, page 4-81). Using the parent rock percentage probably overestimates the airborne cristobalite concentration, because studies of both ambient and occupational airborne crystalline silica have shown that most of this airborne material is coarse and not respirable and that larger particles will deposit rapidly on the surface (EPA 1996, page 3-26).

G.1.1 COMPUTER MODELING AND ANALYSIS

DOE used the Industrial Source Complex computer program to estimate the annual and short-term (24-hour or less) air quality impacts at the proposed Yucca Mountain Repository. The Department has used this program in recent EISs (DOE 1995, all; 1997a,b, all) to estimate nonradiological air quality impacts. The program contains both a short-term model (which uses hourly meteorological data) and a long-term model (which uses joint frequency meteorological data). The program uses steady-state Gaussian plume models to estimate pollutant concentrations from a variety of sources associated with industrial complexes (EPA 1995a, all). This modeling approach assumes that (1) the time-averaged pollutant concentration profiles at any distance downwind of the release point may be represented by a Gaussian (normal) distribution in both the horizontal and vertical directions; and (2) the meteorological conditions are constant (persistent) over the time of transport from source to receptor. The Industrial Source Complex program is appropriate for either flat or rolling terrain, and for either urban or rural environments. The Environmental Protection Agency has approved this program for specific regulatory applications. Input requirements for the program include source configuration and pollutant emission parameters. The short-term model was used in this analysis to estimate all nonradiological air quality impacts and uses hourly meteorological data that include wind speed, wind direction, and stability class to compute pollutant transport and dispersion.

Because the short-term pollutant concentrations were based on annual usage or release parameters, conversion of annual parameter values to short-term values depended on the duration of the activity. Many of the repository activities were assumed to have a schedule of 250 working days per year, so the daily release would be the annual value divided by 250.

In many cases, site- or activity-specific information was not available for estimating pollutant emissions at the Yucca Mountain site. In these cases, generic information was used and conservative assumptions were made that tended to overestimate actual air concentrations.

As noted in Section G.1, the total nonradiological air quality impacts are described in Chapter 4, Section 4.1.2, for the Proposed Action and in Chapter 8, Section 8.2.2, for the inventory modules. These impacts are the sum of air quality impacts from individual sources and activities that take place during each of the project phases and that are discussed later in this section (for example, dust emissions from the concrete batch facility during the construction phase). The maximum air quality impact (that is, air concentration) resulting from individual sources or activities could occur at different land withdrawal area boundary locations depending on the release period and the regulatory averaging time (see Section G.1.3). These maximums generally occur in a westerly or southerly direction. The total nonradiological air quality impacts presented in Sections 4.1.2 and 8.2.2 are the sum of the calculated maximum concentrations regardless of direction. Therefore, the values presented would be larger than the actual sum of the concentrations for a particular distance and direction. This approach was selected to simplify the presentation of air quality results.

G.1.2 LOCATIONS OF HYPOTHETICALLY EXPOSED INDIVIDUALS

The location of the public maximally exposed individual was determined by calculating the maximum ground-level pollutant concentrations. Because unrestricted public access would be limited to the site boundary, the analysis assumed that a hypothetical individual would be present at one point on the site boundary during the entire averaging time of the regulatory limit (Table G-1).

Table G-2 lists the distances from the North and South Portals to the land withdrawal area boundary where the analysis assumed members of the public would be present. The table does not list all directions because the land withdrawal area boundaries would not be accessible to members of the public in some directions (restricted access areas of the Nevada Test Site and Nellis Air Force Range). The distance to the nearest unrestricted public access in these directions would be so large that there would be no air quality impacts. For the east to south-southeast directions, the distances to the land withdrawal area boundary would be large, but the terrain is such that plumes traveling in these directions tend to enter Fortymile Wash and turn south. The analysis used the distance to the south land withdrawal area boundary for those sectors.

Table G-2. Distance to the nearest point of unrestricted public access (kilometers).[a,b,c]

Direction	From North Portal	From South Portal
Northwest	14	15
West-northwest	12	12
West	11	11
West-southwest	14	12
Southwest	18	16
South-southwest	23	19
South	21	18
South-southeast[d]	21	18
Southeast[d]	21	18

a. Source: DOE (1997c, all).
b. Numbers are rounded to two significant figures.
c. To convert kilometers to miles, multiply by 0.6217.
d. Distances assumed to be the same as those to the south.

G.1.3 METEOROLOGICAL DATA AND REFERENCE CONCENTRATIONS

DOE estimated the concentrations of criteria pollutants in the region of the repository by using the Industrial Source Complex program and site-specific meteorological data for 1993 to 1997 from air quality and meteorology monitoring Site 1 (TRW 1999c, electronic addendum). Site 1 is less than 1 kilometer (0.6 mile) south of the proposed North Portal surface facility location. Similar topographic exposure leads to similar prevailing northerly and southerly winds at both locations. DOE used Site 1 data because an analysis of the data collected at all the sites showed that site to be most representative of the surface facilities (TRW 1999c, page 7). Wind speed data are from the 10-meter (33-foot) level, as are atmospheric stability data, using the night-adjusted sigma-theta method (EPA 1987, pages 6-20 to 6-32). Mixing height measurements were not available for Yucca Mountain so the analysis assumed a mixing height of approximately 140 meters (470 feet), which is one-tenth of the 1,420 meters (4,700 feet) mixing-layer depth for Desert Rock, Nevada. Desert Rock is the nearest upper air meteorological station, about 44 kilometers (27 miles) east-southeast near Mercury, Nevada. The average mixing height at Desert Rock was divided by 10 to simulate the mixing height during very stable conditions, which is when the highest concentrations from a ground-level source would normally occur. All nonradiological pollutant releases were assumed to come from ground-level point sources. Both of these conservative assumptions, made because of a lack of site-specific information, tend to overestimate actual air concentrations. Fugitive dust emissions could be modeled as an area source, but the distance from the source to the exposure location would be large [more than 10 kilometers (6 miles)] so a point source provides a good approximation. Some sources would have plume rise, such as boiler emissions, but this was not considered because there is inadequate information to characterize the rise.

The analysis estimated unit release concentrations at the land withdrawal area boundary points of maximum exposure for ground-level point-source releases. The concentrations were based on release rates of 1 gram (0.04 ounce) per second for each of the five regulatory limit averaging times (annual, 24-hour, 8-hour, 3-hour, or 1-hour). Various activities at the Yucca Mountain site could result in pollutants being released over four different periods in a 24-hour day [continuously, 8-hour, 12-hour (two 6-hour periods), or 3-hour]. Eleven combinations of release periods and regulatory limit averaging times would be applicable to activities at the Yucca Mountain site.

The analysis assumed that the 8-hour pollutant releases would occur from 8 a.m. to 4 p.m. and to be zero for all other hours of the day. Similarly, it assumed that the 3-hour releases would occur from 9 a.m. to 12 p.m. and to be zero for all other hours. The 12-hour release would occur over two 6-hour periods, assumed to be from 9 a.m. to 3 p.m. and from 5 p.m. to 11 p.m.; other hours would have zero release. Continuous releases would occur throughout the 24-hour day. The estimates of all annual-average concentrations assumed the releases were continuous over the year.

Table G-3 lists the maximum unit release concentrations for the 11 combinations of the Yucca Mountain site-specific release periods and regulatory limit averaging times. The analysis estimated the unit

Table G-3. Unit release concentrations (micrograms per cubic meter based on a release of 1 gram per second) and direction to maximally exposed individual location for 11 combinations of 4 release periods and 5 regulatory limit averaging times.[a]

	Direction from South Portal Operations area	Unit release concentration	Direction from North Portal Operations Area	Unit release concentration
Continuous release – annual average concentration (1995)[b]				
	South-southeast	0.12	South-southeast	0.099
Continuous release – 24-hour average concentration (1993)				
	Southeast	1.0	West	0.95
Continuous release – 8-hour average concentration (1995)				
	Southeast	3.0	Southeast	2.5
Continuous release – 3-hour average concentration (1995)				
	West	6.1	West	6.1
Continuous release – 1-hour average concentration (1995)				
	West	18	West	18
8-hour release (8 a.m. to 4 p.m.) – 24-hour average concentration (1997)				
	West-southwest	0.19	West-northwest	0.18
8-hour release (8 a.m. to 4 p.m.) – 8-hour average concentration (1997)				
	West-southwest	0.57	West-northwest	0.52
8-hour release (8 a.m. to 4 p.m.) – 3-hour average concentration (1997)				
	West-southwest	1.5	West-northwest	1.4
8-hour release (8 a.m. to 4 p.m.) – 1-hour average concentration (1997)				
	West-northwest	3.3	West-northwest	3.3
12-hour release (9 a.m. to 3 p.m. and 5 p.m. to 11 p.m.) – 24-hour average concentration (1997)				
	West	0.95	West	0.95
3-hour release (9 a.m. to 12 p.m.) – 24-hour average concentration (1997)				
	West-northwest	0.17	West-northwest	0.17

a. Numbers are rounded to two significant figures.

b. Number in parentheses is the year from 1993 through 1997 for which meteorological data would result in the highest unit concentration.

concentrations and directions using the meteorological data during a single year from 1993 through 1997 (TRW 1999c, electronic addendum) that would result in the highest unit concentration. For all years, the unit release concentrations for a particular averaging time are within a factor of 2 of each other. Table G-3 lists the 24-hour averaged concentration for the 3- and 12-hour release scenarios because the activities associated with these scenarios would only release PM_{10}, which has annual and 24-hour regulatory limits. The estimated concentration at the point of exposure was calculated by multiplying the estimated source release rate (presented for each source in the following sections) by the maximum unit release concentration for that averaging period.

G.1.4 CONSTRUCTION PHASE

This section describes the method used to estimate air quality impacts during the 5-year construction phase. DOE would complete the surface facilities during the construction phase, as well as sufficient excavation of the subsurface to support initial emplacement activities.

This analysis used calculations of the pollutant concentrations from various construction activities to determine air quality impacts. To calculate these impacts, estimated pollutant emission rates discussed in this section were multiplied by the unit release concentration (see Section G.1.3). This produced the pollutant concentration for comparison to regulatory limits. Short-term pollutant emission rates and concentrations were estimated using the method described in Section G.1.1.

The principal emission sources of particulates would be fugitive dust from construction activities on the surface, excavation of rock from the repository, storage of material on the excavated rock pile, and dust emissions from the concrete batch facility. The principal sources of nitrogen dioxide, sulfur dioxide, and carbon monoxide would be fuel combustion in trucks, cranes, and graders and emissions from a boiler in the South Portal Operations Area. Nitrogen dioxide, sulfur dioxide, and carbon monoxide would also be emitted during maintenance of the excavated rock pile. The following sections describe these sources in more detail.

G.1.4.1 Fugitive Dust Emissions from Surface Construction

Fugitive dust would be generated during such construction activities as earth moving and truck traffic. All surface construction activities and associated fugitive dust releases were assumed to occur during 250 working days per year with one 8-hour shift per day. The preferred method suggested by the Environmental Protection Agency would be to break the construction activities into component activities (for example, earth moving, truck traffic) and calculate the emissions for each component. However, detailed information was not available for the construction phase, so a generic, conservative approach was taken. The release rate of total suspended particulates (particulates with aerodynamic diameters of 30 micrometers or less) was estimated as 0.27 kilogram per square meter (1.2 tons per acre) per month (EPA 1995b, pages 13.2.3-1 to 13.2.3-7). This estimated emission rate for total suspended particulates was based on measurements made during the construction of apartments and shopping centers.

The amount of PM_{10} (the pollutant of interest) emitted from the construction of the Yucca Mountain Repository probably would be less than 0.27 kilogram per square meter (1.2 tons per acre) per month because many of the particulates suspended during construction would be at the larger end of the 30-micrometer range and would tend to settle rapidly (Seinfeld 1986, pages 26 to 31). Experiments on dust suspension due to construction found that at 50 meters (160 feet) downwind of the source, a maximum of 30 percent of the remaining suspended particulates at respirable height were in the PM_{10} range (EPA 1988, pages 22 to 26). Based on this factor, only 30 percent of the 0.27 kilogram per square meter per month of total suspended particulates, or 0.081 kilogram per square meter (0.36 ton per acre) per month, would be emitted as PM_{10} from construction activities. Because the default emission rate was based on continuous emissions over 30 days, the daily PM_{10} emission rate would be 0.0027 kilogram per square meter (0.012 ton per acre) per day, or 0.00011 kilogram per square meter (0.00050 ton per acre) per hour. Dust suppression activities would reduce PM_{10} emissions; however, the analysis took no credit for normal dust suppression activities.

The estimation of the annual and 24-hour average PM_{10} emission rates required an estimate of the size of the area to be disturbed along with the unit area emission rate [0.00011 kilogram per square meter (0.00050 ton per acre) per hour] times 8 hours of construction per day. The analysis estimated that 20 percent of the total disturbed land area would be actively involved in construction activities at any given time. This was based on the total disturbed area at the end of the construction period divided by the 5 years construction activities would last. Table G-4 lists the total areas of disturbance at various repository operation areas. The analysis assumed that the entire land area required for excavated rock storage (for both the construction and operation phases) would be disturbed by excavated rock storage preparation activities, although only a portion of it would be used during the construction phase. The much larger volume of rock that DOE would remove during excavation for the low thermal load scenario would require that the excavated rock pile not be in the South Portal Operations Area. Rather, it would be about 5 kilometers (3 miles) east of the South Portal (TRW 1999b, pages 6-41 and 6-43). The excavated rock could be piled higher in this location [to about 15 meters (50 feet)] than in the South Portal Operations Area [where the piles could be no more than about 6 meters (20 feet) high], requiring less land area under this option and making the area required for all three thermal load scenarios about the same. Table G-5 lists fugitive dust emissions from surface construction; Table G-6 lists estimated air quality impacts from fugitive dust as the pollutant concentration in air and as the percent of the applicable regulatory limit.

Table G-4. Land area (square kilometers)[a] disturbed during the construction phase for each thermal load scenario.[b,c]

Operations area	High	Intermediate	Low
North Portal and roads	0.62	0.62	0.62
South Portal	0.15	0.15	0.15
Ventilation shafts	0.02	0.02	0.06
Total excavated rock storage	1.0	1.2	1.1
Rail construction on site[d]	0.6	0.6	0.6
Totals[b]	**2.4**	**2.6**	**2.6**
Area disturbed per year	0.48	0.52	0.50

a. To convert square kilometers to acres, multiply by 247.1.
b. Numbers are rounded to two significant figures; therefore, totals might differ from sums of values.
c. Source: Jessen (1998, all).
d. Onsite rail line assumed to be 10 kilometers (6 miles) long and 0.06 kilometer (0.04 mile) wide.

Table G-5. Fugitive dust releases from surface construction (PM_{10}).[a]

Thermal load scenario	Period	Pollutant emission (kilograms)[b]	Emission rate (grams per second[c])
High	Annual	110,000 per year	3.4
	24-hour	430 per day	15[d]
Intermediate	Annual	120,000 per year	3.6
	24-hour	460 per day	16[d]
Low	Annual	120,000 per year	3.7
	24-hour	460 per day	16[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on an 8-hour release period.

Fugitive dust from construction would produce small offsite PM_{10} concentrations. The annual and 24-hour average concentrations of PM_{10} would be about 1 percent and about 2 percent, respectively, of the regulatory limit for all three thermal load scenarios. The differences between the thermal load

Table G-6. Estimated fugitive dust air quality impacts (micrograms per cubic meter) from surface construction (PM_{10}).

Thermal load scenario	Period	Maximum concentration[a]	Regulatory limit	Percent of limit[a]
High	Annual	0.41	50	0.83
	24-hour	2.9	150	1.9
Intermediate	Annual	0.44	50	0.88
	24-hour	3.0	150	2.0
Low	Annual	0.44	50	0.88
	24-hour	3.1	150	2.0

a. Numbers are rounded to two significant figures.

scenarios would be very small; the high thermal load would have the smallest impacts due mainly to the smaller area required for excavated rock storage.

For Modules 1 and 2, the same technique was used as for the Proposed Action, but the amount of land disturbed would be about 1.1, 1.1, and 1.3 times larger than for the Proposed Action for the high, intermediate, and low thermal load scenarios, respectively (Jessen 1998, all). The increase in disturbed land area would lead to estimated air quality impacts about 1.1, 1.1, and 1.3 times larger than the Proposed Action for the high, intermediate, and low thermal load scenarios, respectively.

G.1.4.2 Fugitive Dust from Subsurface Excavation

Fugitive dust would be released during the excavation of rock from the repository. Subsurface excavation activities would take place 250 days per year in three 8-hour shifts per day. Excavation would generate dust in the tunnels, and some of the dust would be emitted to the surface atmosphere through the ventilation system. DOE estimated the amount of dust that would be emitted by the ventilation system by using engineering judgment and best available information (DOE 1998, page 37). Table G-7 lists the release rates of PM_{10} for excavation activities. Table G-8 lists estimated air quality impacts from fugitive dust as pollutant concentration in air and percentage of regulatory limit.

Table G-7. Fugitive dust releases from excavation activities (PM_{10}).[a]

Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Annual	920 per year	0.029
24-hour	3.7 per day	0.043[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 24-hour release period.

Table G-8. Fugitive dust (PM_{10}) and cristobalite air quality impacts (micrograms per cubic meter) from excavation activities.

Period	Maximum concentration[a]	Regulatory limit	Percent of regulatory limit[a]
PM_{10}			
Annual	0.0035	50	0.0070
24-hour	0.044	150	0.029
Cristobalite			
Annual	0.0010	10[b]	0.010

a. Numbers are rounded to two significant figures.
b. This value is a benchmark; there is no regulatory limit for cristobalite. See Section G.1.

Fugitive dust emissions from excavation operations would produce small offsite PM_{10} concentrations. Both annual and 24-hour average concentrations of PM_{10} would be much less than 1 percent of the regulatory standards. The highest estimated annual and 24-hour excavation rates, and hence the highest estimated fugitive dust concentrations, would be the same for all three thermal load scenarios.

Dust generated during excavation would contain cristobalite, a naturally occurring form of crystalline silica discussed in Section G.1. The analysis estimated the amount of cristobalite released by multiplying the amount of dust released annually (shown in Table G-7) by the percentage of cristobalite in the parent rock (28 percent). Table G-8 also lists the potential air quality impacts for releases of cristobalite from excavation of the repository. Because there are no public exposure limits for cristobalite, the annual average concentration was compared to a derived benchmark level for the prevention of silicosis, as discussed in Section G.1. The offsite cristobalite concentration would be about 0.01 percent of this benchmark.

The air quality impacts from fugitive dust emissions from excavation operations under the construction phase would be the same for Modules 1 and 2 as for the Proposed Action.

G.1.4.3 Fugitive Dust from Excavated Rock Pile

The disposal and storage of excavated rock on the surface excavated rock pile would generate fugitive dust. Dust would be released during the unloading of the excavated rock and subsequent smoothing of the excavated rock pile, as well as by wind erosion of the material. DOE used the total suspended particulate emission for active storage piles from a report by Cowherd, Muleski, and Kinsey (1988, pages 4-17 to 4-37) to estimate fugitive dust emission. The equation is:

$$E = 1.9 \times (s \div 1.5) \times [(365 - p) \div 235] \times (f \div 15)$$

where E = total suspended particulate emission factor (kilogram per day per hectare [1 hectare = 0.01 square kilometer = 2.5 acres])
s = silt content of aggregate (percent)
p = number of days per year with 0.25 millimeter or more of precipitation
f = percentage of time wind speed exceeds 5.4 meters per second (12 miles per hour) at pile height

For this analysis, *s* is equal to 4 percent [no value was available for this variable, so the average silt content of limestone quarrying material (EPA 1995b, page 13.2.4-2) was used], *p* is 37.75 (Fransioli 1999, all) and *f* is 16.5 (calculated from meteorological data used in the Industrial Source Complex model). Thus, *E* is equal to 7.8 kilograms of total particulates per day per hectare (6.9 pounds per day per acre). Only about 50 percent of the total particulates would be PM_{10} (Cowherd, Muleski, and Kinsey 1988, pages 4-17 to 4-37); therefore, the emission rate for PM_{10} would be 3.9 kilograms per day per hectare (3.5 pounds per day per acre).

The analysis estimated fugitive dust from disposal and storage using the size of the area actively involved in storage and maintenance. Only a portion of the excavated rock pile would be actively disturbed by the unloading of excavated rock and the subsequent contouring of the pile, and only that portion would be an active source of fugitive dust. The analysis assumed that the rest of the excavated rock pile would be stabilized by either natural processes or DOE stabilization measures and would release small amounts of dust.

DOE based its estimate of the size of the active portion of the excavated rock pile on the amount of material it would store there each year. The volume of rock placed on the excavated rock pile from excavation activities during the construction phase (TRW 1999b, page 6-7) was divided by the height of the storage pile. The average height of the excavated rock pile would be about 6 meters (20 feet) for the high and intermediate thermal load scenarios (TRW 1999b, page 6-42) and 15 meters (50 feet) for the low thermal load scenario (TRW 1999b, page 6-43). Table G-9 lists the areas of the excavated rock pile and the active portion for each thermal load scenario. The active area of the excavated rock pile was estimated using the total area of the rock pile at the end of the construction phase divided by the number of years of construction multiplied by 2 (Smith 1999, all). As noted in Section G.1.4.1, under the low thermal load scenario the excavated rock pile would be several kilometers east of the South Portal Operations Area. Under this option the pile could be higher in this location, allowing for a smaller area of disturbance than for the excavated rock piles of the high and intermediate thermal load scenarios in the South Portal Operations Area.

Table G-9. Active area (square kilometers)[a] of excavated rock pile during the construction phase.[b,c]

Thermal load	Area	Number of years	Average annual active area
High	0.34	5	0.14
Intermediate	0.41	5	0.17
Low	0.17	5	0.066

a. To convert square kilometers to square miles, multiply by 0.3861.
b. Numbers are rounded to two significant figures.
c. The construction phase would last 5 years. Subsurface excavation and rock pile activities would continue during the operation and monitoring phase (see Section G.1.5).

Table G-10 lists the fugitive dust release rate from disposal and storage of the excavated rock pile by thermal load scenario. Table G-11 lists the air quality impacts from fugitive dust as pollutant concentration and percent of regulatory limit.

Table G-10. Fugitive dust released from the excavated rock pile during the construction phase (PM_{10}).[a]

Thermal load	Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
High	Annual	19,000 per year	0.61
	24-hour	53 per day	0.61[d]
Intermediate	Annual	23,000 per year	0.74
	24-hour	64 per day	0.74[d]
Low	Annual	9,400 per year	0.30
	24-hour	26 per day	0.30[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a continuous release.

Fugitive dust emissions from the excavated rock pile during the construction phase would produce small offsite PM_{10} concentrations. Both the annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards. The low thermal load scenario would have the smallest concentrations due to the smaller area of active disturbance, which is directly related to the taller pile with a resultant smaller surface-area-to-volume ratio.

Table G-11 also lists potential air quality impacts for releases of cristobalite. The methods used were the same as those described in Section G.1.4.2 for the construction phase, where cristobalite was assumed to be 28 percent of the fugitive dust released, based on its percentage in parent rock. The land withdrawal area boundary cristobalite concentration would be small, about 0.25 percent or less of the benchmark level discussed in Section G.1.

Table G-11. Fugitive dust (PM_{10}) and cristobalite air quality impacts (micrograms per cubic meter) from the excavated rock pile during the construction phase.

Thermal load	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
PM_{10}				
High	Annual	0.074	50	0.15
	24-hour	0.62	150	0.41
Intermediate	Annual	0.090	50	0.18
	24-hour	0.76	150	0.51
Low	Annual	0.036	50	0.071
	24-hour	0.30	150	0.19
Cristobalite				
High	Annual	0.021	10[c]	0.21
Intermediate	Annual	0.025	10[c]	0.25
Low	Annual	0.010	10[c]	0.010

a. Numbers are rounded to two significant figures.

b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

c. This value is a benchmark; there are no regulatory limits for cristobalite other than worker exposure limits. See Section G.1.

For Modules 1 and 2, the volume of rock excavated during the construction phase would be nearly 1.8 million cubic meters (2.3 million cubic yards) for all three thermal load scenarios (TRW 1999b, pages 6-7 and 6-53). This represents an increase of about 16 percent over the Proposed Action for the high thermal load scenario, and a slight decrease of about 5 percent for the intermediate and low thermal load scenarios. The estimated air quality impacts would change proportionately from Proposed Action impacts, increasing 16 percent for the high thermal load scenario and decreasing by 5 percent for the intermediate and low thermal load scenarios.

G.1.4.4 Fugitive Dust from Concrete Batch Facility

The concrete batch facility for the fabrication and curing of tunnel inverts and tunnel liners would emit dust. This facility would run 3 hours a day and would produce 115 cubic meters (150 cubic yards) of concrete per hour of operation (TRW 1999b, pages 4-4 and 4-5). It would operate 250 days per year. Table G-12 lists emission factor estimates for the concrete batch facility (EPA 1995b, pages 11.12-1 to 11.12-5). About 0.76 cubic meter (1 cubic yard) of typical concrete weighs 1,800 kilograms (4,000 pounds) (EPA 1995b, page 11.12-3). The size of the aggregate storage pile for the concrete batch facility would be 800 square meters (0.2 acre) (TRW 1999b, pages 4-4 and 4-5).

Table G-12. Dust release rates for the concrete batch facility (kilograms per 1,000 kilograms of concrete).[a,b]

Source/activity	Emission rate
Sand and aggregate transfer to elevated bin	0.014
Cement unloading to elevated storage silo	0.13
Weight hopper loading	0.01
Mixer loading	0.02
Wind erosion from aggregate storage	3.9 kilograms per hectare[c] per day

a. Source: EPA (1995b, page 11.12-3).

b. To convert kilograms to pounds, multiply by 2.2046.

c. 3.9 kilograms per hectare = about 21 pounds per acre.

Table G-13 lists the dust release rates of the concrete batch facility. The releases would be the same for all thermal load scenarios. Table G-14 lists estimated potential air quality impacts as the estimated pollutant concentration and percent of regulatory limit.

Table G-13. Dust release rates for the concrete batch facility during the operation and monitoring phase (PM_{10}).[a]

Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Annual	36,000 per year	1.1
24-hour	140 per day	13[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 3-hour release.

Table G-14. Particulate matter (PM_{10}) air quality impacts (micrograms per cubic meter) from the concrete batch facility during the construction phase.

Period	Maximum concentration[a]	Regulatory limit	Percent of regulatory limit[a]
Annual	0.14	50	0.27
24-hour	2.2	150	1.1

a. Numbers are rounded to two significant figures.

Dust emissions from the concrete batch facility during the operation and monitoring phase would produce small offsite PM_{10} concentrations. The annual and 24-hour averaged concentrations of PM_{10} would be less than 1 percent and about 1.5 percent of the regulatory standards, respectively.

For Modules 1 and 2, the air quality impacts from the concrete batch facility during the construction phase would be the same as for the Proposed Action.

G.1.4.5 Exhaust Emissions from Construction Equipment

Diesel- and gasoline-powered equipment would emit all four criteria pollutants during the construction phase. EPA (1991, pages II-7-1 to II-7-7) provided pollutant emission rate estimates for heavy-duty equipment. This analysis assumed construction equipment would emit the average of the EPA reference emission rates. Table G-15 lists the emission rates for this equipment.

Table G-15. Pollutant emission rates (kilograms[a] per 1,000 liters[b] of fuel) for construction equipment.[c]

	Estimated emission	
Pollutant	Diesel	Gasoline
Carbon monoxide	15	450
Nitrogen dioxide	39	13
PM_{10}	3.5	0.86
Sulfur dioxide	3.7	0.63

a. To convert kilograms to pounds, multiply by 2.2046.
b. To convert liters to gallons, multiply by 0.26418.
c. Source: Average of rates from EPA (1991, pages II-7-1 to II-7-7).

Table G-16 lists the estimated average amount of fuel per year for the construction of the North and South Portal Operations Areas. The fuel for the South Portal Operations Area would include fuel consumed during maintenance of the excavated rock pile.

Table G-16. Amount of fuel consumed per year during the construction phase (liters).[a,b]

	South Portal Operations Area[c]		North Portal Operations Area[d]
Thermal load	Diesel	Gasoline	Diesel
High	360,000	20,000	640,000
Intermediate	360,000	20,000	640,000
Low	560,000	20,000	640,000

a. To convert liters to gallons, multiply by 0.26418.
b. Numbers are rounded to two significant figures.
c. Source: Based on total fuel use from TRW (1999b, page 6-3).
d. Source: Based on total fuel use from TRW (1999a, Table 6.1, page 71).

Table G-17 lists pollutant releases from construction equipment for each thermal load scenario. The emission rate for the annual concentration was calculated from the total fuel consumed, assuming the same amount of fuel would be consumed each year.

Table G-17. Pollutant release rates from surface equipment during the construction phase.[a]

		Mass of pollutant per averaging period (kilograms)[b]		Emission rate[c] (grams per second)[d]	
Pollutant	Period	South	North	South	North
High and intermediate thermal load					
Nitrogen dioxide	Annual	14,000	25,000	0.46	0.80
Sulfur dioxide	Annual	1,400	2,400	0.043	0.076
	24-hour	5.4	9.6	0.019	0.33
	3-hour	2.0	3.6	0.019	0.33
Carbon monoxide	8-hour	57	39	2.0	1.3
	1-hour	7.2	4.8	2.0	1.3
PM_{10}	Annual	1,300	2,200	0.040	0.071
	24-hour	5.1	8.9	0.18	0.31
Low thermal load					
Nitrogen dioxide	Annual	22,000	25,000	0.71	0.80
Sulfur dioxide	Annual	2,100	2,400	0.067	0.076
	24-hour	8.4	9.6	0.29	0.33
	3-hour	3.2	3.6	0.29	0.33
Carbon monoxide	8-hour	69	39	2.4	1.3
	1-hour	8.7	4.8	2.4	1.3
PM_{10}	Annual	2,000	2,200	0.062	0.071
	24-hour	7.9	8.9	0.27	0.31

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release for averaging periods 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-18 lists the impacts on air quality from construction equipment emission by thermal load scenario as the pollutant concentration in air and the percent of the regulatory limit. Emissions from surface equipment during the construction phase would produce small offsite (outside the land withdrawal area) criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards.

For Modules 1 and 2, the same analysis method was used as that for the Proposed Action, but the amount of fuel used in the South Portal Operations Area would vary from the Proposed Action. Diesel fuel use would be about 7.4 times larger for the high and intermediate thermal load scenarios and about 4.8 times larger for the low thermal load scenario. Gasoline use would be two times larger for all thermal load scenarios (TRW 1999b, page 6-45). There would be no change in the amount of fuel used during the

Table G-18. Air quality impacts from construction equipment during the construction phase (micrograms per cubic meter).[a]

Pollutant	Period	Maximum concentration	Regulatory limit[b]	Percent of regulatory limit
High and intermediate thermal load				
Nitrogen dioxide	Annual	0.13	100	0.13
Sulfur dioxide	Annual	0.013	80	0.016
	24-hour	0.096	365	0.026
	3-hour	0.77	1,300	0.059
Carbon monoxide	8-hour	1.8	10,000	0.018
	1-hour	11	40,000	0.028
PM_{10}	Annual	0.012	50	0.024
	24-hour	0.090	150	0.060
Low thermal load				
Nitrogen dioxide	Annual	0.16	100	0.16
Sulfur dioxide	Annual	0.016	80	0.020
	24-hour	0.12	365	0.032
	3-hour	0.93	1,300	0.071
Carbon monoxide	8-hour	2.1	10,000	0.020
	1-hour	12	40,000	0.031
PM_{10}	Annual	0.014	50	0.029
	24-hour	0.11	150	0.072

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

construction of the North Portal. These increases in fuel use would lead to estimated air quality impacts that would be about 3.5 times larger for the high and intermediate thermal load scenarios and about 2.5 times larger for the low thermal load scenario except for carbon monoxide. Carbon monoxide air quality impacts, which are more heavily weighted towards gasoline, would be about 2.5, 2.5 and 2.0 times larger than the Proposed Action for the high, intermediate, and low thermal load scenarios, respectively.

G.1.4.6 Exhaust from Boiler

A proposed boiler in the South Portal Operations Area would emit the four criteria pollutants. The boiler would use diesel fuel and provide steam and hot water for the heating, ventilation, and air conditioning system. The analysis assumed that this boiler would be the same size as the boiler that would operate in the North Portal Operations Area during the operation and monitoring phase (TRW 1999a, Table 6-2, page 75) but not during construction. Table G-19 lists the annual emission rates of the boiler in the South Portal Operations Area. To estimate the short-term (24 hours or less) emission rate, the analysis assumed the boiler would run 250 days (6,000 hours) per year. Given the annual boiler emissions, this was a conservative assumption because continuous operation 365 days (8,760 hours) per year would result in lower daily emissions. This assumption considered periods when the boiler would not be operating. The actual period of boiler operation is not known. In addition, specific information on the boiler stack height and exhaust air temperature (which would affect plume rise) has not been developed. The analysis assumed that releases would be from ground level, which overestimates actual concentrations. Table G-20 lists releases of criteria pollutants by the boiler. Table G-21 lists estimated potential air quality impacts as pollutant concentrations in air and percent of regulatory limit.

Table G-19. Annual pollutant release rates (kilograms per year)[a] for the South Portal Operations Area boiler.[b,c]

Pollutant	Annual emission rate
Nitrogen dioxide	58,000
Sulfur dioxide	20,000
Carbon monoxide	15,000
PM_{10}	5,600

a. To convert kilograms to tons, multiply by 0.0011023.
b. Source: TRW (1999a, Table 6-2, page 75).
c. Numbers are rounded to two significant figures.

Table G-20. Pollutant release rates from the boiler during the construction phase.[a]

Pollutant	Period	Mass of pollutant (kilograms)[b] per averaging time	Emission rate[c] (grams per second)[d]
Nitrogen dioxide	Annual	58,000	1.83
Sulfur dioxide	Annual	20,000	0.63
	24-hour	80	0.92
	3-hour	10	0.92
Carbon monoxide	8-hour	20	0.67
	1-hour	2.5	0.67
PM_{10}	Annual	5,600	0.18
	24-hour	22	0.25

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release for averaging periods of 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-21. Air quality impacts from boiler pollutant releases from the South Portal Operations Area during the construction phase (micrograms per cubic meter of pollutant).

Pollutant	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Nitrogen dioxide	Annual	0.22	100	0.22
Sulfur dioxide	Annual	0.076	80	0.095
	24-hour	0.94	365	0.26
	3-hour	5.5	1,300	0.43
Carbon monoxide	8-hour	2.0	10,000	0.020
	1-hour	12	40,000	0.031
PM_{10}	Annual	0.022	50	0.044
	24-hour	0.27	150	0.18

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Emissions from the boiler during the construction phase would produce small offsite (outside the land withdrawal area) criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards.

For Modules 1 and 2, the air quality impacts from the boiler during the construction phase would be the same as those for the Proposed Action.

G.1.5 OPERATION AND MONITORING PHASE

This section describes the method DOE used to estimate air quality impacts during the operation and monitoring phase (2010 to 2110). Activities during this phase would include the continued development of the subsurface facilities, which would last 22 years for all thermal load scenarios. Emplacement activities in the surface and subsurface facilities would continue concurrently with development operations for 24 years; 76 years of monitoring and maintenance would begin after the end of emplacement operations. The duration of the monitoring and maintenance period has not been finalized, but could be as long as 276 years for a 300-year operation and monitoring phase. For purposes of analysis, workers would use the following schedule for activities during the operation and monitoring phase: three 8-hour shifts a day, 5 days a week, 50 weeks a year; the maintenance of the excavated rock pile would occur in one 8-hour shift a day, 5 days a week, 50 weeks a year.

For Modules 1 and 2, the continued development of the subsurface facilities would last 36 years for all thermal load scenarios. Emplacement activities in the surface and subsurface facilities would continue concurrently with development operations for 38 years. The duration of the monitoring and maintenance period has not been finalized, but could be as long as 262 years for a 300-year operation and monitoring phase.

The analysis estimated air quality impacts by calculating pollutant concentrations from various operation and monitoring activities. Emission rates were developed for each activity that would result in pollutant releases. The emission rates were multiplied by the unit release concentrations (see Section G.1.3) to calculate the pollutant concentration for comparison to the various regulatory limits.

The principal emission sources of particulates would be dust emissions from concrete batch facility operations and fugitive dust emissions from excavation and storage on the excavated rock pile. Fuel combustion from maintenance of the excavated rock pile and emissions from the North Portal and South Portal boilers would be principal sources of nitrogen dioxide, sulfur dioxide, and carbon monoxide. The following sections describe these sources in more detail.

G.1.5.1 Fugitive Dust from Concrete Batch Facility

The concrete batch facility for the fabrication and curing of tunnel inverts and liners would emit dust. The analysis assumed that the dust emissions from the concrete batch facility would be the same as those during the construction phase. Thus, the dust release rate and potential air quality impacts would be the same as those listed in Tables G-13 and G-14.

G.1.5.2 Fugitive Dust from Subsurface Excavation

The excavation of rock from the repository would generate fugitive dust in the drifts. Some of the dust would reach the external atmosphere through the repository ventilation system. Fugitive dust emission rates from excavation during operations would be the same as those during the construction phase. Thus, the fugitive dust release rate and potential air quality impacts for excavation of rock would be the same as those listed in Tables G-7 and G-8. Air quality impacts from cristobalite released during excavation of the repository would be the same as those listed in Table G-8.

G.1.5.3 Fugitive Dust from Excavated Rock Pile

The disposal and storage of excavated rock on the excavated rock pile would release fugitive dust. The analysis used the same method to estimate fugitive dust releases from the excavated rock pile during operations that it used for the construction phase (See Section G.1.4.3). Table G-22 lists the areas of the active portion of the excavated rock pile by thermal load scenario. The total land area used for storage and the active portion of the excavated rock pile was based on the amount of rock that would be stored during operations (TRW 1999b, page 6-17). Sections G.1.4.1 and G.1.4.3 compare the excavated rock pile areas for the three thermal load scenarios.

Table G-22. Estimated active excavated rock pile area (square kilometers)[a] during subsurface excavation activities during the operation and monitoring phase.[b]

Thermal load	Storage area	Years of repository development	Annual average active area
High	0.63	22	0.058
Intermediate	0.76	22	0.069
Low	1.0	22	0.095

a. To convert square kilometers to acres, multiply by 247.1.

b. Numbers are rounded to two significant figures.

While the land area used for storage of excavated rock during the operation and monitoring phase would be nearly twice as large as that used during the construction phase for the high and intermediate thermal load scenarios, the active area per year would be about half of that for construction due to the larger number of years over which storage would occur (22 years compared to 5 years). The land area used during the operation and monitoring phase for the low thermal load scenario would be nearly 10 times that used during the construction phase. The annual active area would be larger during the operation and monitoring phase than during the construction phase, but only about twice as large because of the longer period over which storage would take place (22 years compared to 5 years). Table G-23 lists fugitive dust releases from the excavated rock pile; Table G-24 lists potential air quality impacts as the pollutant concentration and percent of the regulatory limit.

Table G-23. Fugitive dust release rate from the excavated rock pile during the operation and monitoring phase (PM_{10}).[a]

Thermal load	Period	Emissions (kilograms)[b]	Emission rate[c] (grams per second)[d]
High	Annual	8,200 per year	0.26
	24-hour	22 per day	0.26
Intermediate	Annual	9,800 per year	0.31
	24-hour	27 per day	0.31
Low	Annual	13,000 per year	0.42
	24-hour	37 per day	0.42

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on a continuous release.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-24. Fugitive dust (PM_{10}) and cristobalite air quality impacts from the excavated rock pile during the operation and monitoring phase (micrograms per cubic meter).

Thermal load	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
PM_{10}				
High	Annual	0.031	50	0.062
	24-hour	0.27	150	0.18
Intermediate	Annual	0.038	50	0.075
	24-hour	0.32	150	0.21
Low	Annual	0.051	50	0.10
	24-hour	0.43	150	0.29
Cristobalite				
High	Annual	0.0087	10[c]	0.087
Intermediate	Annual	0.011	10[c]	0.11
Low	Annual	0.014	10[c]	0.14

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.
c. This value is a benchmark; there is no regulatory limit for cristobalite. See Section G.1.

Fugitive dust emissions from the excavated rock pile during the operation and monitoring phase would produce very small offsite (outside the land withdrawal area) PM_{10} concentrations. Both annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards for all three thermal load scenarios.

Table G-24 also lists potential air quality impacts for releases of cristobalite. The methods used were the same as those described in Section G.1.4.2 for the construction phase, where cristobalite was assumed to be 28 percent of the fugitive dust released, based on its percentage in parent rock. The site boundary cristobalite concentration would be small, about 0.1 percent of the benchmark level discussed in Section G.1.

The Module 1 and 2 analysis used the same technique as for the Proposed Action, but the estimated active excavated rock pile area would be about 1.4, 1.2, and 1.1 times larger than the Proposed Action for the high, intermediate, and low thermal load scenarios, respectively, based on the volumes of rock added annually to the pile (TRW 1999b, page 6-56). The estimated air quality impacts from the excavated rock pile would also be 1.4, 1.2, and 1.1 times larger than the Proposed Action for the high, intermediate, and low thermal load scenarios, respectively.

G.1.5.4 Exhaust from Excavated Rock Pile Maintenance Equipment

Surface equipment would emit the four criteria pollutants during excavated rock pile maintenance. The analysis used the same method to determine air quality impacts for surface equipment during operations that it used for the construction phase (see Section G.1.4.5). Table G-15 lists the pollutant release rates of the equipment. Table G-25 lists the average amount of fuel consumed each year during the operation and monitoring phase at the South Portal Operations Area.

Table G-25. Annual amount of fuel (liters)[a] consumed during the operation and monitoring phase.[b,c]

Thermal load	Diesel	Gasoline
High	350,000	4,500
Intermediate	350,000	4,500
Low	2,800,000	9,000

a. To convert liters to gallons, multiply by 0.26418.
b. Source: Based on total fuel use from TRW (1999b, pages 6-14 and 6-21).
c. Numbers are rounded to two significant figures.

Table G-26 lists pollutant release rates for surface equipment during operations activities of the operation and monitoring phase. Monitoring activity emissions would be much smaller. Table G-27 lists potential air quality impacts.

Table G-26. Pollutant release rates from surface equipment during the operation and monitoring phase.[a]

Pollutant	Period	Mass of pollutant per averaging time (kilograms)[b]	Emission rate[c] (grams per second)[d]
High and intermediate thermal load			
Nitrogen dioxide	Annual	14,000	0.44
Sulfur dioxide	Annual	1,300	0.041
	24-hour	5.2	0.18
	3-hour	4.9	0.18
Carbon monoxide	8-hour	29	1.0
	1-hour	3.6	1.0
PM_{10}	Annual	1,200	0.039
	24-hour	4.9	0.17
Low thermal load			
Nitrogen dioxide	Annual	110,000	3.5
Sulfur dioxide	Annual	10,000	0.33
	24-hour	42	1.4
	3-hour	16	1.4
Carbon monoxide	8-hour	180	6.4
	1-hour	23	6.4
PM_{10}	Annual	9,700	0.31
	24-hour	39	1.4

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release for averaging periods of 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-27. Air quality impacts from surface equipment during the operation and monitoring phase (micrograms per cubic meter of pollutant).

Pollutant	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
High and intermediate thermal load				
Nitrogen dioxide	Annual	0.052	100	0.052
Sulfur dioxide	Annual	0.0049	80	0.0063
	24-hour	0.034	365	0.0094
	3-hour	0.27	1,300	0.021
Carbon monoxide	8-hour	0.58	10,000	0.0056
	1-hour	3.3	40,000	0.0084
PM_{10}	Annual	0.0046	50	0.0092
	24-hour	0.032	150	0.021
Low thermal load				
Nitrogen dioxide	Annual	0.42	100	0.42
Sulfur dioxide	Annual	0.040	80	0.051
	24-hour	0.28	365	0.076
	3-hour	2.2	1,300	0.17
Carbon monoxide	8-hour	3.7	10,000	0.036
	1-hour	21	40,000	0.053
PM_{10}	Annual	0.037	50	0.074
	24-hour	0.26	150	0.17

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Emissions from surface equipment during operation and monitoring would produce very small concentrations of offsite (outside the land withdrawal area) criteria pollutants. All estimated concentrations would be less than 1 percent of the regulatory standards.

The Module 1 and 2 analysis used the same technique as for the Proposed Action, but the amount of fuel used during the operation and monitoring phase would increase. Annual diesel fuel use during development would increase by 1.6, 3.0, and 2.0 times the Proposed Action; annual gasoline use would increase by 1.2, 1.8, and 1.5 times the Proposed Action for the high, intermediate, and low thermal load scenarios, respectively, based on total fuel use (TRW 1999b, page 6-53). Annual diesel fuel use during emplacement would increase only by about 1 percent over the Proposed Action for all thermal load scenarios (TRW 1999b, page 6-61). Estimated air quality impacts for surface equipment during the operation and monitoring phase under Module 1 and 2 would increase by about 1.6, 3.0, and 2.0 times the Proposed Action for the high, intermediate, and low thermal load scenarios.

G.1.5.5 Exhaust from Boiler

Boilers in the North and South Portal Operations Areas would emit the four criteria pollutants. The annual emission rates of the boiler in the North Portal Operations Area would be the same as those listed in Table G-19 (the boilers were assumed to be the same size). There would be small variations in the North Portal boiler emissions for the transportation and waste packaging options because of different operational requirements. The emissions listed in Table G-19 are for the combination of legal-weight truck transport and uncanistered waste scenario, which would require the largest boiler because a larger Waste Handling Building would be required (TRW 1999a, pages 66 to 75). Other options would require a slightly smaller boiler (TRW 1999a, Table 6-2, page 75) and the release rate of pollutants would be about 15 percent smaller. The size of the boiler would not depend on the thermal load scenario. The analysis assumed the boiler would run 250 days (6,000 hours) per year. Given an annual emission rate, this was a conservative assumption because continuous operation 365 days (8,760 hours) per year would result in lower daily emissions. This assumption considered periods when the boiler would not be operating. The actual period of boiler operation is not known. Rates from the North Portal boiler for evaluating pollutant releases during the operation and monitoring phase would be the same as those listed in Table G-20 for the South Portal boiler.

Table G-28 lists estimated potential air quality impacts as pollutant concentrations in air and percent of regulatory limit. These impacts would be due to emissions from the boilers in the North and South Portal Operations Areas. Although total emissions during the operation and monitoring phase would be double those during the construction phase (when only the South Portal boiler would operate), air quality impacts would not double because of different atmospheric dispersion factors from the two operations areas to the location of the hypothetically maximally exposed individual. Emissions from the two boilers during the operation and monitoring phase would produce small offsite criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards.

Table G-28. Air quality impacts from boiler pollutant releases from both North and South Portal Operations Areas (micrograms per cubic meter of pollutant).

Pollutant	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Nitrogen dioxide	Annual	0.40	100	0.40
Sulfur dioxide	Annual	0.14	80	0.18
	24-hour	1.8	365	0.49
	3-hour	11	1,300	0.85
Carbon monoxide	8-hour	3.7	10,000	0.037
	1-hour	24	40,000	0.061
PM_{10}	Annual	0.039	50	0.078
	24-hour	0.51	150	0.34

a. Numbers are rounded to two significant figures.

b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

For Module 1 or 2, the estimated air quality impacts from boilers during the operation and monitoring phase would be the same as those for the Proposed Action.

G.1.6 CLOSURE PHASE

This section describes the method used to estimate air quality impacts during the closure phase at the proposed repository. The closure phase would last 6, 6, or 15 years for the high, intermediate, or low thermal load scenario, respectively. For Modules 1 and 2, the closure phase would last 13, 17, and 27 years for the high, intermediate, and low thermal load scenarios, respectively. The work schedule would be one 8-hour shift per day, 5 days a week, 50 weeks a year.

The analysis estimated air quality impacts by calculating pollutant concentrations from various closure activities. Emission rates were developed for each activity that would result in releases of pollutants. These pollutant emission rates were then multiplied by the unit release concentration (see Section G.1.3) to calculate the pollutant concentration for comparison to the various regulatory limits.

The sources of particulates would be emissions from the backfill plant and the concrete batch facility and fugitive dust from closure activities on the surface and the reclamation of material from the excavated rock pile for backfill. The principal source of nitrogen dioxide, sulfur dioxide, and carbon monoxide during closure would be fuel combustion. The following sections describe these sources in more detail.

G.1.6.1 Dust from Backfill Plant

The Closure Backfill Preparation Plant would process (separate, crush, screen, and wash) rock from the excavated rock pile for use as backfill for the underground access openings (TRW 1999b, pages 4-77 and 4-78). The facility would have the capacity to handle 91 metric tons (100 tons) an hour (TRW 1999b, pages 4-77 and 4-78). For purposes of analysis, the backfill plant would run 6 hours a shift, 2 shifts a day, 5 days a week, 50 weeks a year.

The plant was assumed to have emissions similar to a crushed-stone processing plant. Table G-29 lists the emission rates for various activities associated with a crushed stone processing plant (EPA 1995b, pages 11.19.2-1 to 11.19.2-8). Table G-30 lists estimated pollutant release rates for the backfill plant. Table G-31 lists potential air quality impacts as pollutant concentrations in air and percent of regulatory limit.

Table G-29. Emission rates from a crushed stone processing plant.[a,b]

Source/activity	Emission rate (kilogram[c] per 1,000 kilograms of material processed)
Dump to conveyor or truck	0.00005
Screening	0.0076
Crusher	0.0012
Fine screening	0.036

a. Source: EPA (1995b, pages 11.19.2-1 to 11.19.2-8).
b. Numbers are rounded to two significant figures.
c. To convert kilograms to pounds, multiply by 2.2046.

Table G-30. Dust release rates from the backfill plant (PM_{10}).[a]

Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Annual	12,000 per year	0.39
24-hour	49 per day	1.1[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 12-hour release period.

Table G-31. Particulate matter (PM_{10}) air quality impacts from backfill plant (micrograms per cubic meter).

Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Annual	0.047	50	0.093
24-hour	1.1	150	0.71

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Dust emissions from the backfill plant would produce small PM_{10} concentrations. Both annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards for all thermal load scenarios.

For Modules 1 and 2, the estimated air quality impacts for the backfill plant would be the same as those for the Proposed Action.

G.1.6.2 Fugitive Dust from Concrete Batch Facility

A concrete batch facility for the fabrication of seals would be similar to the facility that would operate during the construction and operation and monitoring phases (see Sections G.1.4.4 and G.1.5.1). The only difference would be that it would run only ten 3-hour shifts a year per concrete seal (TRW 1999b, page 4-78). The analysis assumed that two seals per year would be produced. Table G-12 lists activities associated with the concrete batch facility and their emissions. Table G-32 lists emissions from the concrete batch facility during closure. Table G-33 lists potential air quality impacts as pollutant concentration in air and percent of regulatory limit.

Table G-32. Dust release rates from the concrete batch facility during the closure phase (PM_{10}).[a]

Period	Mass of pollutant (kilograms)[b]	Emission rate (grams per second)[c]
Annual	2,800 per year	0.090
24-hour	140 per day	13[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 3-hour release period.

Table G-33. Particulate matter (PM_{10}) air quality impacts from the concrete batch facility during the closure phase (micrograms per cubic meter).

Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Annual	0.011	50	0.022
24-hour	2.2	150	1.5

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Dust emissions from the concrete batch facility during closure would produce small offsite (outside the land withdrawal area) PM_{10} concentrations. The annual and 24-hour average concentrations of PM_{10} would be less than 1 percent and around 1.5 percent, respectively, of the regulatory standards.

For Modules 1 and 2, the estimated air quality impacts from the concrete batch facility during the closure phase would be the same as those for the Proposed Action.

G.1.6.3 Fugitive Dust from Closure Activities

Closure activities such as smoothing and reshaping the excavated rock pile and demolishing buildings would produce the same fugitive dust releases as construction activities because they would disturb nearly the same amount of land. Thus, the pollutant release and air quality impacts from fugitive dust emissions from surface closure activities would be the same as those listed in Tables G-5 and G-6, respectively.

G.1.6.4 Fugitive Dust from Excavated Rock Pile

During backfill operations, fugitive dust would occur from the removal of excavated rock from the storage pile. The analysis used the same method to estimate fugitive dust emission from the excavated rock pile during the closure phase that it used for the construction phase (Section G.1.4.3). Table G-34 lists the total area of the excavated rock pile disturbed and the active portion, based on the amount of material to be removed from the pile (TRW 1999b, page 6-39). The analysis assumed that the rock used

Table G-34. Active excavated rock pile area (square kilometers)[a] during the closure phase.[b]

Thermal load	Total area disturbed for backfill operation	Number of years of closure	Active area (per year)
High	0.21	6	0.069
Intermediate	0.27	6	0.091
Low	0.26	15	0.035

a. To convert square kilometers to acres, multiply by 247.1.
b. Numbers are rounded to two significant figures.

in backfill would be from a limited area of the excavated rock pile, rather than from all over the pile. Table G-35 lists fugitive dust releases from the excavated rock pile. Table G-36 lists potential air quality impacts from the pile as pollutant air concentration and percent of regulatory limit.

Table G-35. Fugitive dust release rates from the excavated rock pile during the closure phase (PM_{10}).[a]

Thermal load	Period	Emission (kilograms)[b]	Emission rate[c] (grams per second)[d]
High	Annual	9,800 per year	0.31
	24-hour	27 per day	0.31
Intermediate	Annual	13,000 per year	0.41
	24-hour	35 per day	0.41
Low	Annual	5,000 per year	0.16
	24-hour	14 per day	0.16

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on a continuous release.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-36. Fugitive dust (PM_{10}) and cristobalite air quality impacts from the excavated rock pile during the closure phase (micrograms per cubic meter).

Thermal load	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
PM_{10}				
High	Annual	0.037	50	0.074
	24-hour	0.32	150	0.21
Intermediate	Annual	0.049	50	0.098
	24-hour	0.42	150	0.28
Low	Annual	0.019	50	0.038
	24-hour	0.16	150	0.11
Cristobalite				
High	Annual	0.010	10[c]	0.10
Intermediate	Annual	0.014	10[c]	0.14
Low	Annual	0.0053	10[c]	0.053

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.
c. This value is a benchmark; there is no regulatory limit for cristobalite. See Section G.1.

Fugitive dust emissions from the excavated rock pile during closure would produce small offsite PM_{10} concentrations. Both the annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards for all three thermal load scenarios.

Table G-36 also lists potential air quality impacts for releases of cristobalite. The methods used were the same as those described in Section G.1.4.2 for the construction phase, where cristobalite was assumed to be 28 percent of the fugitive dust released, based on its percentage in parent rock. The land withdrawal area boundary cristobalite concentration would be small, about 0.1 percent of the benchmark level discussed in Section G.1.

For Modules 1 and 2, the same technique was used, but the estimated active excavated rock pile area would be about 20 percent larger, 4 percent smaller, and 6 percent larger than the Proposed Action for the high, intermediate, and low thermal load scenarios, respectively, based on the volume of rock added to the pile (TRW 1999b, page 6-79). The estimated air quality impacts from the excavated rock pile would also be about 20 percent larger, 4 percent smaller, and 6 percent larger than the Proposed Action for the high, intermediate, and low thermal load scenarios, respectively.

G.1.6.5 Exhaust Emissions from Surface Equipment

The consumption of diesel fuel and gasoline by surface equipment would emit the four criteria pollutants during closure. The analysis used the same method to determine pollutant release rates during closure that it used for the construction phase (see Section G.1.4.5). Table G-15 lists the estimated pollutant release rates of the equipment that would consume the fuel. Table G-37 lists by thermal load scenario the average amount of fuel consumed per year. The length of the closure phase would be 6, 6, or 15 years for the high, intermediate, or low thermal load scenario, respectively. Closure of the North Portal Operations Area would last 6 years (TRW 1999a, page 79).

Table G-37. Annual amount of fuel consumed (liters)[a] during the closure phase.[b]

Thermal load	South Portal diesel[c]	North Portal diesel[d]
High	250,000	340,000
Intermediate	620,000	340,000
Low	510,000	340,000

a. To convert liters to gallons, multiply by 0.26418.
b. Numbers are rounded to two significant figures.
c. Source: Based on total fuel consumed from TRW (1999b, page 6-37).
d. Source: Based on total fuel consumed from TRW (1998, page 87).

Table G-38 lists pollutant releases from surface diesel consumption. Table G-39 lists potential air quality impacts as pollutant concentration in air and percent of regulatory limit. Concentrations would be less than 1 percent of the regulatory limit for all thermal load scenarios.

Table G-38. Pollutant release rates from surface equipment during the closure phase.[a]

		Mass of pollutant per averaging period (kilograms)[b]		Emission rate[c] (grams per second)[d]	
Pollutant	Period	South	North	South	North
High thermal load					
Nitrogen dioxide	Annual[d]	9,800	13,000	0.31	0.42
Sulfur dioxide	Annual	930	1,300	0.030	0.040
	24-hour[e]	3.7	5.1	0.13	0.18
	3-hour[f]	1.4	1.9	0.13	0.18
Carbon monoxide	8-hour[g]	15	21	0.52	0.71
	1-hour[h]	1.9	2.6	0.52	0.71
PM_{10}	Annual	870	1,200	0.028	0.038
	24-hour	3.5	4.7	0.12	0.16
Intermediate thermal load					
Nitrogen dioxide	Annual	24,000	13,000	0.77	0.42
Sulfur dioxide	Annual	2,300	1,300	0.073	0.040
	24-hour	9.2	5.1	0.32	0.18
	3-hour	3.5	1.9	0.32	0.18
Carbon monoxide	8-hour	37	21	1.3	0.71
	1-hour	4.7	2.6	1.3	0.71
PM_{10}	Annual	2,100	1,200	0.068	0.038
	24-hour	8.6	4.7	0.30	0.16
Low thermal load					
Nitrogen dioxide	Annual	20,000	13,000	0.63	0.42
Sulfur dioxide	Annual	1,900	1,300	0.060	0.040
	24-hour	7.6	5.1	0.26	0.18
	3-hour	2.8	1.9	0.26	0.18
Carbon monoxide	8-hour	31	21	1.1	0.71
	1-hour	3.8	2.6	1.1	0.71
PM_{10}	Annual	1,800	1,200	0.056	0.038
	24-hour	7.1	4.7	0.24	0.16

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release period for averaging periods of 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-39. Air quality impacts (micrograms per cubic meter) from surface construction equipment during the closure phase.

Pollutant	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
High thermal load				
Nitrogen dioxide	Annual	0.080	100	0.080
Sulfur dioxide	Annual	0.0076	80	0.0095
	24-hour	0.057	365	0.016
	3-hour	0.45	1,300	0.035
Carbon monoxide	8-hour	0.67	10,000	0.0065
	1-hour	4.1	40,000	0.010
PM_{10}	Annual	0.0071	50	0.014
	24-hour	0.053	150	0.035
Intermediate thermal load				
Nitrogen dioxide	Annual	0.13	100	0.13
Sulfur dioxide	Annual	0.013	80	0.016
	24-hour	0.093	365	0.025
	3-hour	0.74	1,300	0.057
Carbon monoxide	8-hour	1.1	10,000	0.011
	1-hour	6.6	40,000	0.017
PM_{10}	Annual	0.012	50	0.024
	24-hour	0.087	150	0.058
Low thermal load				
Nitrogen dioxide	Annual	0.12	100	0.12
Sulfur dioxide	Annual	0.011	80	0.015
	24-hour	0.082	365	0.022
	3-hour	0.66	1,300	0.050
Carbon monoxide	8-hour	0.98	10,000	0.0095
	1-hour	5.9	40,000	0.015
PM_{10}	Annual	0.010	50	0.020
	24-hour	0.076	150	0.051

a. Numbers are rounded to two significant figures.

b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

For Modules 1 and 2, the same technique was used, but the amount of fuel used during the closure phase would increase. The annual diesel fuel use during closure would be 1.9, 0.81, and 1.2 times that of the Proposed Action for the high, intermediate, and low thermal load scenarios, respectively, based on total fuel use (TRW 1999b, page 6-77). The annual diesel fuel use for closure of the North Portal facility would be the same as that for the Proposed Action for all thermal load scenarios. Estimated air quality impacts for surface equipment during the operation and monitoring phase under Modules 1 and 2 would increase by about 1.4, 0.87, and 1.1 times the Proposed Action for the high, intermediate, and low thermal load scenarios, respectively.

G.1.7 RETRIEVAL SCENARIO

This section describes the method used to estimate air quality impacts during possible retrieval at the proposed repository. The retrieval contingency includes the construction of a retrieval storage facility and storage pad, and retrieval of the waste. Retrieval would last 11 years (TRW 1999b, page 6-32), while construction of the retrieval storage facility and storage pads would last 10 years (TRW 1999a, page I-20). DOE would construct the storage facility before beginning retrieval activities. Storage pads would be constructed in modules concurrently with retrieval activities. The analysis considered concurrent air quality impacts of retrieval and construction. The retrieval scenario work schedule would be one 8-hour shift a day, 5 days a week, 50 weeks a year.

The analysis estimated air quality impacts by calculating pollutant concentrations from various activities associated with retrieval. Emission rates were developed for each activity that would result in releases of pollutants. These rates were multiplied by the unit release concentration (see Section G.1.3) to calculate pollutant concentrations for comparison to the various regulatory limits.

The principal sources of particulates would be fugitive dust emissions from construction activities associated with the waste retrieval facility. The principal source of nitrogen dioxide, sulfur dioxide, and carbon monoxide would be fuel combustion during the construction of the waste retrieval facility and during retrieval of the waste. The following sections describe these sources in more detail.

G.1.7.1 Fugitive Dust from Construction of Retrieval Storage Facility

Construction activities such as earth moving and truck traffic would produce fugitive dust during the construction of the retrieval storage facility and storage pad. The analysis used the same method to estimate fugitive dust releases during retrieval as that for construction (see Section G.1.4.1). The amount of land disturbed to build the retrieval storage facility and storage pad would be 1 square kilometer (250 acres) (TRW 1999a, Table I-2, page I-22). In addition, a 1.8-kilometer (1.1-mile) rail line (TRW 1999a, page I-16) would also be constructed. Assuming the rail line is 0.06 kilometer (0.04 mile) wide, the rail line would require an additional 0.11 square kilometer (27 acres) of land to be disturbed.

Table G-40 lists fugitive dust release rates from construction of the retrieval facility and storage pad. Table G-41 lists air quality impacts as pollutant concentration in air and percent of regulatory limit. Fugitive dust emissions from construction of the retrieval facility and storage pad would produce small offsite (outside the land withdrawal area) PM_{10} concentrations. Annual and 24-hour average concentrations of PM_{10} would be less than 1 percent for facility construction and about 2 percent for storage pad construction of the regulatory standards for all three thermal load scenarios.

Table G-40. Fugitive dust release rates from surface construction of retrieval storage facility and storage pad (PM_{10}).[a]

Period	Pollutant emission (kilograms)[b]	Emission rate (grams per second)[c]
Annual	25,000 per year	0.80
24-hour	100 per day	3.5[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on an 8-hour release period.

Table G-41. Fugitive dust (PM_{10}) air quality impacts from surface construction of the retrieval storage facility and storage pad (micrograms per cubic meter).

Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Annual	0.096	50	0.19
24-hour	0.67	150	0.44

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

G.1.7.2 Exhaust from Construction Equipment

Surface equipment would emit the four criteria pollutants during retrieval and during the construction of the retrieval storage facility and storage pad. The analysis used the same method to estimate pollutant release rates from fuel consumed by construction equipment during retrieval that was used for the construction phase (see Section G.1.4.5). During retrieval, fuel would be consumed at the South Portal

Operations Area; during the construction of the retrieval facility and storage pad, fuel would be consumed at the North Portal Operations Area. Table G-15 lists the pollutant release rates of the equipment that would consume the diesel fuel. The maximum amount of fuel used annually would be about 1.46 million liters (390,000 gallons) for surface construction (TRW 1999a, Table I-2, page I-22), about 1.7 million liters (460,000 gallons) for surface retrieval operations (TRW 1999a, Table I-3, page I-24), and about 27,000 liters (7,200 gallons) for subsurface retrieval operations (TRW 1999b, page 6-33). Total maximum annual usage would be about 1.9 million liters (500,000 gallons).

Table G-42 lists pollutant release rates for surface equipment during retrieval. Table G-43 lists the potential air quality impacts. Emissions from surface equipment during retrieval would produce small offsite criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards.

Table G-42. Pollutant release rates from surface equipment during the retrieval scenario.[a]

Pollutant	Period	Mass of pollutant per averaging time (kilograms)[b]	Emission rate[c] (grams per second)[d]
Nitrogen dioxide	Annual	75,000	2.4
Sulfur dioxide	Annual	7,100	0.22
	24-hour	28	0.98
	3-hour	11	0.98
Carbon monoxide	8-hour	110	4.0
	1-hour	14	4.0
PM_{10}	Annual	6,600	0.21
	24-hour	26	0.92

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release period for averaging periods of 24 hour or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-43. Air quality impacts from surface equipment during the retrieval scenario (micrograms per cubic meter of pollutant).

Pollutant	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Nitrogen dioxide	Annual	0.23	100	0.24
Sulfur dioxide	Annual	0.022	80	0.028
	24-hour	0.18	365	0.049
	3-hour	1.4	1,300	0.11
Carbon monoxide	8-hour	2.1	10,000	0.020
	1-hour	13	40,000	0.033
PM_{10}	Annual	0.021	50	0.042
	24-hour	0.17	150	0.11

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

G.2 Radiological Air Quality

This section describes the methods DOE used to analyze potential radiological impacts to air quality at the proposed Yucca Mountain Repository during the construction, operation and monitoring, and closure phases, and a possible retrieval scenario. The results are presented in Chapter 4, Section 4.1.2. It discusses the radioactive noble gas krypton-85, which would be released from surface facilities during the handling of spent nuclear fuel, and naturally occurring radon-222 and its radioactive decay products, which would be released from the rock to the subsurface facility and then to the ventilation air. The excavated rock pile would not be a notable additional source of radon-222, because the rock would not have enhanced concentrations of uranium or radium (the sources of radon-222) in comparison to surface rock. Somewhat higher concentrations of radon-222 could be present at the rock pile itself but, in general, concentrations of radon-222 released from the excavated rock pile would not differ greatly from naturally occurring surface concentrations of radon.

G.2.1 LOCATIONS OF HYPOTHETICALLY EXPOSED INDIVIDUALS AND POPULATIONS

Members of the public and noninvolved workers could be exposed to atmospheric releases of radionuclides from repository activities. Doses to the maximally exposed individual and population within 80 kilometers (50 miles) were evaluated for the public. The dose to the maximally exposed noninvolved worker and the noninvolved worker populations at the repository and at the Nevada Test Site were also evaluated.

Public

The location of the maximally exposed individual member of the public would be about 20 kilometers (12 miles) south of the repository at the land withdrawal area boundary. This was determined to be the location of unrestricted public access that would have the highest annual average concentration of airborne radionuclides (see Section G.2.2). The locations calculated for nonradiological air quality impacts (Section G.1.2) would be somewhat different because the analysis estimated exposure to nonradiological pollutants for acute (short-term) exposures (1 to 24 hours) and for annual (continuous) exposures.

Table G-44 lists the estimated population of about 28,000 within 80 kilometers (50 miles) of the repository. This is the predicted population for 2000, based on projected changes in the region, including the towns of Beatty, Pahrump, Indian Springs, and the surrounding rural areas. The population in the vicinity of Pahrump was included in Table G-44 and evaluated for air quality impacts, even though the

Table G-44. Projected year 2000 population distribution within 80 kilometers (50 miles) of repository site.[a,b,c]

	Distance (kilometers)										
Direction	8	16	24	32	40	48	56	64	72	80	Totals
S	0	0	16	238	430	123	0	10	0	0	*817*
SSW	0	0	0	315	38	0	0	7	0	0	*360*
SW	0	0	0	0	0	0	868	0	0	0	*868*
WSW	0	0	0	0	0	0	0	0	87	0	*87*
W	0	0	0	638	17	0	0	0	0	0	*655*
WNW	0	0	0	936	0	0	0	0	0	20	*956*
NW	0	0	0	28	2	0	0	0	33	0	*63*
NNW	0	0	0	0	0	0	0	0	0	0	*0*
N	0	0	0	0	0	0	0	0	0	0	*0*
NNE	0	0	0	0	0	0	0	0	0	0	*0*
NE	0	0	0	0	0	0	0	0	0	0	*0*
ENE	0	0	0	0	0	0	0	0	0	0	*0*
E	0	0	0	0	0	0	0	0	0	0	*0*
ESE	0	0	0	0	0	0	0	0	1,055	0	*1,055*
SE	0	0	0	0	3	0	13	0	0	206	*222*
SSE	0	0	0	0	23	172	6	17	6,117	16,399[d]	*22,734*
Grand Total											**27,817**

a. Source: 2000 population projected based on population data in TRW (1998, page 3-7).

b. To convert kilometers to miles, multiply by 0.62137.

c. There is a 4-kilometer (about 2.5-mile)-radius area around the North Portal, from which the analysis determined the 80-kilometer (50-mile) area.

d. Includes the Pahrump vicinity population, which extends beyond the 80-kilometer region.

population extends beyond the 80-kilometer region. The analysis calculated both annual population dose and cumulative dose for the project phases over more than 100 years of construction, operation and monitoring, and closure.

Noninvolved (Surface) Workers

The analysis assumed noninvolved workers on the surface would be at the site 2,000 hours a year (8 hours a day, 5 days a week, 50 weeks a year), or about 23 percent of the total number of hours in a year (8,760). All surface workers, regardless of work responsibility, were considered to be noninvolved workers for evaluation of exposure to radon-222 and radon decay products released from the subsurface facilities. For releases of noble gases (principally krypton-85) from spent fuel handling activities, potentially exposed noninvolved workers would be all surface workers except those in the Waste Handling and Waste Treatment Buildings. The noble gases would be released from the stack of the Waste Handling Building and workers in these facilities would not be exposed.

The maximally exposed noninvolved worker location would be in the South Portal Operations Area, where air from repository development activities would be exhausted. The analysis assumed that this worker would be in the office building about 100 meters (330 feet) northeast of the South Portal. This worker would be exposed to the annual average concentration of radon during the construction phase as radon concentrations increased with the increasing level of subsurface development. However, during operational activities, the radon level would remain approximately constant at the baseline concentration because the development area of the repository, ventilated and exhausted through the South Portal, would remain relatively constant. There would be no South Portal ventilation during monitoring activities and the closure phase, but the maximally exposed noninvolved worker would still be in the South Portal Operations Area.

The population and distribution of repository workers required to staff the North Portal Operations Area surface facilities would depend on the commercial spent nuclear fuel packaging scenario. As shown in Table G-45, the uncanistered packaging scenario would have the highest labor requirements for all project

Table G-45. Noninvolved (surface) worker population distribution for Yucca Mountain activities.[a]

	Packaging scenario		
Worker location	Uncanistered	Disposable canister	Dual-purpose canister
Construction			
North Portal	656	457	485
South Portal	70	70	70
Operation and monitoring			
Emplacement and development	781[b]	630[b]	636[b]
North Portal	1,277	962	982
South Portal	70	70	70
Monitoring and maintenance			
North Portal – decommissioning	1,354	982	1,023
North Portal – monitoring and maintenance	35	35	35
South Portal	6	6	6
Closure			
North Portal	363	256	275
South Portal	6	6	6
Retrieval			
North Portal – construction	780	780	780
North Portal – operations	108	108	108
South Portal	70	70	70

a. Sources: North Portal: TRW (1999a, pages 74, 75, and 79 to 81); South Portal: TRW (1999b, page 4-85).

b. Total workers exposed to krypton-85 releases from surface facilities. Does not include Waste Handling Building or Waste Treatment Building workers; does include 70 workers at the South Portal.

phases and activities in comparison to the disposable canister and dual-purpose canister scenarios. The number of North Portal workers would not vary for different thermal load scenarios. The estimated population of workers in the South Portal Operations Area was based on the number of full-time equivalents. This includes many workers who would be on the surface for only a portion of a day, as they prepared for underground work in the surface operations area. The number of South Portal workers was also assumed to remain constant for all thermal load scenarios.

Also evaluated as a potentially exposed noninvolved worker population were DOE workers at the Nevada Test Site. The analysis used a Nevada Test Site worker population of 6,576 workers (DOE 1996, Volume I, Appendix A, page A-69). For purposes of analysis, all these workers were assumed to be about 50 kilometers (30 miles) east-southeast of the repository at Mercury, Nevada.

G.2.2 METEOROLOGICAL DATA AND ATMOSPHERIC DISPERSION FACTORS

The basis for the atmospheric dispersion factors used in the dose calculations was a joint frequency distribution file for 1993 to 1997. These data were based on site-specific meteorological measurements made at air quality and meteorology monitoring Site 1, combined for 1993 to 1997 (TRW 1999c, page 11). Site 1 is about 1 kilometer (0.6 mile) south of the proposed North Portal surface facility location. Similar topographic exposure would lead to similar prevailing northerly and southerly winds at both locations. DOE used these data because an analysis of the data collected at all the sites showed Site 1 to be most representative of the surface facilities (TRW 1999c, page 7). The joint frequency data are somewhat different from the more detailed meteorological data used for the nonradiological air quality analysis. The dose calculations required only annual average data because they compare doses to annual limits, whereas criteria pollutant limits have 1-, 3-, 8-, or 24-hour averaging periods and the calculation of short-term criteria pollutant concentrations required hourly meteorological data. The nonradiological analysis also calculated concentrations only at the land withdrawal area boundary, not at onsite locations where workers would be.

Depending on the project phase and level of activity, subsurface ventilation air could be exhausted from any or all of three locations: the South Portal, emplacement (exhaust) shaft 1 or emplacement (exhaust) shaft 2. Both of these exhaust shafts would be on the ridge above the repository. Table G-46 lists the distribution of exhaust ventilation air among the three subsurface release points for project phases and activities. These distributions were used to calculate annual average atmospheric dispersion factors for radon releases from the subsurface.

The GENII software system (Napier et al. 1997, all) was used to calculate annual average atmospheric dispersion factors for radon released from the subsurface exhaust points and for noble gases released from the Waste Handling Building stack. The releases from the South Portal would be at ground level, while releases from the two emplacement shafts (ES-1 and ES-2) on the ridge above the repository were modeled as 60-meter (200-foot) releases. Noble gas releases from the Waste Handling Building would be from a 60-meter (200-foot) stack, also modeled as an elevated release. The population distribution data in Tables G-44 and G-45 were used to calculate population-weighted dispersion factors for public and noninvolved worker populations, which were then used to calculate collective doses. Table G-47 lists the individual and population-weighted atmospheric dispersion factors for the radon and krypton-85 release points at the site. These values do not incorporate the release distribution data in Table G-46. The radon dispersion factors would vary slightly among some combinations of project phase and thermal load scenarios because of the slight differences in release point contributions noted in Table G-46. Krypton-85 dispersion factors would not be affected.

Table G-46. Distribution (percent) of repository subsurface exhaust ventilation air.[a]

Project phase and activity	Thermal load scenario	South Portal	Emplacement (exhaust) shaft 1	Emplacement (exhaust) shaft 2
Proposed Action				
Construction	All	100		
Operation and monitoring				
Development and emplacement	High	47	53	
	Intermediate	47	53	
	Low	55	42	3
Monitoring and maintenance	All		100	
Closure	Same exhaust distribution as monitoring and maintenance			
Retrieval scenario	Same exhaust distribution as monitoring and maintenance			
Inventory Modules 1 and 2				
Construction	All	100		
Operation and monitoring				
Development and emplacement	High	46	54	
	Intermediate	39	61	
	Low	42	40	18
Monitoring and maintenance	High		100	
	Intermediate		100	
	Low		50	50
Closure	Same exhaust distribution as monitoring and maintenance			

a. Source: Rasmussen (1998, all); TRW (1999b, pages 4-33 to 4-48).

G.2.3 RADIOLOGICAL SOURCE TERMS

There would be two distinctly different types and sources of radionuclides released to the air from activities at the repository. Naturally occurring radon-222 and its radioactive decay products would be released from the subsurface facility during all phases as the repository ventilation system removed airborne particulates from development operations and exhausted air heated by the emplaced materials. Radioactive noble gases would be released from commercial spent nuclear fuel during handling and transfer operations in the surface facilities during the operation and monitoring phase. Section G.2.3.1 discusses the releases of radon-222 and radon decay products. Section G.2.3.2 discusses the releases of radioactive noble gases from commercial spent nuclear fuel.

G.2.3.1 Release of Radon-222 and Radon Decay Products from the Subsurface Facility

In the subsurface facility the noble gas radon-222 would diffuse continually from the rock into the air of the repository drifts. Radioactive decay of the radon in the air of the drift would produce radon decay products, which would begin to come into equilibrium (having the same activity) with the radon-222 because their radioactive half-lives are much shorter than the 3.8-day half-life of radon-222. Key radionuclide members of the radon-222 decay chain are polonium-218 (sometimes known as radium A) and polonium-214 (radium C′), with half-lives of 3.05 minutes and 164 microseconds, respectively. Exhaust ventilation would carry the radon-222 and the radon decay products from the repository.

The estimates of radon-222 and radon decay product releases were based on concentration observations made in the Exploratory Studies Facility subsurface areas during site characterization. Because the repository would encompass the subsurface areas of the Exploratory Studies Facility, the analysis assumed that these observations would be a reasonable baseline. Concentrations at the 7,350-meter (4.6-mile) measuring station in the South Ramp ranged from 0.65 to 163 picocuries per liter with the ventilation system operating (TRW 1999c, electronic file attachment 7350EBF.XLS). The measured 50th-percentile concentration was 24 picocuries per liter, with 5th- and 95th-percentile concentrations of 1.7 and 124 picocuries per liter, respectively. Because the distribution of these concentration data was

Table G-47. Atmospheric dispersion factors for potentially exposed individuals and populations from releases at the repository site.[a]

Release location[b]	Release type[c]	Receptor type	Receptor location	Dispersion factor[d]
Radon releases[e]				
Public				
South Portal	G	individual	20 km[f] south	2.2×10^{-8}
South Portal	G	population	80 km radius	1.2×10^{-4}
Emplacement shafts 1, 2[g]	E	individual	20 km south	6.0×10^{-9}
Emplacement shafts 1, 2[g]	E	population	80 km radius	3.0×10^{-5}
Noninvolved workers				
South Portal	G	individual	100 meters[h] northeast	6.2×10^{-5}
South Portal	G	population	South Portal Operations Area	3.2×10^{-3}
South Portal	G	individual	North Portal 2.8 km north-northeast[j]	1.9×10^{-7}
South Portal	G	individual	Nevada Test Site, 50 km east-southeast[j]	6.9×10^{-10}
Emplacement shaft 1	E	individual	North Portal 4.2 km southeast	9.0×10^{-9}
Emplacement shaft 1	E	individual	South Portal 6.3 km south-southeast	2.0×10^{-8}
Emplacement shaft 2	E	individual	North Portal, 4.5 km east-southeast	4.9×10^{-9}
Emplacement shaft 2	E	individual	South Portal, 5.3 km southeast	6.7×10^{-9}
Emplacement shafts 1, 2[g]	E	individual	Nevada Test Site, 50 km east-southeast	2.7×10^{-10}
Krypton-85 releases				
Public				
Waste Handling Bldg. stack	E	individual	20 km south	6.0×10^{-9}
Waste Handling Bldg. stack	E	population	80 km radius	3.0×10^{-5}
Noninvolved workers				
Waste Handling Bldg. stack	E	individual	North Portal, 0.4 km north-northwest	1.5×10^{-6}
Waste Handling Bldg. stack	E	individual	South Portal, 2.8 km south-southwest	5.4×10^{-8}
Waste Handling Bldg. stack	E	population	Uncanistered packaging scenario	2.4×10^{-4}
Waste Handling Bldg. stack	E	population	Disposable canister packaging scenario	1.9×10^{-4}
Waste Handling Bldg. stack	E	population	Dual-purpose canister packaging scenario	1.9×10^{-4}
Waste Handling Bldg. stack	E	individual	Nevada Test Site, 50 km east-southeast[i]	2.7×10^{-10}

a. Numbers are rounded to two significant figures.
b. Source: Radon releases: TRW (1999b, pages 4-33 to 4-48); krypton-85 releases: TRW (1999a, page 41).
c. G = ground level; E = elevated.
d. Dispersion factor units are seconds per cubic meter for individuals, and person-seconds per cubic meter for populations.
e. Radon includes radon-222 and its radioactive decay products.
f. To convert kilometers to miles, multiply by 0.62137.
g. Difference in dispersion between the two emplacement shafts is small for this application.
h. To convert meters to feet, multiply by 3.2808.
i. The population dose was calculated at this point by multiplying the individual dispersion factor times population size.

highly skewed, the analysis assumed that the 50th-percentile value was most representative of the entire concentration range.

Exhaust ventilation flowrates in the South Ramp when the radon concentration measurements were made measured from about 100 to 125 cubic meters per second (214,000 to 265,000 cubic feet per minute) (TRW 1999c, electronic file attachment DECRPT.XLS). A value of 110 cubic meters per second (230,000 cubic feet per minute) was used as a representative South Ramp flowrate. This information, combined with an Exploratory Studies Facility excavated volume of 360,000 cubic meters (470,000 cubic yards) (TRW 1999b, page 4-27), yielded a calculated repository air exchange rate of about 1 per 3,300 seconds (about one exchange per hour) and a baseline for radon-222 releases. The exchange rate is the excavated volume (in cubic meters) divided by the ventilation flowrate (in cubic meters per second). The analysis assumed these conditions would be representative for the Exploratory Studies Facility through the beginning of the construction phase. The estimated release of radon-222 and radon decay products for this configuration would be about 80 curies per year.

Table G-48 lists the key input parameters, namely the beginning and ending excavated repository volumes, repository average ventilation rates, and repository average air exchange rates, for each of the phases and thermal load scenarios of the Proposed Action. The analysis assumed that increases in excavated repository volume and ventilation flowrate would occur linearly. In addition, Table G-48 lists the estimated releases of radon-222 and radon decay products annually and by phase.

Table G-48. Estimated radon-222 releases for repository activities for the Proposed Action inventory.[a]

Period and thermal load	Repository volume (millions of cubic meters)[b,c]		Average ventilation rate (cubic meters per second)	Average air exchange rate	Annual average radon[d] release (curies)	Total radon[d] release (curies)
	Beginning	Ending				
Construction (5 years)						
High	0.36	1.9	205	6,200	300	1,500
Intermediate	0.36	2.2	205	7,200	340	1,700
Low	0.36	2.2	205	7,200	340	1,700
Operations (24 years)						
High	1.9	4.7	570	6,700	880	21,000
Intermediate	2.2	5.7	570	7,900	1,000	25,000
Low	2.2	14	680	13,000	1,900	46,000
Monitoring (76 years)						
High	4.7	4.7	190	24,000	1,100	83,000
Intermediate	5.7	5.7	190	29,000	1,300	99,000
Low	14	14	490	28,000	3,200	240,000
Total Operation and Monitoring Phase (100 years)						
High					1,000	100,000
Intermediate					1,200	120,000
Low					2,900	290,000
Closure phase (6, 6, and 15 years)						
High	4.7	4.7	190	24,000	1,100	6,600
Intermediate	5.7	5.7	190	29,000	1,300	7,900
Low	14	14	490	28,000	3,200	48,000
Total, all phases (111, 111, 120 years)						
High						110,000
Intermediate						130,000
Low						340,000
Retrieval scenario (14 years)						
High	4.7	4.7	190	24,000	1,100	14,000

a. Numbers are rounded to two significant figures; totals might not equal sums of values due to rounding.
b. Source: TRW (1999b, pages 4-27, 6-6, and 6-16).
c. To convert cubic meters to cubic yards, multiply by 1.3079.
d. Includes radon-222 and radon decay products.

Construction Phase

During the 5 years of construction, 1.5 million cubic meters (1.96 million cubic yards) of rock would be removed for the high thermal load scenario and 1.9 million cubic meters (2.4 million cubic yards) for the intermediate and low thermal load scenarios (TRW 1999b, page 6-6). During the same period, the ventilation flow would increase from 110 cubic meters per second (230,000 cubic feet per minute) to 270 cubic meters per second (570,000 cubic feet per minute) (TRW 1999b, pages 4-33 to 4-38). Releases of radon-222 would be low but would vary within 15 percent among all three thermal load scenarios, because they would have the same ventilation flow rates but different repository volumes.

Operation and Monitoring Phase

Operation Activities. Development activities would last 22 years during operation and monitoring. During this period about 2.9 million, 3.4 million, and 11.8 million cubic meters (3.8 million, 4.5 million, and 15.4 million cubic yards) of rock would be removed for the high, intermediate, and thermal load scenarios, respectively (TRW 1999b, page 6-16). The repository excavation would be complete during the last two years of the operation activity period, as emplacement activities continued. The flowrate for the repository during emplacement and development activities of the high and intermediate thermal load scenarios would be the maximum development side flowrate [270 cubic meters per second (570,000 cubic feet per minute)], and the maximum emplacement side flowrate [300 cubic meters per second (640,000 cubic feet per minute)] (TRW 1999b, pages 4-33 to 4-38). The flowrate during the low thermal load scenario would vary from 570 to 740 cubic meters per second (1.2 million to 1.6 million cubic feet per minute), depending on the stage of emplacement activities.

The estimation of radon releases for the high and intermediate thermal load scenarios was based on development and emplacement activities taking place only in the upper (primary) block. However, for the low thermal load scenario development and emplacement would be incremental, beginning in the upper block, moving on to the lower block, and finally to the Area 5 block (TRW 1999b, page 3-3). When emplacement in a block was complete, that block would enter an interim period of monitoring and maintenance as activities continued in the other blocks. The analysis assumed that the upper block would be in this interim status for 10 years and the lower block for 5 years.

The high and intermediate thermal load scenarios would have the lowest radon releases because they would use only the upper (primary) block. The low thermal load scenario would have a higher radon release because of the greater repository volume, which would require three blocks, and the added contribution from exhaust ventilation during the interim monitoring and maintenance of the upper and lower blocks.

Monitoring Activities. No excavation would take place during monitoring, and the exhaust flowrate would remain constant. The much greater repository volume for the low thermal load scenario, which would require larger exhaust flowrates, would result in larger releases of radon-222 and radon decay products to the atmosphere through the exhaust ventilation.

Monitoring and maintenance activities would last from 26 to 276 years. Total releases of radon over 26 years would be approximately 29,000, 34,000, and 84,000 curies for the high, intermediate, and low thermal load scenarios, respectively. Total releases of radon over 276 years would be approximately 300,000, 360,000, and 890,000 curies for the high, intermediate, and low thermal load scenarios, respectively. The estimated annual radon release and concentration would be the same as those listed for monitoring in Table G-48.

For 100 years of operation and monitoring, the low thermal load scenario would involve approximately 2.5 times more radon release than the high or intermediate thermal load scenario. About 70 to 75 percent of the radon would be released during the monitoring and maintenance period for all three thermal load scenarios, not including the interim monitoring and maintenance for the low thermal load scenario.

Closure Phase

Annual releases of radon-222 and radon decay products during the closure phase would be the same as for the monitoring period. Differences in the lengths of the closure phases for the three thermal load scenarios would lead to differences in the total amount of radon released. Differences among the thermal load scenarios would be for the same reasons as for the monitoring period, namely the larger repository volume and exhaust ventilation flowrate of the low thermal load scenario.

Retrieval

Only the high thermal load scenario was evaluated for a postulated retrieval scenario. Annual releases of radon-222 and radon decay products would be the same as for the monitoring activities and closure phases. Releases were estimated for 13 years, including 2 years of retrieval-related construction activities plus 11 years of retrieval operations.

Inventory Modules 1 and 2

Releases of radon-222 and radon decay products for Inventory Modules 1 and 2 were estimated using the same methods as for the Proposed Action. The major differences would be the larger repository volumes and higher ventilation flowrates, which would result in larger releases of radon. In addition, 38 years would be required to complete operations (which includes 36 years of development), 62 years would be required for monitoring, and the closure phase would be longer. Table G-49 lists the estimates of radon release and key parameter values. Releases of radon would be higher for the inventory modules than for the Proposed Action in all cases.

Table G-49. Estimated radon-222 releases for repository activities for Inventory Modules 1 or 2.[a]

Thermal load	Repository volume (millions of cubic meters)[b,c]		Average ventilation rate (cubic meters per second)	Average air exchange rate(s)	Annual average radon release (curies)	Total radon release (curies)
	Beginning	Ending				
Construction (5 years)						
High	0.36	2.1	205	6,900	330	1,600
Intermediate	0.36	2.1	205	6,900	330	1,600
Low	0.36	2.1	205	6,900	330	1,600
Operations (38 years)						
High	2.1	8.7	590	9,500	1,300	49,000
Intermediate	2.1	9.0	690	8,200	1,300	51,000
Low	2.1	24	800	16,000	3,100	120,000
Monitoring (62 years)						
High	8.7	8.7	300	29,000	2,000	125,000
Intermediate	9.0	9.0	490	18,000	2,100	130,000
Low	24	24	890	27,000	5,500	340,000
Total operation and monitoring phase (100 years)						
High					1,700	170,000
Intermediate					1,800	180,000
Low					4,600	460,000
Closure (13, 17, and 27 years)						
High	8.7	8.7	300	29,000	2,000	26,000
Intermediate	9.0	9.0	490	18,000	2,100	35,000
Low	24	24	890	27,000	5,500	150,000
Totals (118, 122, and 132 years)						
High						200,000
Intermediate						220,000
Low						610,000

a. Numbers are rounded to two significant figures; totals might not equal sums of values due to rounding.
b. Source: TRW (1999b, pages 4-27, 6-47, and 6-55).
c. To convert cubic meters to cubic yards, multiply by 1.3079.

G.2.3.2 Release of Radioactive Noble Gases from the Surface Facility

The unloading and handling of commercial spent nuclear fuel would produce the only routine emissions of manmade radioactive materials from repository facilities. No releases would occur as a result of emplacement activities. Shipping casks containing uncanistered spent nuclear fuel in dual-purpose canisters would be opened in the transfer pool of the Waste Handling Building at the North Portal Operations Area. Shipping casks containing spent nuclear fuel in disposable canisters would be opened in a dry transfer cell. During spent fuel handling and transfer, radionuclides could be released from a small percentage of fuel elements with pinhole leaks in the fuel cladding; only noble gases would escape the pool and enter the ventilation system of the Waste Handling Building (TRW 1999a, page 17). The largest release of radionuclides from surface facilities would be krypton-85, with about 2,600 curies released annually from the uncanistered and dual-purpose canister packaging options. Krypton-85 would also be the major dose contributor from the airborne pathway. Releases of other noble gas radionuclides would be very small, with estimated annual releases of about 0.0000010 curie of krypton-81, 0.000033 curie of radon-219, 0.014 curie of radon-220, 0.0000046 curie of radon-222, and small quantities of xenon-127 (TRW 1999a, page 75). The same annual releases would occur for both the Proposed Action and for the inventory modules. Table G-50 lists estimated annual average releases of krypton-85 from fuel handling by packaging option. All spent nuclear fuel and DOE high-level radioactive waste in disposable canisters would be transferred from shipping casks to disposal containers inside shielded rooms (hot cells) in the Waste Handling Building. Because all DOE material would be in disposable canisters under all packaging scenarios, no radionuclide releases from these materials would occur.

Table G-50. Krypton-85 releases (curies) from surface facility handling activities for commercial spent nuclear fuel during the operation and monitoring phase. [a]

Packaging option	Annual release[b]	Proposed Action (24 years)	Inventory Module 1 or 2 (38 years)
Uncanistered	2,600	61,000	97,000
Disposable canister	90	2,200	3,500
Dual-purpose canister	2,600	62,000	98,000

a. Numbers are rounded to two significant figures.
b. Source: TRW (1999a, page 75).

Releases from the surface facility would be the same for the three thermal load scenarios. These releases were based on the following assumptions for commercial spent nuclear fuel (TRW 1999a, pages 18 and 19):

- Pressurized-water reactor burnup of about 40 gigawatt-days per metric ton of uranium with 3.6-percent enrichment and an average of 26 years decay
- Boiling-water reactor burnup of 32 gigawatt-days per metric ton of uranium with 3.0-percent enrichment and an average of 27 years decay
- A failure rate of 0.25 percent for fuel assemblies in the canisters, allowing gaseous radionuclides (isotopes of krypton, radon, and xenon) to escape
- Radionuclides other than noble gases (such as cobalt-60, cesium-137, and strontium-90) would not escape the transfer pool if released from fuel assemblies

G.2.4 DOSE CALCULATION METHODOLOGY

The previous three sections provided information on the location and distribution of potentially affected individuals and populations (Section G.2.1), atmospheric dispersion (Section G.2.2), and the type and quantity of radionuclides released to air (Section G.2.3) in the Yucca Mountain region. The analysis used these three types of information to estimate the radionuclide concentration in air (in picocuries of radionuclide per liter of air) at a specific location or for an area where there would be a potentially exposed population. The estimation of the radiation dose to exposed individuals or populations from concentrations of radionuclides in air used this information and published or derived dose factors. This section describes the concentration-to-dose conversion factors that the analysis used to estimate radiation dose to members of the public and noninvolved workers from releases of radionuclides at the repository.

G.2.4.1 Dose to the Public

The analysis estimated doses to members of the public using screening dose factors from the National Council on Radiation Protection and Measurements (NCRP 1996, Volume I, pages 113 and 125). The analysis considered all exposure pathways, including inhalation, ingestion, and direct external radiation from radionuclides in the air and on the ground. For noble gases such as krypton-85, only direct external exposure from the radionuclides in the air would be a contributing pathway. For radon-222, the short-lived decay products would account for essentially all of the dose. The screening dose factors indicate that direct external radiation from radionuclides deposited on the ground would account for about 40 percent of the dose; ingestion of these decay products in foodstuffs and inadvertently consumed soil would account for about 60 percent, based on the published screening dose factors. Inhalation and external irradiation from radionuclides in the air would be minor exposure pathways. The analysis calculated the estimated dose from a specific radionuclide by multiplying the radionuclide-specific dose factor by the estimated air concentration at the exposure location. The results are reported in Chapter 4, Section 4.1.2. Table G-51 lists the screening dose factors for krypton-85 and radon-222 for members of the public. Results are presented in Chapter 4, Section 4.1.2.

Table G-51. Factors for estimating dose to the public and noninvolved workers per concentration of radionuclide in air (millirem per picocurie per liter per hour) for krypton-85 and radon-222.[a,b]

Radionuclide	Public[c]	Noninvolved worker
Krypton-85	0.0000013	0.0000013
Radon-222	0.25[d]	0.029[e]

a. Numbers are rounded to two significant figures.
b. Dose factors for radon-222 include dose contribution from decay products.
c. Source: NCRP (1996, page 61); assumed an exposure time of 8,000 hours per year.
d. Includes all exposure pathways.
e. Source: ICRP (1994, pages 5 and 24); 100 percent equilibrium between radon and decay products; inhalation pathway only.

G.2.4.2 Dose to Noninvolved Workers

The analysis used a National Council on Radiation Protection and Measurements screening dose factor to calculate doses to noninvolved workers from krypton-85 because the exposure pathway is simple (air submersion only) and is the same as for members of the public. Table G-51 also lists this factor. However, the analysis did not use a National Council on Radiation Protection and Measurements screening dose factor to estimate the dose to noninvolved workers from radon-222 and its decay products. The parameters and exposure scenarios used to derive the National Council on Radiation Protection and Measurements screening dose factors for radon-222 and its decay products would not be appropriate for the potential exposure scenario for noninvolved workers at the Yucca Mountain site. Dose to noninvolved workers on the surface would be due mainly to inhalation of the radon decay products, and not from the other exposure pathways noted above for the public. Therefore, the analysis developed a Yucca Mountain repository-specific exposure scenario using site-specific parameters where appropriate. The dose conversion factor is from Publication 65 of the International Commission on Radiological Protection (ICRP 1994, page 24). This dose factor, which is 0.5 rem per working level month for inhalation of radon decay products by workers, corresponds to 0.029 millirem per picocurie per liter per hour, with radon decay products in 100 percent equilibrium (equilibrium factor of 1.0) with the radon-222 parent (ICRP 1994, page 5).

In estimating dose from radon and radon decay products released from the subsurface facility, the analysis assumed the maximally exposed noninvolved worker would be in an office about 100 meters (330 feet) northeast of the South Portal. For the construction phase and development activities, the noninvolved worker exposure analysis used the distribution of radon concentration measurements made at the 7,350-meter (4.6-mile) station in the South Ramp of the Exploratory Studies Facility. These were the best available data for estimating releases of radon from the facility (TRW 1999c, page 12). There would be no releases from the South Portal during the other project phases. Measured concentrations ranged from 0.65 to 163 picocuries per liter, with a median value of 24 picocuries per liter, as noted in Section G.2.3.1. In addition, the analysis considered the distribution of the measured values of the equilibrium fraction between radon-222 and the decay products. This value ranged from 0.0022 to 0.44, with a median of 0.14 (TRW 1999c, electronic file attachment RNFBF.XLS). The annual average atmospheric dispersion factor from the South Portal to the office building would be approximately 6.2×10^{-5} seconds per cubic meter for both the construction phase and development activities (Table G-47), although differences in exhaust flowrate (205 and 269 cubic meters per second, respectively, would result in minor differences in dispersion. The analysis assumed the maximally noninvolved worker would be exposed from 1,600 to 2,000 hours per year.

The estimated median dose to a maximally exposed noninvolved worker during the construction phase would be approximately 5 (4.7 to 5.4) millirem per year. The dose from the Proposed Action intermediate and low thermal load scenarios would be somewhat higher than that from the high thermal load scenario because of the larger average repository volume for these two scenarios during the construction phase (Table G-48). The estimated 5th-percentile dose would be about 0.2 millirem per year for both cases and the 95th-percentile dose would be 42 and 48 millirem per year, respectively. The dose during development activities would be the same for all three thermal load scenarios, with a median dose of about 3.4 millirem per year. The estimated 5th-percentile dose would be about 0.2 millirem per year and the 95th-percentile dose about 29 millirem per year. These estimates were made using a Monte Carlo uncertainty analysis. There would be a small contribution from external radiation, but the analysis did not consider it because it would be indistinguishable from normal external background radiation. The estimated dose from Module 1 or 2 would be about the same as those for the intermediate and low thermal load scenarios.

During the construction phase the maximally exposed noninvolved worker would receive a somewhat larger potential dose because of a larger average repository volume, which would be exhausted through the South Portal, and additional radon release. During operations the ventilation systems for the subsurface development and emplacement areas would be separate. The analysis assumed that the volume during Exploratory Studies Facility operations would represent the volume of the development side exhausted through the South Portal. This volume is somewhat smaller than the estimated average construction phase repository volume.

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Appendix H

Potential Repository Accident Scenarios: Analytical Methods and Results

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APPENDIX H. POTENTIAL REPOSITORY ACCIDENT SCENARIOS: ANALYTICAL METHODS AND RESULTS

This appendix describes the methods and detailed results of the analysis the U.S. Department of Energy (DOE) performed for the Yucca Mountain Repository Environmental Impact Statement (EIS) to assess radiological impacts from potential accident scenarios at the proposed repository. The methods apply to repository accidents that could occur during preclosure only, including operation and monitoring, retrieval, and closure. In addition, this appendix describes the details of calculations for specific accidents that the analysis determined to be credible. Appendix J describes the analytical methods and results for accidents that could occur at the 72 commercial and 5 DOE sites and during transportation to the proposed repository.

The accident scenarios in this analysis, and the estimated impacts, are based on current information from the repository design (TRW 1999a, all). The results are based on assumptions and analyses that were selected to ensure that the impacts from accident scenarios are not likely to be underestimated. DOE has not developed the final design and operational details for the repository, and these details could result in lower impacts. The Department is currently engaged in preliminary efforts to identify accidents and evaluate their impacts as required to support the License Application for the repository that it will send to the Nuclear Regulatory Commission, and to show that the repository would comply with appropriate limits on radiation exposure to workers and the public from accidental releases of radionuclides. The final design could include additional systems and operational requirements to reduce the probability of accidents and to mitigate the release of radionuclides to ensure compliance with these safety requirements. The results from the accident analysis to meet licensing requirements would be more specific and comprehensive than those discussed in this appendix and would reflect final repository design and operational details.

H.1 General Methodology

Because of the large amount of radioactive material to be handled at the proposed repository (see Appendix A), the focus of the analysis was on accident scenarios that could cause the release of radioactive material to the environment. The methodology employed to estimate the impact of accidents involving radioactive material included (1) evaluation of previous accident analyses performed for the repository, (2) identification of bounding accidents (reasonably foreseeable accidents with the maximum consequences) from the previous analyses, (3) identification of other credible accidents the previous analyses did not evaluate, (4) analyses of the selected accidents to determine the amount of radioactive material an accident could release to the environment, and (5) estimation of the consequences of the release of radioactive material in terms of health effects to workers and the public.

The analysis approach involved identifying bounding accidents (that is, accidents with maximum consequences) for each operational phase of the proposed repository. The analysis evaluated the impacts for these accidents, assuming the accident occurred without regard to the estimated probability. Thus, the analysis provides the impacts that could occur for the worst credible accidents. The results do not represent risk estimates because the impacts do not include a consideration of accident probability, which in most cases is very low. The risk from all repository accidents would be likely to be far less than the low risk, which DOE estimated by assuming that all of the bounding (maximum consequence) accidents would occur.

Accident frequency estimates were derived to establish the credibility of accident sequences and were not used to establish risk. Estimates of accident frequency are very uncertain due to the preliminary nature of the currently available repository design information and would be more fully evaluated in the safety analysis required to support a License Application for the repository. Based on the available design information, the accident analysis approach was used to ensure that impacts from accidents are not likely to be underestimated (whether they are low-probability with high-consequence accidents or high-probability with low-consequence accidents).

For accidents not involving radioactive materials, the analysis determined that application of accident statistics from other DOE operations provided a reasonable estimate of nonradiological accident impacts (see Section H.2.2).

H.2 Potential Repository Accident Scenarios

The proposed Yucca Mountain Repository has been the subject of intense evaluations for a number of years. Some of these evaluations included in-depth considerations of preclosure accidents that could occur during repository operations. The EIS used these previous evaluations, to the extent they are applicable and valid, to aid in the identification of initiating events, develop sequences, and estimate consequences. The EIS groups accidents as radiological accidents (Section H.2.1) that involve the unplanned release of radioactive material, and nonradiological accidents that involve toxic and hazardous materials (Section H.2.2).

H.2.1 RADIOLOGICAL ACCIDENT SCENARIOS

Previous analyses that considered impacts of radiological accidents during preclosure included evaluations by Sandia National Laboratories and others (Jackson et al. 1984, all; SNL 1987, all; Ma et al. 1992, all; BMI 1984, all), and include more recent evaluations (DOE 1996a,b, all; DOE 1997a,b all; Kappes 1998, all; TRW 1997a, all). These evaluations were reviewed to assist in this assessment of radiological impacts from accidents during repository operations. In addition, EISs that included accident evaluations involving spent nuclear fuel and high-level radioactive waste were reviewed and used as applicable (USN 1996, all; DOE 1995, all).

Radiological accidents involve an initiating event that can lead to a release of radioactive material to the environment. The analysis considered accidents separately for two types of initiating events: (1) internal initiating events that would originate in the repository and involve equipment failures or human errors, or a combination of both, and (2) external initiating events that would originate outside the facility and affect the ability of the facility to maintain confinement of radioactive or hazardous material. The analysis examined a spectrum of accidents, from high-probability/low-consequence accidents to low-probability/ higher-consequence accidents.

H.2.1.1 Internal Events – Waste Handling Building

The most recent and comprehensive repository accident scenario analysis for internal events in the Waste Handling Building is presented in Kappes (1998, all). This analysis considered the other important applicable accidents that previous analyses identified. It performed an in-depth evaluation of all operations planned for the repository and identified bounding accidents (those with the highest estimated risk) for each operation. More than 150 accidents were selected for analysis in eight operational categories. The accidents were identified based on multiple sources, including the *Preliminary MGDS Hazards Analysis* (DOE 1996b, all), current facility design drawings, and discussions with design personnel. These 150 accidents were reduced to 16 bounding accidents by retaining accidents that would produce the highest doses for groups of similar events (Kappes 1998, page 35). DOE used event trees and fault tree evaluation to estimate frequencies for the accidents. A review of these evaluations indicated that they were valid for use in the EIS with a few exceptions (noted below).

The evaluation used to identify internal accidents did not evaluate criticality events quantitatively (Kappes 1998, page 34). Continuing evaluations are under way to assess the probability and consequences of a criticality event. The risk from criticality events, however, would be unlikely to exceed the risk from the bounding events considered below. This preliminary conclusion is based on several factors:

RISK

Risk is defined as the possibility of suffering harm. It considers both the frequency (or probability) and consequences of an accident. In the scientific community, risk is usually defined and computed as the product of the frequency of an accident and the consequences that result. This is the definition of risk used in this analysis.

Rather than develop a single, overall expression of the risks associated with proposed actions, DOE usually finds it more informative in its EIS accident scenario analyses to consider a spectrum of accidents from low-probability, relatively high-consequence accidents to high-probability, low-consequence accidents. Nevertheless, risk is a valuable concept to apply in evaluating the spectrum of accident scenarios to ensure that accidents that are expected to dominate risk have been adequately considered.

- The probability of a criticality event would be very low. This is based on the Nuclear Regulatory Commission design requirement (10 CFR Part 60) that specifies that two independent low-probability events must occur for criticality to be possible and that this requirement will be part of the licensing basis for the repository. On the basis of this requirement, the event is unlikely to be credible (Jackson et al. 1984, page 18). Further, a criticality event would require the assembly of fuel with sufficient fissionable material to sustain a criticality. Since the commercial spent-nuclear fuel to be handled at the repository is spent (that is, it has been used to produce power), the remaining fissionable material is limited. For the pressurized-water reactor fuel, the amount of fuel that contains sufficient fissionable material to achieve criticality is only a small percent spent nuclear fuel (DOE 1998a, page C-46). This material would have to be assembled in sufficient quantity to achieve criticality, and the moderator (water) would somehow have to be added to the assembled material. A quantitative estimate of criticality frequency is planned as part of the license application (Kappes 1998, page 34).

- The criticality event that could occur despite the preventive measures described above would be unlikely to compromise the confinement function of the ventilation and filtration system of the Waste Handling Building. These features would inhibit the release of particulate radionuclides. By contrast, the seismic event scenario (discussed in Section H.2.1.3) assumes failure of these mitigating features.

- Criticality could occur only if the material was moderated with water and had sufficient fissionable material in a configuration that could allow criticality. The water surrounding the material would act to inhibit the release of particulate material (DOE 1994, Volume 1, Appendix D, page F-85) and, thus, would limit the source term.

- During the monitoring and closure phase of operations, water needs to enter a waste package that contains fuel with sufficient fissionable material to go critical. Water would have to flood a drift and leak into a defective waste package to cause a criticality. Such an event is considered not credible due to the lack of sufficient water sources, detection and remediation of water in-leakage, and high-quality leak proof waste packages.

Considering these factors, the criticality event does not appear to be a large potential contributor to risk.

Table H-1 lists the bounding accident scenarios identified in Kappes (1998, page 40). For each accident scenario, the table lists (1) the location of the accident, (2) the material at risk, or the amount of radioactive material involved in the accident, and (3) if the analysis assumed that filtration (high-efficiency particulate air filters) would be available to mitigate radioactive material releases. Filtration would be provided in most areas of the Waste Handling Building (TRW 1999b, page 41) and in the subsurface emplacement facilities (TRW 1999a, page 4-61). The Frequency column in Table H-1 lists the estimated annual frequency of the event (Kappes 1998, all). The last column indicates if the EIS analysis retained, eliminated, or adjusted details of the accident scenario.

Table H-1. Bounding internal accident scenarios for the Waste Handling Building and emplacement operations.

Location[a]	Number	Accident[b]	Material at risk[c]	Filters	Frequency	Disposition
A	1	6.9-meter drop of shipping cask	61 BWR assemblies	No	4.5×10^{-4}	Retained
A	2	6.9-meter drop of shipping cask	61 BWR assemblies	Yes	--[d]	Eliminated
A	3	7.1-meter drop of shipping cask	26 PWR assemblies	No	6.1×10^{-4}	Retained
A	4	7.1-meter drop of shipping cask	26 PWR assemblies	Yes	--	Eliminated
A	5	4.1-meter drop of shipping cask	61 BWR assemblies	No	1.4×10^{-3}	Retained
A	6	4.1-meter drop of shipping cask	61 BWR assemblies	Yes	--	Eliminated
A	7	4.1-meter drop of shipping cask	26 PWR assemblies	No	1.9×10^{-3}	Retained
B	8	8.6-meter drop of canister	DOE high-level waste	Yes	4.2×10^{-5}	Eliminated[e]
B	9	6.3-meter drop of multicanister overpack	N-Reactor fuel	Yes	4.5×10^{-4}	Retained
B	10	6.3-meter drop of multicanister overpack	N-Reactor fuel	No	2.2×10^{-7}	Added[f]
C	11	5-meter drop of transfer basket	8 PWR assemblies	Yes	1.1×10^{-2}	Retained
C	12	5-meter drop of transfer basket	8 PWR assemblies	No	2.8×10^{-7}	Added[f]
C	13	7.6-meter drop of transfer basket	16 BWR assemblies	Yes	7.4×10^{-3}	Retained
C	14	7.6-meter drop of transfer basket	16 BWR assemblies	No	1.9×10^{-7}	Added[f]
D	15	6-meter vertical drop of disposal container	21 PWR assemblies	Yes	1.8×10^{-3}	Retained
D	16	6-meter vertical drop of disposal container	21 PWR assemblies	No	8.6×10^{-7}	Added[g]
D	17	2.5-meter horizontal drop of disposal container	21 PWR assemblies	Yes	3.2×10^{-4}	Eliminated[g]
E	18	Rockfall on waste package	44 BWR assemblies	No	4.2×10^{-8}	Eliminated[h]
E	19	Transporter runaway and derailment	21 PWR assemblies	Yes	1.2×10^{-7}	Retained[i]

a. Location designators: A = Cask/Carrier Transport and Handling Area, B = Canister Transfer System, C = Assembly Transfer System, D = Disposal Container Handling System, E = Waste Emplacement and Subsurface Facility.

b. To convert meters to feet, multiply by 3.2808.

c. BWR = boiling-water reactor; PWR = pressurized-water reactor.

d. Eliminated from evaluation because current design does not include a filter system for this area (Kappes 1998, page 40).

e. Eliminated on the basis that it would not be a risk contributor because the N-Reactor multicanister overpack drop (accident scenario B10) has an estimated frequency more than 10 times higher, and the N-Reactor fuel has a higher radionuclide inventory (Appendix A).

f. These accident scenarios, involving loss of filtration, were added because they would exceed the level of credibility recommended by DOE (frequency greater than 1×10^{-7} per year) (DOE 1993, page 28). The corresponding U.S. Nuclear Regulatory Commission limit (used in Kappes 1998, page 4) is 1×10^{-6} per year. The Commission considers accidents with frequencies less than 1×10^{-6} per year to be beyond design basis events.

g. Eliminated because it would not contribute to risk in comparison to accident scenario 15 at location D,, a higher drop event that would produce larger consequences with a higher frequency.

h. Eliminated on the basis of low frequency, below the credible level of 1×10^{-7}.

i. Frequency adjusted to account for the filtration system in the current design.

The following paragraphs contain details of the postulated accident scenarios in each location.

H.2.1.1.1 *Cask/Carrier Transport and Handling Area*

These accidents (Table H-1, location A, accidents 1 through 7) would involve mishaps that could occur during the process of handling the transportation casks at the repository. The transportation casks would be designed to withstand impacts from collisions and drops, and this capability is augmented by impact limiters, which would be required during transportation. After cask arrival at the repository, the limiters would be removed to facilitate handling of the casks. The casks would then become more vulnerable to damage from physical impact. The analysis assumed that damage to the casks would occur if they were dropped from heights greater than the design basis of 2 meters (6.6 feet) (Kappes 1998, page 13) without the impact limiters. The various heights of the drops in the “Accident” column in Table H-1 correspond to the maximum height to which the casks could be lifted during the various operations the analysis assumed crane failure would occur. The material-at-risk column lists the contents of the casks when the accident occurred. The largest casks are designed to hold either 61 boiling-water reactor or 26 pressurized-water reactor fuel assemblies.

Accident scenarios from Kappes (1998) that assume a filtration system is available (accidents A2, A4, and A6) were eliminated from consideration in the EIS because the current design concept of the Cask/Carrier Transport and Handling Area does not include such a filtration system; they were considered in Kappes (1998, page 40) for information only.

H.2.1.1.2 *Canister Transfer System*

The Canister Transfer System would handle canisters that arrived at the repository and were suitable for direct transfer to the disposal container. The bounding accident scenarios for these operations would be canister drops of DOE high-level radioactive waste and N-Reactor fuel (accidents 8 and 9 at location B in Table H-1). The analysis eliminated the DOE high-level radioactive waste canister drop because it would not be a risk contributor in comparison to the N-Reactor fuel drop. The N-Reactor multicanister overpack drop would have a frequency more than 10 times greater than that for the high-level radioactive waste canister drop, and the N-Reactor radionuclide inventory would be greater (see Appendix A). The EIS analysis added an additional accident scenario, which would be a drop of the N-Reactor fuel canister with loss of the filtration system. The analysis estimated the filtration system failure probabilities by using the fault tree analysis technique, and the results differ somewhat from the failures identified in Section H.2.1.1.3 due to design variations dependant on location in the surface facilities of the repository. DOE computed this accident scenario probability by combining the accident drop probability of 0.00045 with the filter system failure of 4.8×10^{-4} from Kappes (1998, page 4) for an accident sequence frequency of 2.2×10^{-7} per year. [Kappes (1998, page 4) did not consider accident sequences with frequencies less than 1×10^{-6}.] This sequence frequency is based on failure of the heating, ventilating, and air conditioning system such that it would not provide filtration for 24 hours following the accident, consistent with Kappes (1998, page VIII-1).

H.2.1.1.3 *Assembly Transfer System*

The Assembly Transfer System would handle bare, intact commercial spent nuclear fuel assemblies from pressurized- and boiling-water reactors. The assemblies would be unloaded from the transportation cask in the cask unloading pool. Next, they would be moved to the assembly staging pool where they would be placed in baskets that contained either four pressurized-water reactor assemblies or eight boiling-water assemblies. The baskets would be moved from the pool and transferred to the assembly drying station from which they would be loaded, after drying, in the disposal containers. The bounding accident scenarios found during a review of this operation (Kappes 1998, page 40) were drops of a suspended basket loaded with fuel assemblies on another loaded basket in the drying vessel (accident scenarios 11 and 13 at location C from Table H-1). DOE added two accident scenarios to the EIS analysis that included failure of the high-efficiency particulate air filtration system (accident scenarios 12 and 14 at location C from Table H-1). DOE computed the frequency of these accidents by combining the accident drop frequency with the filter failure probability of 0.000025, which corresponds to the failure probability of the heating, ventilation, and air conditioning system in the assembly transfer area (Kappes 1998, page 11). Thus, the frequency of a drop accident and subsequent failure of the heating, ventilation, and air conditioning system during the 24 hours (the period assumed that the filtration system would need to operate to remove the particulate material effectively) would be:

- For boiling-water reactor assembly drop: 0.011 × 0.000025 = 0.00000028
- For pressurized-water reactor assembly drop: 0.0074 × 0.000025 = 0.00000019

H.2.1.1.4 *Disposal Container Handling System*

The Disposal Container Handling System would prepare empty disposal containers for the loading of nuclear materials, transfer disposal containers to and from the assembly and canister transfer systems, weld the inner and outer lids of the disposal containers, and load disposal containers on the waste emplacement transporter. After the disposal container had been loaded and sealed, it would become a waste package. Disposal containers would be lifted and moved several times during the process of preparing them for loading on the waste emplacement transporter. DOE examined the details of these operations and identified numerous accident scenarios that could occur (Kappes 1998, Attachment V). The bounding accident scenarios from this examination would be the disposal container drop accident scenarios listed as accident scenarios 15 and 17 at Location D in Table H-1. However, the analysis eliminated accident scenario 17 because it would be a minor contributor to risk in comparison to accident scenario 15. Accident scenario 15, which would have a higher probability (by about a factor of 6), would produce a higher radionuclide release due to the increased drop height (by a factor of more than 2). Thus, the overall risk contribution from accident scenario 17 would be less than 10 percent of the risk from accident scenario 15. For the EIS, DOE added another accident scenario (16) to account for the possibility of loss of filtration. The analysis assumed that the heating, ventilation, and air conditioning filtration system would fail with a probability of 0.00048 (Kappes 1998, page 4).

H.2.1.1.5 *Waste Emplacement and Subsurface Facility Systems*

The waste emplacement system would transport the loaded and sealed waste package from the Waste Handling Building to the subsurface emplacement area. This system would operate on the surface between the North Portal and the Waste Handling Building, and in the underground ramps, main drifts (tunnels), and emplacement drifts. It would use a reusable railcar for waste package transportation. The railcar would be moved into the waste emplacement area by an electric locomotive, and the waste package would be placed in the emplacement drift. The bounding accident scenarios identified (Kappes 1998, page 40) for this operation would be accident scenarios 18 and 19 at location E, as listed in Table H-1. However, DOE eliminated accident scenario 18 (rockfall on waste package) because the estimated frequency of a radioactive release from such an event is not credible (estimated frequency of 4.2×10^{-8} per year) (Kappes 1998, page VI-5).

An accident scenario involving a failure of the ventilation system in conjunction with a transporter runaway and collision (accident scenario F19 from Table H-1) would not be credible, so the sequence was not analyzed. The original transporter runaway and derailment accident scenario assumed the involvement of 44 boiling-water reactor assemblies (Kappes 1998, page 40). The EIS analysis assumed the involvement of 21 pressurized-water reactor assemblies because (1) they would represent a slightly higher impact potential due to the greater radionuclide inventory than that in the smaller 44 boiling-water reactor assemblies and would, therefore, bound the equivalent accident involving such assemblies, and

(2) an accident scenario involving pressurized-water reactor fuel would be more likely because DOE expects to emplace about twice as much of this type of fuel in the proposed repository (Appendix A).

Section H.2.1.4 describes the source terms (amount and type of radionuclide release) for these accident scenarios, and Section H.2.1.5 assesses the estimated consequences from the accident scenarios.

H.2.1.2 Internal Events – Waste Treatment Building

An additional source of radionuclides could be involved in accidents in the Waste Treatment Building. This building, which would be connected to the northeast end of the Waste Handling Building, would house the Site-Generated Radiological Waste Handling System (TRW 1999b, page 37). This system would collect site-generated low-level radioactive solid and liquid wastes and prepare them for disposal. The radioactivity of the waste streams would be low enough that no special features would be required to meet Nuclear Regulatory Commission radiation safety requirements (shielding and criticality) (TRW 1999b, page 38).

The liquid waste stream to the Waste Treatment Building would consist of aqueous solutions that could contain radionuclides resulting from decontamination and washdown activities in the Waste Handling Building. The liquid waste would be evaporated, mixed with cement (grouted), and placed in 0.21-cubic-meter (55-gallon) drums for shipment off the site (TRW 1999b, page 53). The evaporation process would reduce the volume of the liquid waste stream by 90 percent (DOE 1997c, Summary).

The solid waste would consist of noncompactible and compactible materials and spent ion-exchange resins. These materials ultimately would be encapsulated in concrete in 0.21-cubic meter (55-gallon) drums after appropriate processing (TRW 1999b, page 55).

Water in the Assembly Staging Pools of the Waste Handling Building would pass through ion exchange columns to remove radionuclides and other contaminants. These columns would accumulate radionuclides on the resin in the columns. When the resin is spent (unable to remove radionuclides effectively from the water), the water flow would be diverted to another set of columns, and the spent resin would be removed and dewatered for disposal as low-level waste or low-level mixed waste. These columns could have external radiation dose rates associated with them because of the activation and fission product radionuclides accumulated on the resins. They would be handled remotely or semiremotely. During the removal of the resin and preparation for offsite shipment in the Waste Treatment Building, an accident scenario involving a resin spill could occur. However, because the radionuclides would have been chemically bound to the resin in the column, an airborne radionuclide release would be unlikely. Containment and filter systems in the Waste Treatment Building would prevent exposure to the public or noninvolved workers. Some slight exposure of involved workers could occur during the event or during recovery operations afterward. DOE made no further analysis of this event.

Because there is no detailed design of the Waste Treatment Building at present and operational details are not yet available, DOE used the recent Waste Management Programmatic EIS (DOE 1997c, all) and supporting documentation (Mueller et al. 1996, all) to aid in identifying potential accident scenarios and evaluating radionuclide source terms. For radiological impacts, the analysis focused on accident scenarios with the potential for airborne releases to the atmosphere. The liquid stream can be eliminated because it has a very low potential for airborne release; the radionuclides would be dissolved and energy sources would not be available to disperse large amounts of the liquid into droplets small enough to remain airborne. Many low-level waste treatment operations, including evaporation, solidifying (grouting), packaging, and compaction can be excluded because they would lack sufficient mechanistic stresses and energies to create large airborne releases, and nuclear criticalities would not be credible for low-level waste (Mueller et al. 1996, page 13). Drum-handling accidents are expected to dominate the risk of exposure to workers (Mueller et al. 1996, page 93).

The estimated frequency of an accident involving drum failure is about 0.0001 failure per drum operation (Mueller et al. 1996, page 39). The total number of drums containing grouted aqueous waste would be 2,280 per year (DOE 1997c, page 30). The analysis assumed that each drum would be handled twice, once from the Waste Treatment Building to the loading area, and once to load the drum for offsite transportation. Therefore, the frequency of a drum failure involving grouted aqueous waste would be:

Frequency = 2,280 aqueous (grouted) low-level waste drums per year
× 2 handling operations per drum
× 0.0001 failure per handling operation
= 0.46 aqueous (grouted) low-level waste drum failures per year.

The number of solid-waste grouted drums produced would be 2,930 per year (DOE 1997c, page 35). Assuming two handling operations and the same failure rate yields a frequency of drum failure of:

Frequency = 2,930 solid low-level waste drums per year
× 2 handling operations per drum
× 0.0001 failure per handling operation
= 0.59 solid low-level waste drum failures per year.

Failure of these drums would result in a release of radioactive material, which later sections evaluate further.

H.2.1.3 External Events

External events are either external to the repository (earthquakes, high winds, etc.) or are natural processes that occur over a long period of time (corrosion, erosion, etc.). DOE performed an evaluation to identify which of these events could initiate accidents at the repository with potential for release of radioactive material.

Because some external events evaluated as potential accident-initiating events would affect both the Waste Treatment and Waste Handling Buildings simultaneously [the buildings are physically connected (TRW 1999b, page 38)], this section considers potential accidents involving external event initiators, as appropriate, for the combined buildings.

Table H-2 lists generic external events developed as potential accident initiators for consideration at the proposed repository and indicates how each potential event could relate to repository operations based on an initial evaluation process. The list, from DOE (1996b, page 15), was developed by an extensive review of relevant sources and known or predicted geologic, seismologic, hydrologic, and other characteristics. The list includes external events from natural phenomena as well as man-caused events.

The center column in Table H-2 (relation to repository) represents the results of a preliminary evaluation to determine the applicability of the event to the repository operations, and is based in part on evaluations previously reported in DOE (1996b, all). Events were excluded for the following reasons:

- Not applicable because of site location (condition does not exist at the site)
- Not applicable because of site characteristics (potential initiator does not exist in the vicinity of the site)

Table H-2. External events evaluated as potential accident initiators.[a]

Event	Relation to repository[b]	Comment
Aircraft crash	A	
Avalanche	C	
Coastal erosion	B	
Dam failure	C	
Debris avalanche	A	Caused by excessive rainfall
Dissolution	A	Chemical weathering of rock
Epeirogenic displacement (tilting of the Earth's crust)	D (earthquake)	Large-scale surface uplifting and subsidence
Erosion	D (flooding)	
Extreme wind	A	
Extreme weather	A	Includes extreme episodes of fog, frost, hail, ice cover, etc.
Fire (range)	A	
Flooding	A	
Denudation	E	Wearing away of ground surface by weathering
Fungus, bacteria, algae	E	A potential waste package long-term corrosion process not relevant during the repository operational period[c]
Glacial erosion	B	
High lake level	C	
High tide	B	
High river stage	C	
Hurricane	B	
Inadvertent future intrusion	E	To be addressed in postclosure Performance Assessment
Industrial activity	A	
Intentional future intrusion	E	
Lightning	A	
Loss of offsite or onsite power	A	
Low lake level	C	
Meteorite impact	A	
Military activity	A	
Orogenic diastrophism	D (earthquake)	Movement of Earth's crust by tectonic processes
Pipeline rupture	C	
Rainstorm	D (flooding)	
Sandstorm	A	
Sedimentation	B	
Seiche	B	Surface water waves in lakes, bays, or harbors
Seismic activity, uplift	D (earthquake)	
Seismic activity, earthquake	A	
Seismic activity, surface fault	D (earthquake)	
Seismic activity, subsurface fault	D (earthquake)	
Static fracture	D (earthquake)	Rock breakup caused by stress
Stream erosion	B	
Subsidence	D (earthquake)	Sinking of Earth's surface
Tornado	A	
Tsunami	B	Sea wave caused by ocean floor disturbance
Undetected past intrusions	E	
Undetected geologic features	D (earthquake, volcanism ash fall)	
Undetected geologic processes	D (erosion, earthquake, volcanism ash fall)	
Volcanic eruption	D (volcanism ash fall)	
Volcanism, magmatic	D (volcanism ash fall)	
Volcanism, ash flow	D (volcanism ash fall)	
Volcanism, ash fall	A	
Waves (aquatic)	B	

a. Source: DOE (1996b, page 15).

b. A = retained for further evaluation; B = not applicable because of site location; C = not applicable because of site characteristics (threat of event does not exist in the vicinity of the site); D = included in another event as noted; E = does not represent an accident-initiating event for proposed repository operations.

c. Source: TRW (1999a, all).

- Included in another event
- Does not represent an accident-initiating event for proposed repository operations

The second column of Table H-2 identifies the events excluded for these reasons. The preliminary evaluation retained the events identified in Table H-2 with "A" for further detailed evaluation. The results of this evaluation are as follows:

1. **Aircraft Crash.** The EIS analysis evaluated the frequency of aircraft crashes on the proposed repository to determine if such events could be credible and, therefore, candidates for consequence analysis. This frequency determination used analytical methods recommended for aircraft crashes into hazardous facilities (DOE 1996c, all).

   An earlier analysis assumed that the only reasonable aircraft crash threat would be from military aircraft operations originating from Nellis Air Force Base (Kimura, Sanzo, and Sharirli 1998, page 8), primarily because commercial and general aviation aircraft are restricted from flying over the Nevada Test Site. DOE considered this assumption valid and adopted it for the EIS analysis.

   The formula used in the crash frequency analysis, taken from Kimura, Sanzo, and Sharirli (1998, pages 9 to 12) based on DOE (1996c, all), was:

   $$F = (N_t \div A_t) \times A_{eff} \times \lambda \times (4 \div \pi) \times (R_{eff} + R_c)$$

   where:

   F = the frequency per year of aircraft crashes on the repository
   N_t = total number of aircraft overflights per year
   A_t = total area of the overflight region
   A_{eff} = effective area of the repository (target area)
   λ = crash rate of the aircraft per mile of flight
   R_{eff} = effective radius of the repository (target area)
   R_c = radius of the crash area potentially affected by a distressed aircraft

   The parameters in this formula were quantified as follows:

   N_t The estimated total number of flights in the flight corridor in the vicinity of the repository would be 13,000 per year, with the repository located on the western edge of the corridor, which extends 49 kilometers (30 miles) to the east. Most flights would not be observed from the repository. However, this value was used in a recent crash assessment for a Nevada Test Site facility beneath the same airspace as the repository (Kimura, Sanzo, and Sharirli 1998, page 7). Future Nellis operations could result in increased overflights. The only known planned change in future activities involve the bed-down of F-22 fighter aircraft. This planned activity involves 17 aircraft that will be at Nellis by 2010. The additional aircraft would increase flight activities by only 2 to 3 percent over current activities (Myers 1997, page 2).

   A_t The total area of the overflight area would be about 3,400 square kilometers (1,300 square miles) (Kimura, Sanzo, and Sharirli 1998, page 18).

A_{eff} The analysis estimated the repository target area by assuming that the roof of the Waste Handling Building would be the only vulnerable location at the repository with the potential for a large radionuclide release as a result of an aircraft impact. This is because the Waste Handling Building would be the only facility that would handle bare spent nuclear fuel assemblies. The shipping casks and the waste packages loaded with spent nuclear fuel or high-level radioactive waste would not be vulnerable to air crash impacts because both would have steel walls thick enough to prevent aircraft penetration. The Waste Treatment Building would not contain large amounts of radioactive material, so radionuclide releases from accidents involving this building would not produce large impacts (see Section H.2.1.4 for details). Further, the walls of the Waste Handling Building around areas for the handling of canisters and fuel assemblies would be 1.5 meters (5 feet) thick to a level of 9 meters (30 feet), and then 1 meter (3.3 feet) thick to the intersection with the roof (TRW 1999b, pages 31 to 37). The aircraft crash would not penetrate these walls because the concrete penetration capability for aircraft is limited to about 0.76 meter (2.5 feet) (see Appendix K for details). Therefore, the only likely vulnerable target area at the repository would be the roof of the Waste Handling Building, which would consist of concrete 20 to 25 centimeters (8 to 10 inches thick) (TRW 1999b, pages 31 to 37). The overall footprint of the Waste Handling Building would be about 163 meters by 165 meters (535 feet by 540 feet), which would produce a target area of approximately 27,000 square meters (290,000 square feet).

λ The crash rate for the small military aircraft involved in the overflights [primarily F-15s, F-16s, and A-10s (USAF 1999, pages 1-34 to 1-35)] would be 1.14×10^{-8} per kilometer (1.84×10^{-8} per mile) (Kimura, Sanzo, and Sharirli 1998, page 7). Large military aircraft fly over the area to some extent, but have a lower crash rate [1.17×10^{-9} per kilometer (1.9×10^{-9} per mile) (Kimura, Sanzo, and Sharirli 1998, page 7)]. Thus, the use of the small aircraft crash rate bounds the large aircraft crash rate.

R_{eff} The effective radius of the repository is the equivalent radius of the repository target effective area (A_{eff}), or R_{eff} is equal to the square root of the quotient 27,000 square meters divided by *pi*, which is about 93 meters (310 feet).

R_c The radius of the crash area potentially affected by a distressed military aircraft represents the distance an aircraft could travel after engine failure (glide distance). This distance is the glide ratio of the aircraft times the elevation of the flight above the ground. The aircraft are required to fly a minimum of 4,300 meters (14,000 feet) above mean sea level while in the airspace over the repository (Kimura, Sanzo, and Sharirli 1998, page 5). The actual altitude flown varies from 4,600 to 7,000 meters (15,000 to 23,000 feet) (Tullman 1997, page 4). For this analysis, a mean altitude of 5,800 meters (19,000 feet) was assumed. Because the Waste Handling Building would be at about 1,100 meters (3,680 feet) (TRW 1998a, page I-6), the mean flight elevation for aircraft above the repository ground level would be about 4,700 meters (10,000 feet). The glide ratio for the aircraft involved in the overflights (F-15, F-16, and A-10) is 8 (Thompson 1998, all). Therefore, R_c would be 4,700 meters multiplied by 8, which is 38,000 meters or 38 kilometers (23 miles).

Substituting these values into the frequency equation yields:

$$\begin{aligned} F &= (13{,}000 \div 3{,}400) \times 0.027 \times 1.14 \times 10^{-8} \times (4 \div \pi) \times (38 + 0.093) \\ &= 5.6 \times 10^{-8} \text{ crash per year.} \end{aligned}$$

Thus, aircraft crashes on the vulnerable area of the repository are not credible because the probability would be below 1×10^{-7} per year, which is the credible limit specified by DOE (1993, page 28).

2. **Debris Avalanche.** This event, which can result from persistent rainfall, would involve the sudden and rapid movement of soil and rock down a steep slope. The nearest avalanche potential to the proposed location for the Waste Handling Building is Exile Hill (the location of the North Portal entrance). The base of Exile Hill is about 90 meters (300 feet) from the location of the Waste Handling Building. Since Exile Hill is only about 30 meters (100 feet) high (TRW 1997a, page 5.09), it would be unlikely that avalanche debris would reach the Waste Handling Building. Furthermore, the design for the Waste Handling Building includes concrete walls about 1.5 meters (5 feet) thick (TRW 1999b, page 38) that would provide considerable resistance to an impact or buildup of avalanche debris.

3. **Dissolution.** Chemical weathering could cause mineral and rock material to pass into solution. This process, called dissolution, has been identified as potentially applicable to Yucca Mountain (DOE 1996b, page 18). However, this is a very slow process, which would not represent an accident-initiating event during the preclosure period being considered in this appendix.

4. **Extreme Wind.** Extreme wind conditions could cause transporter derailment (TRW 1997b, page 72), the consequences of which would be bounded by a transporter runaway accident scenario. The runaway transporter accident scenario is discussed further in Section H.2.1.4.

5. **Extreme Weather.** This potential initiating event includes various weather-related phenomena including fog, frost, hail, drought, extreme temperatures, rapid thaws, ice cover, snow, etc. None of these events would have the potential to cause damage to the Waste Handling Building that would exceed the projected damage from the earthquake event discussed in this section. In addition, none of these events would compromise the integrity of waste packages exposed on the surface during transport operations. Thus, the earthquake event and other waste package damage accident scenarios considered in this appendix would bound all extreme weather events. It would also be expected that operations would be curtailed if extreme weather conditions were predicted.

6. **Fire.** There would be two potential external fire sources at the repository site—diesel fuel oil storage tank fires and range fires. Diesel fuel oil storage tanks would be some distance [more than 90 meters (300 feet)] from the Waste Handling Building and Waste Treatment Building (TRW 1999b, Attachment IV Figure 4). Therefore, a fire at those locations would be highly unlikely to result in any meaningful radiological consequences. Range fires could occur in the vicinity of the site, but would be unlikely to be important accident contributors due to the clearing of land around the repository facilities. Furthermore, the potential for early fire detection and, if necessary, active fire protection measures and curtailment of operations (TRW 1999b, Section 4.2) would minimize the potential for fire-initiated radiological accidents. DOE is performing detailed evaluations of fire-initiating events (Kappes 1998, page III-2), and will incorporate the results in the Final EIS as appropriate.

7. **Flooding.** Flash floods could occur in the vicinity of the repository (DOE 1996b, page 21). However, an earlier assessment (Kappes 1998, page 32) screened out severe weather events as potential accident-initiating events primarily by assuming that operational rules will preclude transport and emplacement operations whenever there are local forecasts of severe weather. A quantitative analysis of flood events (Jackson et al. 1984, page 34) concluded that the only radioactive material that extreme flooding would disperse to the environment would be decontamination sludge from the waste treatment complex. The doses resulting from such dispersion would be limited to workers, and would be very small (Jackson et al. 1984, page 53). A more recent study reached a similar conclusion (Ma et al. 1992, page 3-11).

8. **Industrial Activity.** This activity would involve both drift (tunnel) development activities at the repository and offsite activities that could impose hazards on the repository.

- **a.** Emplacement Drift Development Activities – Drift development would continue during waste package emplacement activities. However, physical barriers in the main drifts would isolate development activities from emplacement activities (TRW 1999a, page 4-52). Thus, events that could occur during drift development activities would be unlikely to affect the integrity of waste packages.

- **b.** External Industrial Activities – The analysis examined anticipated activities in the vicinity of the proposed repository to determine if accident-initiating events could occur. Two such activities—the Kistler Aerospace activities and the Wahmonie rocket launch facility—could initiate accidents at the repository from rocket impacts. The Wahmonie activities, which involved rocket launches from a location several miles east of the repository site, have ended (Wade 1998, all), so this facility no longer poses a risk to the repository. The planned Kistler Aerospace activities would involve launching rockets from the Nevada Test Site to place satellites in orbit (DOE 1996d, Volume 1, page A-42). However, at present there is insufficient information to assess if this activity would pose a threat to the repository. As details become available, the Final EIS will evaluate the potential for this activity to become an external accident-initiating event. (Aircraft activity was discussed in item 1 above.)

9. **Lightning.** This event has been identified as a potential design-basis event (DOE 1997b, pages 86 and 87). Therefore, the analysis assumed that the designs of appropriate repository structures and transport vehicles would include protection against lightning strikes. The lightning strike of principal concern would be the strike of a transporter train during operations between the Waste Handling Building and the North Portal (DOE 1997b, page 86). The estimated frequency of such an event would be 1.9×10^{-7} per year (Kappes 1998, page 33). DOE expects to provide lightning protection for the transporter (TRW 1998b, Volume 1, page 18) such that a lightning strike that resulted in enough damage to cause a release would be well below the credibility level of 1×10^{-7} per year (DOE 1993, page 28).

10. **Loss of Offsite Power.** A preliminary evaluation (DOE 1997b, page 84) concluded that a radionuclide release from an accident sequence initiated by a loss of offsite power would be unlikely. Loss of offsite power events could result in a failure of the ventilation system and of the overhead crane system. However, there would be emergency power for safety systems at the site (TRW 1999b, page 45). Loss of offsite power was included as a contributor to the frequency of crane failure (Kappes 1998, page III-6), as listed in the event frequencies in Table H-1.

11. **Meteorite Impact.** This event would not be credible based on a strike frequency of 2×10^{-8} per year for a damaging meteorite [based on data in Solomon, Erdmann, and Okrent (1975, page 68)]. This estimate accounts for the actual area of the Waste Handling Building roof given previously in item 1.

12. **Military Activity.** Two different military activities would have the potential to affect repository operations. One is the possibility of an aircraft crash from overflights from Nellis Air Force Base. The analysis determined that this event would not be credible, as described above in this section. The second potential activity is the resumption of underground nuclear weapons testing, which the United States has suspended. The only impact such testing could impose on the repository would be ground motion associated with the energy released from the detonation of the weapon. The impact of such motion was the subject of a recent study that concluded that ground motions at Yucca Mountain from nuclear tests would not control seismic design criteria for the potential repository (Walck 1996, page i).

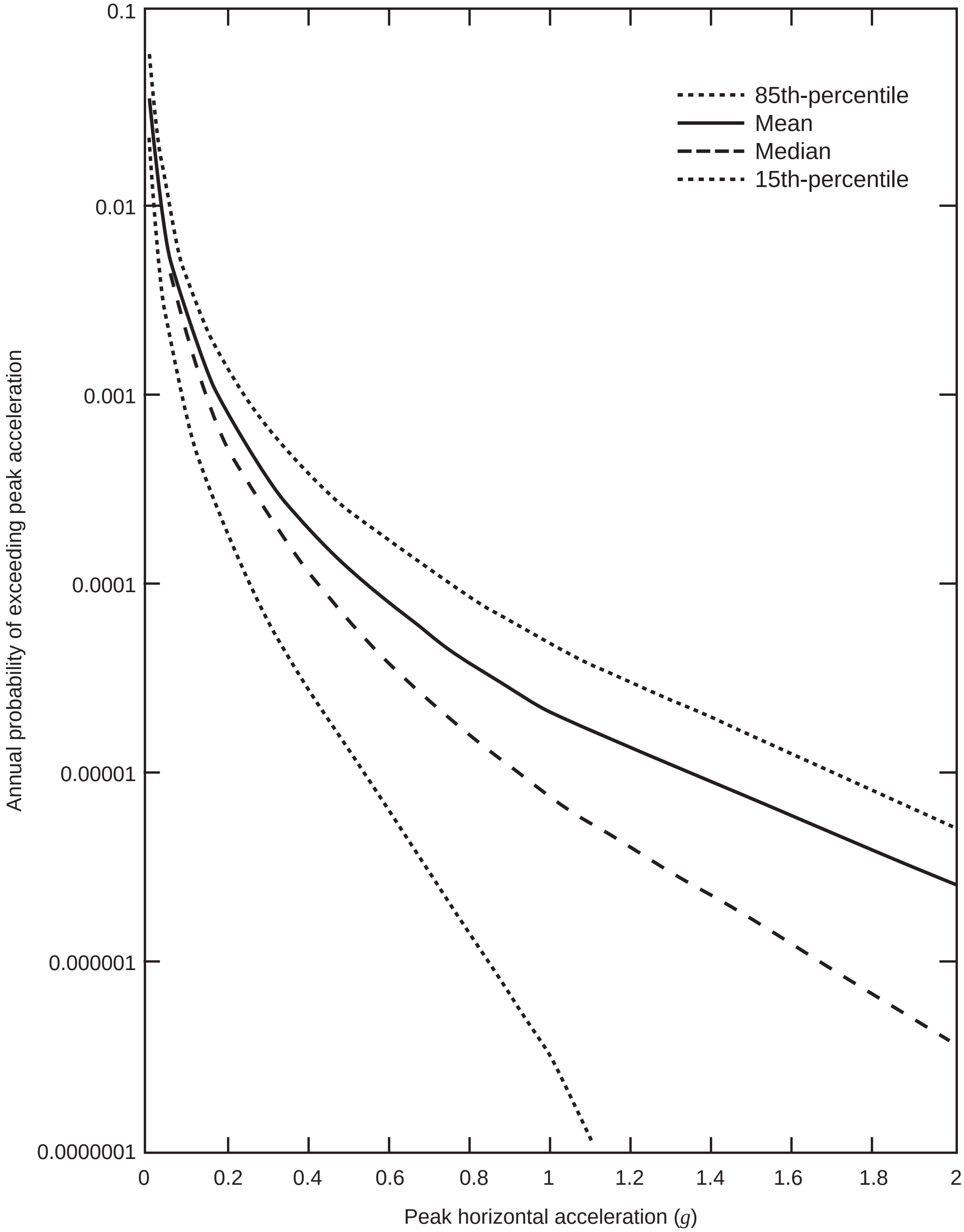
13. **Sandstorm.** Severe sandstorms could cause transporter derailments and sand buildup on structures. However, such events would be unlikely to initiate accidents with the potential for radiological release. Ma et al. (1992, page 3-11) reached a similar conclusion. Furthermore, it is assumed that DOE probably would curtail operations if local forecasts indicated the expected onset of high winds with potential to generate sandstorms (Kappes 1998, page 32). For these reasons, the analysis eliminated this event from further consideration.

14. **Seismic Activity, Earthquake** *(including subsidence, surface faults, uplift, subsurface fault, and static fracture).* DOE has selected the beyond-design-basis earthquake for detailed analysis. The seismic design basis for the repository specifies that structures (including the Waste Handling Building), systems, and components important to safety should be able to withstand the horizontal motion from an earthquake with a return frequency of once in 10,000 years (annual probability of occurrence of 0.0001) (Kappes 1998, page VII-3). A recent comprehensive evaluation of the seismic hazards associated with the site of the proposed repository (USGS 1998, all) concluded that a 0.0001-per-year earthquake would produce peak horizontal accelerations at the site of about 0.53g (mean value). Structures, systems, and components are typically designed with large margins over the seismic design basis to account for uncertainties in material properties, energy absorption, damping, and other factors. For nuclear powerplant structures, the methods for seismic design provide a factor of safety of 2.5 to 6 (Kennedy and Ravindra 1984, page R-53). In the absence of detailed design information, the analysis conservatively assumed that the Waste Handling Building would collapse at an acceleration level twice that associated with the design-basis earthquake, or 1.1g. Figure H-1 shows that this acceleration level would be likely to occur with a frequency of about 2×10^{-5} per year (mean value).

    The Waste Treatment Building is not considered a safety-related structure. Accordingly, the seismic design basis for this building is to withstand an earthquake event with a return frequency of 1,000 years (annual exceedance probability of 1×10^{-3} per year) (TRW 1999b, page 14). Consistent with the assumption for the Waste Handling Building, it is assumed that the Waste Treatment Building would collapse during an earthquake that produced twice the design level acceleration. From Figure H-1, the design-basis acceleration for a 1×10^{-3} per year event is 0.18g. Thus, the building collapse is assumed to occur at an acceleration level of 0.36, which has an estimated return frequency of about 2×10^{-4} per year. The analysis retains these events as accident initiators, and evaluates the consequences in subsequent sections. The effects of other seismic-related phenomena included under this event (subsidence, surface faults, uplift, etc.) would be unlikely to produce greater consequences than those associated with the acceleration produced by the seismic event selected for analysis (complete collapse of the Waste Handling and Waste Treatment Buildings).

15. **Tornado.** The probability of a tornado striking the repository is estimated to be 3×10^{-7} (one chance in 10 million) based on an assessment of tornado strike probability for any point on the Nevada Test Site (DOE 1996d, page 4-146), which is adjacent to the proposed repository. This is slightly above the credibility level of 1×10^{-7} for accidents, as defined by DOE (DOE 1993, page 28). However, most tornadoes in the western United States have relatively modest wind speeds. For example, the probability of a tornado with wind speeds greater than 100 miles per hour is 0.1 or less (Ramsdell and Andrews 1986, page 41). Thus, winds strong enough to damage the Waste Handling Building are considered to be not credible.

    Tornadoes can generate missiles that could penetrate structures at the repository, but radioactive material would be protected either by shipping casks, the Waste Handling Building with thick concrete walls, or the waste package. Therefore, tornado-driven missiles would not be a great hazard.



Source: USGS (1998, Figure 7-4).

Figure H-1. Integrated seismic hazard results: summary hazard curves for peak horizontal acceleration.

16. **Volcanism, Ash Fall.** The potential for volcanic activity at the proposed repository site has been studied extensively. A recent assessment (Geomatrix and TRW 1996, page 4-46) estimates that the mean annual frequency of a volcano event that would intersect the repository footprint would be 1.5×10^{-8} per year (with 5 percent and 95 percent bounds of 5×10^{-10} and 5×10^{-8} per year), which is below the frequency of a credible event (DOE 1993, page 28). This result is consistent with a previous study of volcano activity at the site (DOE 1998b, all). Impacts from a regional volcanic eruption would be more likely; such an event could produce ash fall on the repository, and would be similar to the sandstorm event discussed above. Ash fall could produce a very heavy loading on the roof of the Waste Handling Building. Studies have concluded, however, that the worst case event would be an ash fall of 3 centimeters (1.2 inches) and analyses to date indicate that repository structures would not be affected by a 3-centimeter ash fall (DOE 1998b, Volume 1, pages 2-9).

17. **Sabotage.** The analysis separately considered sabotage (not listed in Table H-2) as a potential initiating event. This event would be unlikely to contribute to impacts from the repository. The repository would not represent an attractive target to potential saboteurs due to its remote location and the low population density in the area. Furthermore, security measures DOE would use to protect the waste material from intrusion and sabotage (TRW 1999b, pages 58 to 60) would make such attempts unlikely to succeed. At all times the waste material would be either in robust shipping or disposal containers or inside the Waste Handling Building, which would have thick concrete walls. On the basis of these considerations, DOE concluded that sabotage events would be unlikely at the repository. DOE expects that both the likelihood and consequences of sabotage events would be greater during transportation of the material to the repository (DOE 1997d, page 14). Appendix J presents the impacts of sabotage events during transportation.

Based on the external event assessment, DOE concluded that the only external event with a credible potential to release radionuclides of concern would be a large seismic event. This conclusion is supported by previous studies that screened out all external event accident initiators except seismic events (Ma et al. 1992, page 3-11; Jackson et al. 1984, pages 12 and 13). DOE is continuing to evaluate a few external events (Kappes 1998, page 33), and will examine the results of these evaluations to confirm the Draft EIS conclusions. If revisions are necessary, they will be provided in the Final EIS.

H.2.1.4 Source Terms for Repository Accident Scenarios

Following the definition of the accident scenarios as provided in previous sections, the analysis then estimated a source term for each accident scenario retained for analysis. The source term specification needed to include several factors, including the quantity of radionuclides released, the elevation of the release, the chemical and physical forms of the released radionuclides, and the energy (if any) of the plume that would carry the radionuclides to the environment. These factors would be influenced by the state of the material involved in the accident and the extent and type of damage estimated for the accident sequence. The estimate of the source term also considered mitigation measures, either active (for example, filtration systems) or passive (for example, local deposition of radionuclides or containment), that would reduce the amount of radioactive material released to the environment.

The analysis developed the source term for each accident scenario retained for evaluation. These include the accident scenarios retained from the internal events as listed in Table H-1 and the seismic event retained from the external event evaluation. Because many of the internal event-initiated accidents would involve drops of commercial spent nuclear fuel, the analysis considered the source term for these accidents as a group. Accordingly, source terms were developed for the following accident scenarios: commercial spent nuclear fuel drops, transporter runaway and derailment, DOE spent nuclear fuel drop, seismic event, and low-level waste drum failure.

H.2.1.4.1 *Commercial Spent Nuclear Fuel Drop Accident Scenario Source Term*

Commercial spent nuclear fuel contains more than 100 radioactive isotopes (SNL 1987, Appendix A). Not all of these isotopes, however, would be important in terms of a potential to cause adverse health effects (radiotoxicity) if released, and many would have decayed by the time the material arrived at the repository. Based on the characteristics of the radioactivity associated with an isotope (including type and energy of radioactive emissions, amount produced during the fissioning process, half-life, physical and chemical form, and biological impact if inhaled or ingested by a human), particular isotopes could be meaningful contributors to health effects if released. To determine the important radionuclides for an accident scenario consequence analysis, DOE consulted several sources. The Nuclear Regulatory Commission has identified a minimum of eight radionuclides in commercial spent nuclear fuel that “must be analyzed for potential accident release” (NRC 1997, page 7-6). Repository accident scenario evaluations (SNL 1987, pages 5-3 and 5-4) identified 14 isotopes (five of which were also on the Nuclear Regulatory Commission list) that contribute to “99 percent of the total dose consequence.” A more recent analysis (DOE 1996a, pages 6 to 9) lists 24 radionuclides (10 of which were not included in either of the other two lists) that are important for consequence analysis (99.9-percent cumulative dose for at least one organ). The DOE analysis also included carbon-14. Appendix A contains a list of 53 radionuclides, which includes the important isotopes discussed above. DOE used this longer list in the development of the source term for the accident scenario analyses.

Commercial spent nuclear fuel includes two primary types—boiling-water reactor and pressurized-water reactor spent fuel. For these commercial fuels, the radionuclide inventory depends on burnup (power history of the fuel) and cooling time (time since removal from the reactor). The EIS accident scenario analysis used “typical” fuels for each type. These typical fuels are representative of the majority of the fuel DOE would receive at the repository (see Appendix A). Table H-3 lists the characteristics of typical commercial spent nuclear fuel types.

A recent sensitivity study examined the consequences from accident scenarios involving bounding fuel types and illustrated the adequacy of selecting typical fuel types for this accident scenario analysis. Table H-4 lists the radionuclide inventory selected for estimating the accident scenario consequences for the fuel types selected (typical boiling-water reactor and pressurized-water reactor).

Table H-3. Typical commercial spent nuclear fuel characteristics.[a]

Fuel type[b]	Cooling time (years)	Burnup (GWd/MTHM)[c]
PWR typical	25.9	39.56
BWR typical	27.2	32.2

a. Source: Appendix A.
b. PWR = pressurized-water reactor; BWR = boiling-water reactor.
c. GWd/MTHM = gigawatt-days per metric ton of heavy metal.

Commercial spent nuclear fuel damaged in the accidents evaluated in this EIS could release radionuclides from three different sources. These sources, and a best estimate of the release potential, are as follows:

H.2.1.4.1.1 Crud. During reactor operation, crud (corrosion material) builds up on the outside of the fuel rod cladding and becomes radioactive from neutron activation. Five years after discharge from the reactor (the minimum age of any commercial spent nuclear fuel for acceptance at the repository), the dominant radioactive constituent in the crud is cobalt-60, which accounts for 98 percent of the activity (Sandoval et al. 1991, page 15). Cobalt-60 concentration measurements have been made on several boiling-water and pressurized-water reactor fuel rods; the results indicate that the maximum activity density is 0.0000094 curie per square centimeter for pressurized-water reactors and 0.000477 curie per square centimeter for boiling-water reactors (Sandoval et al. 1991, pages 14 and 15). The maximum values are about twice the average value over the length of the fuel rod (Sandoval et al. 1991, page 14). Accordingly, the values used in these source term determinations were 0.00005 for pressurized-water

Table H-4. Inventory used for typical reactor fuel (curies per assembly).[a,b]

Isotope	Pressurized-water reactor	Boiling-water reactor
Hydrogen-3	9.8×10^{1}	3.4×10^{1}
Carbon-14	6.4×10^{-1}	3.0×10^{-1}
Chlorine-36	5.4×10^{-3}	2.2×10^{-3}
Cobalt-60[c]	1.4×10^{1}	2.0×10^{1}
Nickel-59	1.3	3.5×10^{-1}
Nickel-63	1.8×10^{2}	4.6×10^{1}
Selenium-79	2.3×10^{-1}	7.9×10^{-2}
Krypton-85	9.3×10^{2}	2.9×10^{2}
Strontium-90	2.1×10^{4}	7.1×10^{3}
Zirconium-93	1.2	4.8×10^{-1}
Niobium-93m	8.2×10^{-1}	3.5×10^{-1}
Niobium-94	5.8×10^{-1}	1.9×10^{-2}
Technetium-99	7.1	2.5
Rhodium-102	1.2×10^{-3}	2.8×10^{-4}
Ruthenium-106	4.8×10^{-3}	6.7×10^{-4}
Palladium-107	6.3×10^{-2}	2.4×10^{-2}
Tin-126	4.4×10^{-1}	1.5×10^{-1}
Iodine-129	1.8×10^{-2}	6.3×10^{-3}
Cesium-134	1.6×10^{1}	3.4
Cesium-135	2.5×10^{-1}	1.0×10^{-1}
Cesium-137	3.1×10^{4}	1.1×10^{4}
Samarium-151	1.9×10^{2}	6.6×10^{1}
Lead-210	2.2×10^{-7}	9.4×10^{-8}
Radium-226	9.3×10^{-7}	3.7×10^{-7}
Radium-228	1.3×10^{-10}	4.7×10^{-11}
Actinium-227	7.8×10^{-6}	3.1×10^{-6}
Thorium-229	1.7×10^{-7}	6.1×10^{-8}
Thorium-230	1.5×10^{-4}	5.8×10^{-5}
Thorium-232	1.9×10^{-10}	6.9×10^{-11}
Protactinium-231	1.6×10^{-5}	6.0×10^{-6}
Uranium-232	1.9×10^{-2}	5.5×10^{-3}
Uranium-233	3.3×10^{-5}	1.1×10^{-5}
Uranium-234	6.6×10^{-1}	2.4×10^{-1}
Uranium-235	8.4×10^{-3}	3.0×10^{-3}
Uranium-236	1.4×10^{-1}	4.8×10^{-2}
Uranium-238	1.5×10^{-1}	6.2×10^{-2}
Neptunium-237	2.3×10^{-1}	7.3×10^{-2}
Plutonium-238	1.7×10^{3}	5.5×10^{2}
Plutonium-239	1.8×10^{2}	6.3×10^{1}
Plutonium-240	2.7×10^{2}	9.5×10^{1}
Plutonium-241	2.0×10^{4}	7.5×10^{3}
Plutonium-242	9.9×10^{-1}	4.0×10^{-1}
Americium-241	1.7×10^{3}	6.8×10^{2}
Americium-242/242m	1.1×10^{1}	4.6
Americium-243	1.3×10^{1}	4.9
Curium-242	8.7	3.8
Curium-243	8.3	3.1
Curium-244	7.0×10^{2}	2.5×10^{2}
Curium-245	1.8×10^{-1}	6.3×10^{-2}
Curium-246	3.8×10^{-2}	1.3×10^{-2}
Curium-247	1.3×10^{-7}	4.3×10^{-8}
Curium-248	3.9×10^{-7}	1.2×10^{-7}
Californium-252	3.1×10^{-8}	6.0×10^{-9}

a. Source: Appendix A, except cobalt-60.

b. Inventory numbers have been rounded to two significant figures.

c. Cobalt-60 inventory in crud, as calculated in this appendix.

reactors and 0.00025 for boiling-water reactors. Using the fuel rod dimensions and the number of rods per fuel assembly from Appendix A, these concentrations produce the following total inventory of cobalt-60 for a pressurized-water reactor fuel assembly at discharge:

Cobalt-60 inventory (per assembly) = fuel rod surface area per assembly × cobalt-60 concentration
= fuel rod diameter × π
× fuel rod length × number of fuel rods per assembly
× cobalt 60 concentration

For pressurized-water reactor assemblies, the corresponding values are (from Appendix A):

Pressurized-water reactor cobalt-60 inventory (per assembly) = 0.95 centimeters × 3.14
× 366 centimeters × 264 rods
× 0.00005 curie per square centimeter
≅ 14 curies per pressurized-water reactor fuel assembly (at reactor discharge)

For boiling-water reactor assemblies, the corresponding values are (from Appendix A):

Boiling-water reactor cobalt-60 inventory (per assembly) = 1.25 centimeters × 3.14
× 366 centimeters × 55 rods
× 0.00025 curie per square centimeter
≅ 20 curies per boiling-water reactor fuel assembly (at reactor discharge)

The analysis used these concentrations, decayed to appropriate levels (25.9 years for pressurized-water reactor fuel and 27.2 years for boiling-water reactor fuel, from Table H-3), to obtain the final cobalt-60 inventory used in the source term determination.

The amount of crud that would be released from the surface of the fuel rod cladding is uncertain because there are very few data for the accident conditions of interest, and the physical condition of the crud can be highly variable (Sandoval et al. 1991, page 18). Two sources (NRC 1997, Table 7-1; NRC 1998, Table 4-1) recommend a release fraction of 1.0 (100 percent of the cobalt-60) for accident conditions; therefore, the EIS analysis assumed this value.

Following their release from the cladding, some crud particles would be retained by deposition on the surrounding surfaces (the fuel assembly cladding, spacer grids and structural hardware). The estimated fraction of released particles deposited on these surfaces would be 0.9 (SNL 1987, page 5-27), resulting in an escape fraction of 0.1. In accidents involving casks or canisters, additional surfaces represented by these components would offer surfaces for further plateout.

The inhalation radiation dose from cobalt-60 (or any radioactive particle) depends on the amount of particulate material inhaled into and remaining in the lungs (called the respirable fraction). The analysis assumed that the respirable fraction would be 0.05 (based on Wilmot 1981, page B-3). Therefore, the analysis assumed that the total cobalt-60 respirable airborne release fraction would be 0.005 (the escape fraction of 0.1 multiplied by the respirable fraction of 0.05) for accident scenarios involving commercial spent nuclear fuel assemblies.

H.2.1.4.1.2 Fuel Rod Gap. The space between the fuel rod cladding and the fuel pellets (called the *gap*) contains fission products released from the fuel pellets during reactor operation. The only potentially important radionuclides in the gap are the gases tritium (hydrogen-3) and krypton-85, and the volatile radionuclides strontium-90, cesium-134, cesium-137, ruthenium-106, and iodine-129 (NRC 1997, page 7-6). The Nuclear Regulatory Commission recommends fuel rod release fractions (the fraction of the total fuel rod inventory) of 0.3 for tritium and krypton-85, 0.000023 for the strontium and cesium components, 0.000015 for ruthenium-106, and 0.1 for iodine under accident conditions that rupture the cladding (NRC 1997, page 7-6). The release fraction for the gases (tritium and krypton), as expected, would be rather high because most of the gas would be in the fuel rod gap and under pressure inside the fuel rod. The analysis also considered the fraction of the rods damaged in a given accident scenario. SNL (1987, page 6-19 *et seq.*) assumed that the fraction of damaged fuel pins in each assembly involved in a collision or drop accident scenario would be 20 percent. Another assessment (Kappes 1998, page 18) assumed that any drop of the fuel rods in a fuel assembly or basket of assemblies would result in failure of 10 percent of the fuel rods, regardless of the drop distance. Because neither value seems to have a strong basis, the EIS analysis assumed the more conservative 20-percent figure. For the particulate species released from the gap, the analysis applied a retention factor of 0.9 (escape factor of 0.1) to account for local deposition of the particles on the fuel assembly structures, consistent with SNL (1987, page 5-27). SNL (1987, page 5-28) also applies a similar factor to account for retention on the failed shipping cask structures for accident scenarios involving cask failure. However, the EIS analysis judged that this factor does not have a strong basis, especially because the actual mode of cask failure is unknown. For accident scenarios that could rupture the cask, surfaces on the cask structure might not be in the path of the released material and, therefore, would not be a potential deposition site. Furthermore, particulate material, which would escape local deposition on the fuel assembly surfaces, probably would be less susceptible to deposition on surfaces it encountered subsequently. Therefore, the analysis assumed no retention factor for cask structures. The final consideration is the fraction of remaining airborne particulates that would be respirable. No specific reference could be found to the volatile materials in the gap. The analysis conservatively assumed, therefore, that the respirable fraction would be 1.0.

H.2.1.4.1.3 Fuel Pellet. During reactor operation, the fuel pellets undergo cracking from thermal and mechanical stresses. This produces a small amount of pellet particulate material that contains radionuclides. The analysis assumed that the radionuclides are distributed evenly in the fuel pellets so that the fractional release of the pellet particulates is equivalent to the same fractional release of the total inventory of the appropriate radionuclides in the fuel. If the fuel cladding failed during an accident, a fraction of these particulates would be small enough (diameter less than 10 micrometers) for release to the atmosphere and would be respirable (small enough to remain in the lungs if inhaled). Sandia National Laboratories estimates this fraction to be 0.000001 (SNL 1987, page 5-26) based on experiments performed at Oak Ridge National Laboratory. The EIS used this value to develop source terms for the accident scenarios considered. Additional particulates could be produced by pulverization due to mechanical stresses imposed on the fuel pellets from the accident conditions. This pulverization factor has been evaluated in SNL (1987, page 5-17) and applied in Kappes (1998, page I-3). Based on experimental results involving bare fuel pellets, the analysis determined that the fraction likely to be pulverized into respirable particles would be proportional to the drop height (which is directly proportional to energy input) and would be:

$2.0 \times 10^{-7} \times$ energy partition factor $\times$ unimpeded drop height (centimeters) (Kappes 1998, page I-3).

The energy partition factor is the fraction of the impact energy that is available for pellet pulverization. A large fraction of the impact energy is expended in deforming the fuel assembly structures and rupturing the fuel rod cladding. It has been estimated (SNL 1987, page 5-25) that the energy partition factor is 0.2.

As indicated above, some of the dispersible pellet particulates released in the accident could deposit on surfaces in the vicinity of the damaged fuel. Consistent with the particulate material considered above, the estimated fraction that would not deposit locally and would remain airborne would be 0.1 based on

SNL (1987, page 5-26). Based on these considerations, the respirable airborne release fraction produced from pulverization of the fuel pellets would be:

$$\begin{aligned}\text{Respirable airborne release fraction} &= 2 \times 10^{-7} \times \text{drop height (centimeters)} \\ &\quad \times \text{energy partition factor} \times \text{fraction not deposited} \\ &\quad \times \text{fuel rod damage fraction} \\ &= 2 \times 10^{-7} \times \text{drop height} \\ &\quad \times 0.2 \times 0.1 \\ &\quad \times 0.2 \\ &= 8 \times 10^{-10} \times \text{drop height}\end{aligned}$$

This result is reasonably consistent with the value of 8×10^{-7} from SAIC (1998, page 3-9), which is characterized as a bounding value for the respirable airborne release fraction for accident scenarios that would impose mechanical stress on fuel pellets for a range of energy densities (drop heights). This value would correspond to a drop from 1,000 centimeters (10 meters or 33 feet) based on the formulation above.

H.2.1.4.1.4 Conclusions. Table H-5 summarizes the source term parameters for commercial spent nuclear fuel drop accident scenarios, as discussed above.

Table H-5. Source term parameters for commercial spent nuclear fuel drop accident scenarios.

Radionuclide[a]	Location	Damage fraction	Release fraction	Fraction not deposited	Respirable fraction	Respirable airborne release fraction
Co-60	Clad surface	1.0	1.0	0.1	0.05	0.005
H-3, Kr-85, C-14	Gap	0.2	0.3	1.0	1.0	0.06
I-129	Gap	0.2	0.1	1.0	1.0	0.02
Cs-137, Sr-90	Gap	0.2	2.3×10^{-5}	0.1	1.0	4.6×10^{-7}
Ru-106	Gap	0.2	1.5×10^{-5}	0.1	1.0	3.0×10^{-7}
All solids	Gap (existing fuel fines)	0.2	1.0×10^{-6}	0.1	1.0	2.0×10^{-8}
All solids	Pellet-pulverization	0.2	$4.0\times10^{-8} \times h$[b]	0.1	1.0	$8.0\times10^{-10} \times h$[b]

a. Abbreviations: Co = cobalt; H = hydrogen (H-3 = tritium); Kr = krypton; C = carbon; I = iodine; Cs = cesium; Sr = strontium; Ru = ruthenium.

b. h = drop height in centimeters.

H.2.1.4.2 *Transporter Runaway and Derailment Accident Source Term*

This accident, as noted in Section H.2.1.3, would involve the runaway and derailment of the waste package transporter. It assumes the ejection of the waste package from the transporter during the event; the waste package would be split open by impact on the access tunnel wall. The calculated maximum impact speed would be 18 meters per second (38 miles per hour) (DOE 1997b, page 98). This analysis assumed that the source term from the damage to the 21 pressurized-water reactor fuel assemblies in the waste package is equivalent to a drop height that would produce the same impact velocity (equivalent to the same energy input). The equivalent drop height was computed from basic equations for the motion of a body falling under the influence of gravity:

$$\text{velocity} = \text{acceleration} \times \text{time}$$

and,

$$\text{distance} = \tfrac{1}{2} \times \text{acceleration} \times \text{time squared}$$

where: velocity = velocity of the impact (18 meters per second)

time = time required for the fall
acceleration = acceleration due to gravity (9.8 meters per second squared)

By substitution,

$$\begin{aligned} \text{distance} &= \tfrac{1}{2} \times \text{acceleration} \times (\text{velocity} \div \text{acceleration})^2 \\ &= (\text{velocity})^2 \div (\text{acceleration} \times 2) \\ &= (18)^2 \div (9.8 \times 2) \\ &= 16 \text{ meters} \end{aligned}$$

Thus, the calculation of the source term for this accident scenario assumed a drop height of 16 meters and used the parameters in Table H-5 for the various nuclide groups.

H.2.1.4.3 *DOE Spent Nuclear Fuel Drop Accident Source Term*

Appendix A lists the various types of DOE spent nuclear fuel and high-level radioactive waste that the Department would place in the proposed repository. A review of the inventory indicates that the spent nuclear fuel from the Hanford Site (N-Reactor fuel) represents a large percentage of DOE spent nuclear fuel. The N-Reactor fuel also has one of the highest radionuclide inventories of any of the DOE spent fuels. Although a canister of naval spent nuclear fuel would have a higher radionuclide inventory than a canister of N-Reactor fuel (Appendix A, Table A-18), the amount of radioactive material that would be released from a naval canister during this hypothetical accident scenario would be less than the amount released from an N-Reactor fuel canister due to the highly robust design of naval fuel (Appendix A, Section A.2.2.5.3) (USN 1996, all). Therefore, DOE selected N-Reactor spent nuclear fuel material as the bounding form to represent the source term for accidents that would involve DOE material. The analysis derived the source term for accidents involving a drop of N-Reactor fuel from DOE (1995, page 5-88), which lists the estimated source term for a drop of a cask containing 1,000 kilograms (2,200 pounds) of N-Reactor fuel from a height of 4.6 meters (15 feet). For the repository accident scenario involving N-Reactor fuel, a total of 4,800 kilograms (10,600 pounds) of fuel would be involved in a multi-canister overpack drop (Appendix A) from a height of 6.3 meters (21 feet), as noted above. The analysis adjusted the DOE (1995, page 5-88) source term upward by a factor of 4.8 to account for the increased amount of material involved (4,800 kilograms as opposed to 1,000 kilograms), and by a factor of 1.37 to account for the increased drop height (6.3/4.6) because the analysis assumed the source term would be proportional to the energy input, which is proportional to the drop height. These two factors were applied to the DOE (1995, page 5-88) source term and the result is listed in Table H-6. The behavior of N-Reactor fuel during an accident is uncertain (Kappes 1998, page 15) and the Final EIS analysis might utilize a revised source term estimate based on the results of further studies of this fuel. Furthermore, DOE has not developed the requirements for receipt of the fuel at the repository. These requirements could influence the source term, as could the corresponding requirements for processing the fuel prior to shipment.

H.2.1.4.4 *Seismic Accident Scenario Source Term*

Waste Handling Building. In this event, as noted in Section H.2.1.3, the Waste Handling Building could collapse from a beyond-design-basis earthquake. Bare fuel assemblies being transferred during the event would be likely to drop to the floor and concrete from the ceiling could fall on the fuel assemblies, causing damage that could result in radioactive release, which would discharge to the atmosphere through the damaged roof. In addition, other radioactive material stored or being handled in the Waste Handling Building could be vulnerable to damage. To estimate the source term, the analysis evaluated the extent of damage to the fuel rods and pellets for the assemblies being transferred and then examined the other material that could be vulnerable.

Table H-6. Source term used for N-Reactor Mark IV fuel drop accident scenario analysis (curies).[a]

Radionuclide	Total release	Radionuclide	Total release	Radionuclide	Total release
Tritium (H$_3$)	1.7×10^{-2}	Tin-119m	1.7×10^{-8}	Europium-154	8.3×10^{-2}
Carbon-14	2.6×10^{-4}	Tin-121m	3.0×10^{-5}	Uranium-234	1.7×10^{-4}
Iron-55	1.3×10^{-3}	Tin-126	5.6×10^{-5}	Uranium-235	5.7×10^{-6}
Nickel-59	1.4×10^{-5}	Stibium-125 (antimony)	2.4×10^{-2}	Uranium-236	3.3×10^{-5}
Nickel-63	1.7×10^{-3}	Stibium-126	7.9×10^{-6}	Uranium-238	1.4×10^{-4}
Cobalt-60	5.4×10^{-2}	Stibium-126m	5.6×10^{-5}	Neptunium-237	2.6×10^{-5}
Selenium-79	2.9×10^{-5}	Tellurium-125m	6.7×10^{-3}	Plutonium-238	7.9×10^{-2}
Krypton-85	2.4×10^{-2}	Iodine-129	2.3×10^{-6}	Plutonium-239	7.3×10^{-2}
Strontium-90	3.6	Cesium-134	2.3×10^{-2}	Plutonium-240	5.9×10^{-2}
Yttrium-90	3.6	Cesium-135	2.6×10^{-5}	Plutonium-241	4.3
Niobium-93m	7.2×10^{-5}	Cesium-137	4.9	Plutonium-242	4.9×10^{-5}
Zirconium-93	1.3×10^{-4}	Cerium-144	8.9×10^{-5}	Americium-241	1.7×10^{-1}
Technetium-99	9.7×10^{-4}	Praseodymium-144	8.9×10^{-5}	Americium-242	3.9×10^{-4}
Ruthenium-106	8.0×10^{-4}	Praseodymium-144m	1.1×10^{-6}	Americium-242m	3.9×10^{-4}
Palladium-107	6.7×10^{-6}	Promethium-147	2.4×10^{-1}	Americium-243	5.4×10^{-5}
Silver-110m	1.3×10^{-8}	Samarium-151	4.6×10^{-2}	Curium-242	3.2×10^{-4}
Cadmium-113m	1.6×10^{-3}	Europium-152	4.9×10^{-4}	Curium-244	2.4×10^{-2}

a. Source: DOE (1995, page 5-88), with adjustments as noted above.

The ceiling of the transfer cell, which would consist of concrete 20 to 25 centimeters (8 to 10 inches) thick, would be about 15 meters (50 feet) high (TRW 1999b, Attachment IV, Figure 13). Typical pressurized-water reactor fuel assemblies weigh 660 kilograms (1,500 pounds) each (see Appendix A). The assemblies are about 21 centimeters (8.3 inches) wide by about 410 centimeters (160 inches) long, for an effective cross-sectional area (horizontal) of 1 square meter (11 square feet) (SNL 1987, page 5-2). The weight of a single fuel assembly is roughly equivalent to a 25-centimeter-thick concrete block with a 1-square-meter cross-section [about 750 kilograms (1,700 pounds) based on a density of 2.85 grams per cubic centimeter (180 pounds per cubic foot) (CRC 1997, page 15-28)]. Thus, as a first approximation, the analysis assumed that the concrete blocks falling from the ceiling onto the fuel assemblies would produce about the same energy as the fuel assemblies falling from the same height.

Some of the energy imparted to the fuel assemblies from the falling debris would be absorbed in deforming the fuel assembly structures and, thus, would not be available to pulverize the fuel pellets. As evaluated above for falling fuel assemblies, this energy absorption factor would result in an estimated 20 percent of the energy being imparted to the pellets and the rest absorbed by the structure (SNL 1987, page 5-25). Finally, as noted above, the analysis used a 0.1 release factor (0.9 retention) to represent the retention of the released fuel particles by deposition on the cladding and other fuel assembly structures (SNL 1987, page 5-27). In addition, it assumed that additional retention would be associated with the concrete and other rubble that would be on top, or in the vicinity, of the fuel assemblies. It assumed this release factor would be 0.1 (0.9 retention) consistent with that used by SNL (1987, page 5-28) for retention by deposition on the cask and canister materials that surround the fuel assemblies during accident scenarios. It also assumed a fuel pellet pulverization factor of $8 \times 10^{-10} \times h$, the same as that used for fuel assembly drop accident scenarios. Thus, the overall pellet respirable airborne release fraction for the fuel pellet particulates is:

$$\begin{aligned}\text{Respirable airborne release fraction} &= 8 \times 10^{-10} \times \text{drop height (centimeters)} \times \text{rubble retention}\\ &= 8 \times 10^{-10} \times 1{,}500 \times 0.1\\ &= 1.2 \times 10^{-6}\end{aligned}$$

Other radioactive materials either stored or being handled in the Waste Handling Building could also be at risk. For material in casks and canisters and waste packages, the analysis assumed that the damage potential from falling debris would not be great enough to cause a large radionuclide release. This is based on the fact that canisters and casks are quite robust and that, even if the containers were breached by the energy of the impact, there would be very little energy remaining to cause fuel pellet pulverization. There could be, however, bare fuel assemblies exposed in the dryers and in disposal containers awaiting lid attachment. An estimated 375 bare pressurized-water reactor fuel assemblies could be exposed to falling debris (Montague 1999, page 1). The location of this material would be as follows:

- Assembly transfer system dryers: 25 pressurized-water reactor assemblies
- Disposal canister handling system welding stations: 346 pressurized-water reactor assemblies
- Transfer operations: four pressurized-water reactor assemblies

Because the concrete roof heights over these areas would be roughly the same as the assembly transfer system area in the Waste Handling Building [15 meters (50 feet)] where the analysis assumed the four bare pressurized-water reactor assemblies would be involved, the analysis assumed the pellet pulverization contribution to the source term to be equivalent to that for the fuel assemblies being transferred. The overall source term, then, was determined by assuming 375 typical pressurized-water reactor assemblies with the release fractions listed in Table H-5.

Boiling-water reactor fuel assemblies could be exposed at these areas, but the analysis evaluated only pressurized-water reactor fuel assemblies because they would result in a slightly higher source term under equivalent accident conditions and would be more likely to be involved because they would comprise a larger amount of material (see Appendix A) to be received at the repository. Thus, the source term for the seismic event would be 375 typical pressurized-water reactor fuel assemblies (Table H-4) with release fractions based on Table H-5.

Waste Treatment Building. It is assumed that the radionuclide concentration for the dry compactable waste in the Waste Treatment Building would be similar to that for power reactors (McFeely 1998, page 2). This material would consist of paper, plastic, and cloth with a specific activity of 0.025 curie per cubic meter (0.7 millicurie per cubic foot) (McFeely 1998, page 2). This activity would consist primarily of cobalt isotopes (primarily cobalt-60) representing 67 percent of the total activity, and cesium, which would contribute 28 percent of the total (McFeely 1999, all).

The Waste Treatment Building would operate a single shift per day, and would continuously process waste such that no large accumulation would occur. Because Waste Handling Building operations would be likely to involve three shifts per day (TRW 1999b, Section 6.2), the analysis assumed that three shifts of solid waste would accumulate before the Waste Treatment Building began its single-shift operation. The generation rate of solid compactible waste would be about 1,500 cubic meters (53,000 cubic feet) per year (DOE 1997a, page 32) or about 0.17 cubic meter (5.8 cubic feet) per hour. Thus, three shifts (24 hours) of Waste Handling Building operation would produce about 4.0 cubic meters (140 cubic feet) of solid compactible waste. The total radionuclide inventory in this waste would be:

Cobalt-60 = 4.0 cubic meters × 0.025 curie per cubic meters × 0.67 (cobalt-60 fraction)
≅ 0.07 curie

Cesium-137 = 4.0 cubic meters × 0.025 curie per cubic meters × 0.28 (cesium-137 fractions)
≅ 0.03 curie

The respirable airborne release fraction for a fire involving combustible low-level waste has been conservatively estimated at 0.4 (Mueller et al. 1996, page D-21). Thus, the respirable airborne release source term for the fire accident scenario would be:

Cobalt-60 = 0.07 curie × 0.4 = 0.028 curie
Cesium-137 = 0.03 curie × 0.4 = 0.012 curie

The assumed release height for the accident scenario is 2 meters (6.6 feet). This is the minimum release height for the consequences analysis and represents a ground-level release.

H.2.1.4.5 *Low-Level Waste Drum Failure Source Term*

As indicated in Section H.2.1.2, the most meaningful accident scenarios involving exposure to workers would be those related to puncture or rupture of waste drums that contained low-level waste. Such events could occur during handling operations and probably would involve the puncture of a drum by a forklift, or the drop of the drum during stacking and loading operations.

Two types of waste drums would contain the processed waste. Concentrated liquid waste would be mixed with cement and poured into 0.21-cubic-meter (55-gallon) drums. Compacted and noncompacted solid waste would also be placed in the same drums, which would, in turn, be placed in 0.32-cubic-meter (85-gallon) drums with the space between the two drums grouted. The probability of a drum failure was analyzed for these two drum types.

Following a drum failure, some fraction of the radionuclides in the waste would be released and workers in the immediate vicinity could be exposed to the material. The amount released would depend on the radionuclide concentration in the low-level waste material, the fraction of low-level waste released from the drum on its failure, and the respirable airborne release fraction from the released waste.

For liquid waste, the concentration of radionuclides is expected to be (McFeely 1998, page 3):

Cobalt-60 = 0.001 curie per cubic meter
Cesium-137 = 0.0015 curie per cubic meter

As noted in Section H.2.1.2, the evaporator would concentrate the liquid waste down to 10 percent of the original generated so the concentration of radionuclides in the waste would be increased to:

Cobalt 60 = 0.01 curie per cubic meter
Cesium-137 = 0.015 curie per cubic meter

The grouting operation would dilute this concentration somewhat by adding cement, but this dilution has been ignored for conservatism.

The total activity in a 0.21-cubic meter (55-gallon) drum would become:

Cobalt-60 = 0.01 curie per cubic meter × 0.21 cubic meter
≅ 0.0021 curie per drum

Cesium-137 = 0.015 curie per cubic meter × 0.21 cubic meter
≅ 0.0032 curie per drum

For dry compacted waste, the total inventory in a 0.21-cubic-meter (55-gallon) drum would be

Cobalt-60 = 0.21 cubic meter × 0.025 curie per cubic meter × 0.67 (cobalt-60 fraction)
≅ 0.0035 curie

Cesium-137 = 0.21 cubic meter × 0.025 curie per cubic meter × 0.28 (cesuim-137 fraction)
≅ 0.0015 curie

The estimated amount of material released from drums containing solid waste is 25 percent of the contents based on Mueller et al. (1996, page 94). Values from Mueller et al. (1996, all) were used for the respirable airborne release fraction. For dry waste, the recommended respirable airborne release fraction is 0.001. For grouted liquid waste, this fraction is determined by the following equation:

Respirable airborne release fraction = $A \times D \times G \times H$

where:

A = constant (2.0×10^{-11}) (Mueller et al. 1996, page D-25)
D = material density [3.14 grams per cubic centimeter (196 pounds per cubic foot)] (McFeely 1998, all)
G = gravitational acceleration [980 centimeters (32.2 feet) per second squared]
H = height of fall of the drum in the accident scenario

The assumed height of the fall is 2 meters (6.6 feet), which would be the approximate maximum lift height when the drum was stacked on another drum or placed on a carrier for offsite transportation. This same formula applies to drum puncture accident scenarios (Mueller et al. 1996, page D-30), and the 2-meter drop event would be equivalent in damage potential to a forklift impact at about 4.5 meters per second (10 miles per hour). The respirable airborne release fraction for this case then becomes:

Respirable airborne release fraction = $2.0 \times 10^{-11} \times 3.14 \times 980 \times 200$
≅ 1.23×10^{-5}

Based on these results, the worker risk would be dominated by accidents involving drums that contained dry waste because both the frequency of the event [0.59 versus 0.46 (Section H.2.1.2)] and the release fraction [1×10^{-3} versus 1.23×10^{-5} (derived above)] would be greater. The total amount of airborne respirable material release (source term) for the risk-dominant dry waste accident scenario would be:

Cobalt-60 = 0.0035 curie (total drum inventory) × 0.25 (fraction released)
× 0.001 (respirable airborne release fraction)
≅ 8.5×10^{-7} curies

Cesium-137 = 0.0015 curie (total drum inventory) × 0.25 (fraction released)
× 0.001 (respirable airborne release fraction)
≅ 3.8×10^{-7} curies

The analysis assumed that, following normal industrial practice, workers would not be in the area beneath suspended objects. Accordingly, the nearest worker was assumed to be 5 meters (16 feet) from the impact area. Therefore, the volume assumed for dispersion of the material prior to reaching the worker would be 125 cubic meters (4,400 cubic feet), which represents the immediate vicinity of the accident location [a volume approximately 5 meters (16 feet) by 5 meters by 5 meters]. The breathing rate of the worker would be 0.00035 cubic meter (about 0.012 cubic foot) per second (ICRP 1975, page 346).

H.2.1.5 Assessment of Accident Scenario Consequences

Accident scenario consequences were calculated as individual doses (rem), collective doses (person-rem), and latent cancer fatalities. The receptors considered were (1) the maximally exposed offsite individual, defined as a hypothetical member of the public at the point on the proposed repository land withdrawal boundary who would receive the largest dose from the assumed accident scenario (a minimum distance of 11 kilometers (7 miles), (2) the maximally exposed involved worker, the hypothetical worker who would be nearest the spent nuclear fuel or high-level radioactive waste when the accident occurred, (3) the noninvolved worker, the hypothetical worker near the accident but not involved in handling the material, assumed to be 100 meters (about 330 feet) from the accident, and (4) the members of the public who reside within about 80 kilometers (50 miles) of the proposed repository.

For radiation doses below about 20 rem and low dose rates (below 10 rem per hour), potential health effects would be those associated with a chronic exposure or an increase in the risk of fatal cancer (ICRP 1991, Chapter 3) (see the discussion in Appendix F, Section F.1). The International Committee on Radiation Protection has recommended the use of a conversion factor of 0.0005 fatal cancer per person-rem for the general population for low doses, and a value of 0.0004 fatal cancer per person-rem for workers for chronic exposures. The higher value for the general population accounts in part for the fact that the general population contains young people, who are more susceptible to the effects of radiation. These conversion factors were used in the EIS consequence analysis. The latent cancer fatality caused by radiation exposure could occur at any time during the remaining lifetime of the exposed individual. As dose increases above about 15 rem over a short period (acute exposures), observable physical effects can occur, including temporary male sterility (ICRP 1991, page 15). At even higher acute doses (above about 500 rem), death within a few weeks is probable (ICRP 1991, page 16).

DOE used the MACCS2 computer program (Rollstin, Chanin, and Jow 1990, all; Chanin and Young 1998, all) and the radionuclide source terms for the identified accident scenarios in Section H.2.1.4 to calculate consequences to receptors. This program, developed by the U.S. Nuclear Regulatory Commission and DOE, has been widely used to compute radiological impacts from accident scenarios involving releases of radionuclides from nuclear fuel and radioactive waste. DOE used this program for offsite members of the public, the maximally exposed offsite individual, and the noninvolved worker. The MACCS2 program calculates radiological doses based on a sampling of the distribution of weather conditions for a year of site-specific weather data. Meteorological data were compiled at the proposed repository site from 1993 through 1997. This analysis used the weather conditions for 1993. The selection of 1993 was based on a sensitivity analysis that showed that, on the average, the weather conditions for 1993 produced somewhat higher consequences than those for the other years for most receptors, although the variation from year to year was small.

For exposure to inhaled radioactive material, it was assumed (in accordance with U.S. Environmental Protection Agency guidance) that doses would accumulate in the body for a total of 50 years after the accident (Eckerman, Wollbarst, and Richardson 1988, page 7). For external exposure (from ground contamination and contaminated food consumption), the dose was assumed to accumulate for 70 years (DOE 1993, page 21).

The MACCS2 program provides doses to selected receptors for a contiguous spectrum of site-specific weather conditions. Two weather cases were selected for the EIS: (1) a median weather case (designated at 50 percent) that represents the weather conditions that would produce median consequences to the receptors, and (2) a 95 percent weather case that provides higher consequences that would only be exceeded 5 percent of the time.

The MACCS2 program is not suitable for calculating doses to receptors near the release point of radioactive particles [within about 100 meters (330 feet)]. For such cases, the analysis calculated involved worker dose estimates using a breathing rate of 0.00035 cubic meter (0.012 cubic foot) per second (ICRP 1975, page 346). For involved worker dose calculations from accident scenarios in the cask transfer and handling area, the analysis assumed that the worker would be a minimum of 4.6 meters (15 feet) from the location of the cask impact with the floor during the accident (normal industrial practice would preclude workers from being in the immediate vicinity of areas where heavy objects could strike the floor during lifting operations). Because of the perceived hazard following a breached cask, the analysis assumed that the worker would immediately vacate the area after observing that the cask had ruptured. Accordingly, the analysis assumed that the worker would breathe air containing airborne radioactive material from the ruptured cask for 10 seconds.

For involved worker doses from the drum handling accident scenario, the analysis assumed that the worker (a forklift operator) would be 3 meters (10 feet) from the drum rupture location, and would breathe air containing radioactive material from the ruptured drum for 30 seconds.

The involved worker dose estimates used the same dose conversion factors as those used by the MACCS2 program for inhalation exposure.

The analysis assumed that the population around the repository would be that projected for the year 2000 (see Appendix G, Table G-44). The exposed population would consist of individuals living within about 80 kilometers (50 miles) of the repository, including pockets of people who would reside just beyond the 80-kilometer distance. The dose calculations included impacts from the consumption of food contaminated by the radionuclide releases. The contaminated food consumption analysis used site-specific data on food production and consumption for the region around the proposed site (TRW 1997b, all). For conservatism, the analysis assumed no mitigation measures, such as post-accident evacuation or interdiction of contaminated foodstuffs. However, DOE would take appropriate mitigation actions in the event of an actual release.

The results of the consequence analysis are listed in Tables H-7 (for 50-percent weather) and H-8 (for 95-percent weather). These tables list doses in rem for individual receptors and in person-rem (collective dose to all exposed persons) for the 80-kilometer (50-mile) population around the site. For selected receptors, as noted, the tables list estimated latent cancer fatalities predicted to occur over the lifetime of the exposed receptors as a result of the calculated doses using the conversion factors described in this section. These estimates do not consider the accident frequency. For comparison, in 1995 the lifetime incidence of fatal cancer from all causes for Nevada residents was 0.24 (CDC 1998, page 215). Thus, the estimated latent cancer fatalities for the individual receptors from accidents would be very small in comparison to the cancer incidence from other causes. For the 28,000 persons living within 80 kilometers of the site (see Appendix G), 6,720 (28,000 × 0.24) would be likely to die eventually of cancer. The accident of most concern for the 95-percent weather conditions (earthquake, Table H-8, number 14) would result only in an estimated 0.0072 latent cancer fatality for this same population.

H.2.2 NONRADIOLOGICAL ACCIDENT SCENARIOS

A potential release of hazardous or toxic materials during postulated operational accident scenarios at the repository would be very unlikely. Because of the large quantities of radioactive material, radiological considerations would outweigh nonradiological concerns. The repository would not accept hazardous waste as defined by the Resource Conservation and Recovery Act (40 CFR Parts 260 to 299). Some

Table H-7. Radiological consequences of repository operations accidents for median (50th-percentile) meteorological conditions.

		Maximally exposed offsite individual		Population		Noninvolved worker		Involved worker	
Accident scenario[a,b,c]	Frequency (per year)[a]	Dose (rem)	LCFi[d]	Dose (person-rem)	LCFp[d]	Dose (rem)	LCFi	Dose (rem)	LCFi
1. 6.9-meter drop of shipping cask in CTHA-61 BWR assemblies-no filtration	4.5×10^{-4}	1.9×10^{-3}	1.0×10^{-6}	5.5×10^{-2}	2.7×10^{-5}	9.4×10^{-1}	3.8×10^{-4}	76	3.0×10^{-2}
2. 7.1-meter drop of shipping cask in CTHA-26 PWR assemblies-no filtration	6.1×10^{-4}	2.3×10^{-3}	1.2×10^{-6}	6.6×10^{-2}	3.3×10^{-5}	1.1	4.4×10^{-4}	90	3.6×10^{-2}
3. 4.1-meter drop of shipping cask in CTHA-61 BWR assemblies- no filtration	1.4×10^{-3}	1.3×10^{-3}	6.5×10^{-7}	3.9×10^{-2}	2.0×10^{-5}	5.7×10^{-1}	2.3×10^{-4}	46	1.8×10^{-2}
4. 4.1-meter drop of shipping cask in CTHA-26 PWR assemblies-no filtration	1.9×10^{-3}	1.4×10^{-3}	7.0×10^{-7}	4.6×10^{-2}	2.3×10^{-5}	6.6×10^{-1}	2.6×10^{-4}	53	2.1×10^{-2}
5. 6.3-meter drop of MCO in CTS-10 N-Reactor fuel canisters-filtration	4.5×10^{-4}	3.7×10^{-7}	1.9×10^{-10}	1.1×10^{-5}	5.3×10^{-9}	1.1×10^{-4}	4.4×10^{-8}	(e)	(e)
6. 6.3-meter drop of MCO in CTS-10 N-reactor fuel canisters-no filtration	2.2×10^{-7}	1.2×10^{-3}	6.0×10^{-7}	3.4×10^{-2}	1.7×10^{-5}	3.6×10^{-1}	1.4×10^{-4}	(e)	(e)
7. 5-meter drop of transfer basket in ATS-8 PWR assemblies-filtration	1.1×10^{-2}	6.6×10^{-7}	3.3×10^{-10}	4.0×10^{-4}	2.0×10^{-7}	1.7×10^{-4}	6.8×10^{-8}	(e)	(e)
8. 5-meter drop of transfer basket in ATS-8 PWR assemblies-no filtration	2.8×10^{-7}	5.6×10^{-4}	2.8×10^{-7}	1.7×10^{-2}	8.6×10^{-6}	1.6×10^{-1}	6.4×10^{-5}	(e)	(e)
9. 7.6-meter drop of transfer basket in ATS-16 BWR assemblies-filtration	7.4×10^{-3}	5.1×10^{-7}	2.6×10^{-10}	2.9×10^{-4}	1.5×10^{-7}	1.3×10^{-4}	5.2×10^{-8}	(e)	(e)
10. 7.6-meter drop of transfer basket in ATS-16 BWR fuel assemblies-no filtration	1.9×10^{-7}	6.1×10^{-4}	3.1×10^{-7}	1.6×10^{-2}	8.2×10^{-6}	1.8×10^{-1}	7.2×10^{-5}	(e)	(e)
11. 6-meter drop of disposal container in DCHS-21 PWR assemblies-filtration	1.8×10^{-3}	1.8×10^{-6}	9.0×10^{-10}	1.0×10^{-3}	5.2×10^{-7}	5.0×10^{-4}	2.0×10^{-7}	(e)	(e)
12. 6-meter drop of disposal container in DCHS-21 PWR fuel assemblies-no filtration	8.6×10^{-7}	1.7×10^{-3}	8.5×10^{-7}	5.1×10^{-2}	2.5×10^{-5}	5.1×10^{-1}	2.0×10^{-4}	(e)	(e)
13. Transporter runaway and derailment in access tunnel-21 PWR assemblies-filtration-16-meter drop height equivalent	1.2×10^{-7}	4.3×10^{-3}	2.2×10^{-6}	1.1×10^{-1}	5.4×10^{-5}	1.5	6.0×10^{-4}	(f)	(f)
14. Earthquake - 375 PWR assemblies	2.0×10^{-5}	9.1×10^{-3}	4.6×10^{-6}	3.6×10^{-1}	1.8×10^{-4}	8.3	3.3×10^{-3}	(f)	(f)
15. Earthquake w/fire in WTB	2.0×10^{-5}	1.8×10^{-5}	9.0×10^{-9}	6.3×10^{-4}	3.2×10^{-7}	5.2×10^{-3}	2.1×10^{-6}	(f)	(f)
16. LLW drum rupture in WTB	0.59	6.1×10^{-10}	3.1×10^{-13}	2.1×10^{-8}	1.1×10^{-11}	1.4×10^{-7}	5.6×10^{-11}	7.0×10^{-5}	2.8×10^{-8}

a. Source: Kappes (1998, all). These frequency estimates are highly uncertain due to the preliminary nature of the repository design and are provided only to show potential accident sequence credibility. They represent conservative estimates based on the approach taken in Kappes (1998, all).

b. CTHA = Cask Transfer/Handling Area, CTS = Canister Transfer System, ATS = Assembly Transfer System, DCHS = Disposal Container Handling System, WTB = Waste Treatment Building.

c. To convert meters to feet, multiply by 3.2808.

d. LCFi is the likelihood of a latent cancer fatality for an individual who receives the calculated dose. LCFp is the number of cancers probable in the exposed population from the collective population dose (person-rem). These values were computed based on a conversion of dose in rem to latent cancers as recommended by the International Council on Radiation Protection as discussed in this section.

e. For these cases, the involved workers are not expected to be vulnerable to exposure during an accident because operations are done remotely. Thus, involved worker impacts were not evaluated.

f. For these events, involved workers would likely be severely injured or killed by the event; thus, no radiological impacts were evaluated. For the seismic event, as many as 39 people could be injured or killed in the Waste Handling Building, and as many as 36 in the Waste Treatment Building based on current staffing projections (TRW 1998c, pages 17 and 18).

Table H-8. Radiological consequences of repository operations accidents for unfavorable (95th-percentile) meteorological conditions.

		Maximally exposed offsite individual		Population		Noninvolved worker		Involved worker	
Accident scenario[a,b,c]	Frequency (per year)[a]	Dose (rem)	LCFi[d]	Dose (person-rem)	LCFp[d]	Dose (rem)	LCFi	Dose (rem)	LCFi
1. 6.9-meter drop of shipping cask in CTHA-61 BWR assemblies-no filtration	4.5×10^{-4}	7.2×10^{-3}	3.5×10^{-6}	1.7	8.6×10^{-4}	5.1	2.0×10^{-3}	76	3.0×10^{-2}
2. 7.1-meter drop of shipping cask in CTHA-26 PWR assemblies-no filtration	6.1×10^{-4}	8.0×10^{-3}	4.0×10^{-6}	2.1	1.1×10^{-3}	5.9	2.4×10^{-3}	90	3.6×10^{-2}
3. 4.1-meter drop of shipping cask in CTHA-61 BWR assemblies-no filtration	1.4×10^{-3}	4.3×10^{-3}	2.2×10^{-6}	1.3	6.5×10^{-4}	3.1	1.2×10^{-3}	46	1.8×10^{-2}
4. 4.1-meter drop of shipping cask in CTHA-26 PWR assemblies-no filtration	1.9×10^{-3}	5.2×10^{-3}	2.6×10^{-6}	1.5	7.8×10^{-4}	3.5	1.4×10^{-3}	53	2.1×10^{-2}
5. 6.3-meter drop of MCO in CTS-10 N-Reactor fuel canisters-filtration	4.5×10^{-4}	1.2×10^{-6}	6.0×10^{-10}	2.6×10^{-4}	1.3×10^{-7}	3.3×10^{-4}	1.3×10^{-7}	(e)	(e)
6. 6.3-meter drop of MCO in CTS-10 N-reactor fuel canisters-no filtration	2.2×10^{-7}	4.3×10^{-3}	2.2×10^{-6}	8.6×10^{-1}	4.3×10^{-4}	1.1	4.4×10^{-4}	(e)	(e)
7. 5-meter drop of transfer basket in ATS-8 PWR assemblies- filtration	1.1×10^{-2}	2.5×10^{-6}	1.3×10^{-9}	3.3×10^{-2}	1.6×10^{-5}	4.6×10^{-4}	1.8×10^{-7}	(e)	(e)
8. 5-meter drop of transfer basket in ATS-8 PWR assemblies-no filtration	2.8×10^{-7}	2.1×10^{-3}	1.1×10^{-6}	5.6×10^{-1}	2.8×10^{-4}	4.6×10^{-1}	1.8×10^{-4}	(e)	(e)
9. 7.6-meter drop of transfer basket in ATS-16 BWR assemblies-filtration	7.4×10^{-3}	2.1×10^{-6}	1.1×10^{-9}	2.4×10^{-2}	1.2×10^{-5}	3.8×10^{-4}	1.5×10^{-7}	(e)	(e)
10. 7.6-meter drop of transfer basket in ATS-16 BWR fuel assemblies-no filtration	1.9×10^{-7}	2.2×10^{-3}	1.1×10^{-6}	5.1×10^{-1}	2.6×10^{-4}	5.1×10^{-1}	2.0×10^{-4}	(e)	(e)
11. 6-meter drop of disposal container in DCHS-21 PWR assemblies-filtration	1.8×10^{-3}	7.3×10^{-6}	3.7×10^{-9}	8.6×10^{-2}	4.3×10^{-5}	1.3×10^{-3}	5.2×10^{-7}	(e)	(e)
12. 6-meter drop of disposal container in DCHS-21 PWR fuel assemblies-no filtration	8.6×10^{-7}	6.1×10^{-3}	3.1×10^{-6}	1.6	8.0×10^{-4}	1.3	5.2×10-4	(e)	(e)
13. Transporter runaway and derailment in access tunnel-21 PWR assemblies-filtration-16-meter drop height equivalent	1.2×10^{-7}	1.3×10^{-2}	6.5×10^{-6}	3.2	1.6×10^{-3}	3.9	1.6×10^{-3}	(f)	(f)
14. Earthquake - 375 PWR assemblies	2.0×10^{-5}	3.2×10^{-2}	1.6×10^{-5}	14	7.2×10^{-3}	7.0	2.8×10^{-2}	(f)	(f)
15. Earthquake w/fire in WTB	2.0×10^{-4}	5.8×10^{-5}	2.9×10^{-8}	2.1	1.1×10^{-5}	5.2×10^{-3}	2.1×10^{-6}	(f)	(f)
16. LLW drum rupture in WTB	0.59	1.9×10^{-9}	9.5×10^{-13}	7.5×10^{-7}	3.7×10^{-10}	1.4×10^{-7}	5.6×10^{-11}	7.0×10^{-5}	2.8×10^{-8}

a. Source: Kappes (1998, all). These frequency estimates are highly uncertain due to the preliminary nature of the repository design and are provided only to show potential accident sequence credibility. They represent conservative estimates based on the approach taken in Kappes (1998, all).

b. CTHA = Cask Transfer/Handling Area, CTS = Canister Transfer System, ATS = Assembly Transfer System, DCHS = Disposal Container Handling System, WTB = Waste Treatment Building.

c. To convert meters to feet, multiply by 3.2808.

d. LCFi is the likelihood of a latent cancer fatality for an individual who receives the calculated dose. LCFp is the number of cancers probable in the exposed population from the collective population dose (person-rem). These values were computed based on a conversion of dose in rem to latent cancers as recommended by the International Council on Radiation Protection, as discussed in this section.

e. For these cases, the involved workers are not expected to be vulnerable to exposure during an accident since operations are done remotely. Thus, involved worker impacts were not evaluated.

f. For these events, involved workers would likely be severely injured or killed by the event; thus, no radiological impacts were evaluated. For the seismic event, as many as 39 people could be injured or killed in the Waste Handling Building, and as many as 36 in the Waste Treatment Building based on current staffing projections (TRW 1998c, pages 17 and 18).

potentially hazardous metals such as arsenic or mercury could be present in the high-level radioactive waste. However, they would be in a solid glass matrix that would make the exposure of workers or members of the public from operational accidents highly unlikely. Appendix A contains more information on the inventory of potentially hazardous materials.

Some potentially nonradioactive hazardous or toxic substances would be present in limited quantities at the repository as part of operational requirements. Such substances would include liquid chemicals such as cleaning solvents, sodium hydroxide, sulfuric acid, and various solid chemicals. These substances are in common use at other DOE sites. Potential impacts to workers from normal industrial hazards in the workplace including workplace accidents were derived from DOE accident experience at other sites. These impacts include those from accident scenarios involving the handling of hazardous materials and toxic substances as part of typical DOE operations. Thus, the industrial health and safety impacts to workers include impacts to workers from accidents involving such substances.

Impacts to members of the public would be unlikely because the hazardous materials would be mostly liquid and solid so that a release would be confined locally. (For example, chlorine used at the site for water treatment would be in powder form, so a gaseous release of chlorine would be unlikely. Furthermore, the repository would not use propane as a heating fuel, so no potential exists for propane explosions or fires.) The potential for hazardous chemicals to reach surface water during the Proposed Action would be limited to spills or leaks followed immediately by a rare precipitation or snow melt event large enough to generate runoff. Throughout the project, DOE would install engineered measures to minimize the potential for spills or releases of hazardous chemicals and would comply with written plans and procedures to ensure that, if a spill did occur, it would be properly managed and remediated. The Spill Prevention Control and Countermeasures Plan that would be in place for Yucca Mountain activities is an example of the plans DOE would follow under the Proposed Action.

The construction phase could generate as many as 3,500 drums [about 730 cubic meters (26,000 cubic feet)] of solid hazardous waste, and emplacement operations could generate as much as 100 cubic meters (3,500 cubic feet) per year (TRW 1999b, Section 6.1). Maintenance operations and closure would generate similar or smaller waste volumes. DOE would accumulate this waste in onsite staging areas in accordance with the regulations of the Resource Conservation and Recovery Act. Emplacement and maintenance operation could generate as many as 2,700 liters (1,700 gallons) of liquid hazardous waste annually (TRW 1999b, Section 6.1). The construction and closure phases would not generate liquid hazardous waste. The generation, storage, packaging, and shipment off the site of solid and liquid hazardous waste would present a very small potential for accidental releases and exposures of workers. Although a specific accident scenario analysis was not performed for these activities, the analysis of human health and safety (see Chapter 4, Section 4.1.7.3) included these impacts to workers implicitly through the use of a data base that includes impacts from accidents involving hazardous and toxic materials. Impacts to members of the public would be unlikely.

H.3 Accident Scenarios During Retrieval

During retrieval operations, activities at the repository would be essentially the reverse of waste package emplacement, except operations in the Waste Handling Building would not be necessary because the waste packages would not be opened. The waste packages would be retrieved remotely from the emplacement drifts, transported to the surface, and transferred to a Waste Retrieval Storage Facility (TRW 1999b, Attachment I). This facility would include a Waste Retrieval Transfer Building where the waste packages would be unloaded from the transporter, transferred to a concrete storage unit, and moved to a concrete storage pad. The storage pad would be a 24- by 24-meter (80- by 80-foot) pad, about 1 meter (3.3 feet) thick, which probably would be about 3 kilometers (2 miles) over flat terrain from the

North Portal. Each storage pad would contain 14 waste packages. The number of pads required would depend on how many waste packages would be retrieved.

Because retrieval operations would be essentially the reverse of emplacement operations, accidents involving the disposal container during emplacement bound the retrieval operation. The bounding accident scenario during emplacement of the disposal container would be transporter runaway and derailment in the access tunnel (see Section H.2.1.4). This accident scenario would also bound accident scenarios during retrieval.

During storage, no credible accidents resulting in radioactive release of any measurable consequence would be expected to occur. This prediction is based on an evaluation of above-ground dry storage accident scenarios at the commercial sites under similar conditions, as evaluated in Appendix K.

In view of these considerations, DOE has concluded that the waste transporter derailment and the rockfall accident scenarios analyzed in Section H.2 would bound accident impacts during retrieval.

H.4 Accident Scenarios During Monitoring and Closure

During monitoring and closure activities, DOE would not move the waste packages, with the possible exception of removing a container from an emplacement drift for examination or drift maintenance. Such operations could result in a transporter runaway and derailment accident, but the frequency of release from such an event would be extremely low, as would the consequences, resulting in minimal risk. Thus, DOE expects the radiological impacts from operations during monitoring and closure to be very small.

H.5 Accident Scenarios for Inventory Modules 1 and 2

Inventory Modules 1 and 2 are alternative inventory options that the EIS considers. These modules involve the consideration of additional waste material for emplacement in the repository. They would involve the same waste and handling activities as those for the Proposed Action, but the quantity of materials received would increase, as would the period of emplacement operations. The analysis assumed the receipt and emplacement rates would remain the same as those for the Proposed Action. Therefore, DOE expects the accident impacts evaluated for the Proposed Action to bound those that could occur for Inventory Modules 1 and 2 because the same set of operations would be involved.

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Appendix I

Environmental Consequences of Long-Term Repository Performance

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APPENDIX I. ENVIRONMENTAL CONSEQUENCES OF LONG-TERM REPOSITORY PERFORMANCE

This appendix provides detailed supporting information on the calculation of the environmental consequences of long-term (postclosure, up to 1 million years) repository performance. Chapter 5 summarizes these consequences for the Proposed Action, and Section 8.3 summarizes the cumulative impacts of Inventory Modules 1 and 2.

Section I.1 introduces the bases for long-term performance assessment calculations. Section I.2 provides an overview of the use of computational models developed for the Total System Performance Assessment – Viability Assessment used for this environmental impact statement (EIS). Section I.3 identifies and quantifies the inventory of waste constituents of concern for long-term performance assessment. Section I.4 details the modeling extensions to the Viability Assessment *base case* (high thermal load scenario with the Proposed Action inventory) developed to estimate potential impacts for other thermal load scenarios and expanded inventories. Section I.5 provides detailed results for waterborne radioactive material impacts, while Section I.6 provides the same for waterborne chemically toxic material impacts. Section I.7 describes atmospheric radioactive material impacts. To aid readability, all the figures have been placed at the end of the appendix.

I.1 Long-Term Repository Performance Assessment Calculations

HOW ARE THE VIABILITY ASSESSMENT AND THIS EIS PERFORMANCE ASSESSMENT RELATED?

The long-term performance assessment for this EIS builds incrementally on the Viability Assessment (DOE 1998a, Volume 3, all; TRW 1998a,b,c,d,e,f,g,h,i,j,k, all).

This appendix reports only those aspects of the EIS long-term performance assessment that are incremental over the Viability Assessment. Only those parts of the analysis unique to the EIS are reported here, and the text refers to the appropriate Viability Assessment documents for information on the bases of the analyses.

This EIS analysis of postclosure impacts used and extended the modeling work done for the Total System Performance Assessment – Viability Assessment, as reported in the U.S. Department of Energy's (DOE's) *Viability Assessment of A Repository at Yucca Mountain, Volume 3* (DOE 1998a, Volume 3, all) and in the *Total System Performance Assessment – Viability Assessment (TSPA-VA) Analyses Technical Basis Document* (TRW 1998a,b,c,d,e,f,g,h,i,j,k, all). The Proposed Action inventory under the high thermal load scenario is identical to the Viability Assessment base case, except that the Viability Assessment only considered 20 kilometers (12 miles) from the repository, while the EIS considers impacts of radiological dose to maximally exposed individuals through the groundwater pathway at 5, 20, 30, and 80 kilometers (3, 12, 19, and 50 miles) from the repository. The EIS analysis used a repository integrated program computer model (Golder 1998, all) that DOE used for the total-system model to calculate radiological doses through the groundwater pathway. This performance assessment model and supporting Viability Assessment process models were extended to predict waterborne chemically toxic material impacts. Additional calculations provided estimates of atmospheric radiological doses to local and global populations.

The process of performing performance assessment analyses for this EIS required several steps. The EIS analysis was designed to incorporate the Total System Performance Assessment – Viability Assessment model of the base case repository configuration. Additional modeling (described in this appendix) was performed to evaluate the impacts of alternative thermal load scenarios and expanded waste inventories. The performance assessment model used for the Viability Assessment was expanded to accommodate calculations of the radiological dose to people at distances other than those used in the Viability

Assessment. Other adaptations to the model were made to calculate impacts from nonradiological materials not considered in the Viability Assessment.

The performance assessment model simulates the transport of radionuclides away from the repository into the unsaturated zone, through the unsaturated zone, and ultimately through the saturated zone to the accessible environment. Performance assessment analyses depend greatly on the underlying process models necessary to provide thermal-hydrologic conditions, near-field geochemical conditions, unsaturated zone flow fields, and saturated zone flow fields as a function of time. Using these underlying process models involves multiple steps that must be performed sequentially before performance assessment modeling can begin.

Figure I-1 shows the general flow of information between data sources, process models, and the total system performance assessment model. (Note: Figures are on pages I-67 to I-110.) Several computer models are identified in Figure I-1; these models are introduced in Section I.2. The general purpose of each of these computer models is described below its name in the figure. For example, TOUGH-2 is used for the mountain-scale thermohydrology model and the drift-scale and mountain-scale unsaturated zone flow model. The dashed box in the figure encompasses those portions of the performance assessment model that are modeled within the repository integration program. Other functions are run externally as "process models" to provide information to the repository integration program model. The ultimate result sought from performance assessment modeling is a characterization of radiological dose to humans with respect to time, which is depicted as the "Final Performance Measure" in the figure (the depiction is for illustrative purposes only).

I.2 Total System Performance Assessment Methods and Models

DOE conducted analyses for this EIS to evaluate potential long-term impacts to human health from the release of radioactive materials from the Yucca Mountain Repository. The analyses were conducted in parallel with, but distinct from, the Total System Performance Assessment calculations for the Viability Assessment (DOE 1998a, Volume 3, all). The methodologies and assumptions are detailed in the Total System Performance Assessment – Viability Assessment Technical Bases Document (TRW 1998a,b,c,d,e,f,g,h,i,j,k, all). Extensions of the Viability Assessment analyses to meet distinct EIS requirements were made using the same overall methodology.

The Total System Performance Assessment is a comprehensive systems analysis in which models of appropriate levels of complexity represent all important features, events, and processes to predict the behavior of the system being analyzed and to compare this behavior to specified performance standards. In the case of the potential Yucca Mountain Repository system, a Total System Performance Assessment must capture all of the important components of both the engineered and the natural barriers. In addition, the Yucca Mountain Total System Performance Assessment must evaluate the overall uncertainty in the prediction of waste containment and isolation, and the risks caused by the uncertainty in the individual component models and corresponding parameters.

The components of the Yucca Mountain Repository system include five major elements that the Total System Performance Assessment must evaluate:

- The natural environment unperturbed by the presence of underground openings or emplaced wastes
- Perturbations to the natural system caused by construction of the underground facilities and waste emplacement
- The long-term degradation of the engineered components designed to contain the radioactive wastes

- The release of the radionuclides from the engineered containment system
- The migration of these radionuclides through the engineered and natural barriers to the biosphere and their potential uptake by people, leading to a radiation dose consequence

The processes that operate within these five elements are interrelated. To model the complexity of the system efficiently, however, the following distinct process models were used in Total System Performance Assessment – Viability Assessment and in performance assessment calculations for this EIS:

- The unsaturated-zone flow was modeled directly with a three-dimensional, site-scale, unsaturated zone flow model, using the TOUGH2 program (Pruess 1991, all). Total System Performance Assessment calculations modeled *climate change* by assuming a series of step changes in climatic boundary conditions.
- Drift-scale unsaturated zone thermal-hydrology was modeled with the NUFT program (Nitao 1998, all) in three dimensions using a model domain that contains discrete waste packages and extends vertically from the water table to the ground surface.
- Waste package degradation was modeled using the WAPDEG program (TRW 1998l, all), which includes both individual package variability and package-to-package variability.
- Waste-form and cladding degradation was modeled in the repository integration program model using empirical degradation-rate formulas developed from available data. The model analyses used for the Total System Performance Assessment – Viability Assessment and for this EIS included representation of the protective benefits of fuel cladding for commercial spent nuclear fuel. The cladding failure model is described in detail in DOE (1998a, Volume 3, Section 3.5.2, pages 3-100 to 3-103).

CLIMATE CHANGE

The EIS performance assessment considered three climate scenarios: (1) a *present-day climate*, (2) a *long-term average* climate (wetter than the present-day climate) scenario, and (3) a scenario in which *superpluvial* conditions (much wetter than the present-day climate) are added at a short-duration fixed interval on a periodic basis 100,000 years after waste emplacement. The climate changes are step changes for the duration of the climate periods, and the lengths of the sequences are 10,000 years for the present-day dry climate and the superpluvial climate, and 90,000 years for the long-term average climate (DOE 1998a, Volume 3, Section 5.1.1, page 5-1).

- Engineered barrier-system transport was modeled in the repository integration program model (Golder 1998, all), using the program's cells algorithm. The transport modeling was based on an idealized representation consisting of a linked series of equilibrium batch reactors, including the waste form, waste package, corrosion products, and invert, and radionuclide transport through these reactors (TRW 1998e, all).
- Unsaturated zone radionuclide transport was modeled directly with a three-dimensional site-scale unsaturated zone-transport model using the FEHM model (Zyvoloski et al. 1995, all).
- Saturated zone flow and transport were modeled using a convolution method, in which the three-dimensional, site-scale, saturated zone, flow-and-transport FEHM model (Zyvoloski et al. 1995, all; TRW 1998g, all) was used to generate a library of solutions for translating time-varying mass inputs to the saturated zone into water concentrations at exposure locations downgradient.

- The biosphere was modeled using biosphere dose-conversion factors that convert saturated zone radionuclide concentrations to total radiological dose to an individual. The biosphere dose-conversion factors were developed using the GENII-S program (Leigh et al. 1993, all). The total radiological doses would be the final product of the Total System Performance Assessment calculations.

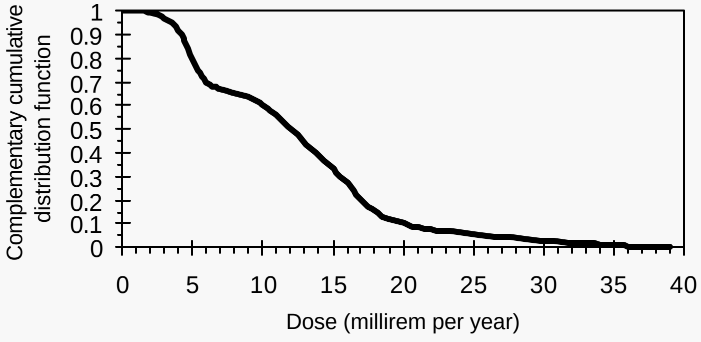
The performance assessment calculations for both the Total System Performance Assessment – Viability Assessment and this EIS were performed within a probabilistic framework combining the most likely ranges of behavior for the various component models, processes, and related parameters. This appendix presents the results in three main forms: (1) as probability distributions (for example, *complementary cumulative distribution functions*) for peak radiological dose to a maximally exposed individual during the 10,000 and 1 million years following repository closure; (2) as time histories of peak radiological dose to a maximally exposed individual over 10,000 and 1 million years following repository closure; and (3) in the case of this EIS only, as peak population radiological dose during 10,000 years for the local population using contaminated groundwater. For maximally exposed individuals, the Viability Assessment considered only a person 20 kilometers (12 miles) downgradient of the repository, while this EIS considers individuals 5, 20, 30, and 80 kilometers (3, 12, 19, and 50 miles) downgradient from the repository.

THE COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

Example application for individual radiological dose

The value of many variables such as individual radiological dose in the performance assessment models cannot be known precisely, but they can be described in a statistical sense. One of the statistical descriptions used is a complementary cumulative distribution function. The function for individual radiological dose is a curve that represents the probability of exceeding various levels of radiological dose. Although the complementary cumulative distribution function is a curve, one can make probability statements for points on the curve. For example, the stylized function for total radiological dose to an individual shown here indicates that there is a probability of 1 that radiological dose exceeds millirem per year, a probability of 0.6 that radiological dose exceeds 10 millirem per year, a probability of 0.1 that radiological dose exceeds 20 millirem per year, and a probability of 0 that radiological dose exceeds 39 millirem per year.

Stylized Complementary Cumulative Distribution Function of Individual Dose



As noted above, the repository integration program model implements some of the individual process models directly, while other process models run outside the repository integration program model to produce *abstractions* in the form of data tables, response surfaces, or unit-response functions. The repository integration program model provides a framework for incorporating these abstractions, integrating them with other subsystem models. This is done in a *Monte Carlo* simulation-based methodology to create multiple random combinations of the likely ranges of the parameter values related to the process models. Probabilistic performance of the entire waste-disposal system is computed in terms of radiological dose to individuals at selected distances from the repository.

The EIS performance assessment methodology draws on the extensive analyses performed in support of the Total System Performance Assessment – Viability Assessment. Most of the process models (and their

ABSTRACTION

Abstraction is the distillation of the essential components of a process model into a suitable form for use in a total system performance assessment. The distillation must retain the basic intrinsic form of the process model but does not usually require its original complexity. Model abstraction is usually necessary to maximize the use of limited computational resources while allowing a sufficient range of sensitivity and uncertainty analyses (DOE 1998a, Volume 3, page A-1).

MONTE CARLO METHOD: UNCERTAINTY

An analytical method that uses random sampling of parameter values available for input into numerical models as a means of approximating the uncertainty in the process being modeled. A Monte Carlo simulation comprises many individual runs of the complete calculation using different values for the parameters of interest as sampled from a probability distribution. A different final outcome for each individual calculation and each individual run of the calculation is called a *realization* (DOE 1998a, Volume 3, page A-48).

abstractions) developed for the Viability Assessment were used directly in the analyses described in this appendix. Only components that were modified to account for the additional analyses considered in this EIS (but not the Viability Assessment) are described in this appendix.

I.3 Inventory

The analyses of long-term performance considered the following waste categories for radioactive materials:

- Commercial spent nuclear fuel comprised of both conventional enriched uranium fuel and mixed-oxide fuel using treated surplus fissile material that was reprocessed (consisting primarily of plutonium)
- DOE spent nuclear fuel
- High-level radioactive waste (some of which contains immobilized surplus weapons-usable plutonium)
- Greater-Than-Class-C waste and Special-Performance-Assessment-Required waste

The analysis assumed the waste would be in dual-shell waste packages. The outer shell would be comprised of corrosion-allowance material (carbon steel) with an inner shell of corrosion-resistance material (Alloy-22, a nickel-chromium alloy) (DOE 1998a, Volume 3, Figure 3-40, page 3-74). As described in TRW (1997a, Section 2.6), it was assumed that the waste packages would contain fuel assemblies from boiling-water reactors or pressurized-water reactors, naval ship or submarine reactors, DOE research reactors, foreign research reactors, or vitrified high-level radioactive waste in canisters. In addition, surplus plutonium not suitable for use in mixed-oxide fuel would be immobilized into 6.7-centimeter (2.6-inch)-diameter ceramic disks that would be packed in cylindrical *cans*, each containing approximately 1.0 kilogram (2.2 pounds) of plutonium (see Appendix A). Twenty-eight of these cans would be placed in a high-level radioactive waste canister and would occupy about 12 percent of the volume of the canister. The remainder of each canister would be filled with vitrified high-level radioactive waste. The plutonium encased in the high-level radioactive waste glass would then be incorporated in standard waste packages. This analysis assumed that the high-level radioactive waste would be in five-pack waste packages, each containing five high-level radioactive waste canisters and disposed of with or without a canister of DOE spent nuclear fuel. The inventory used for this EIS assessment was the same as that used in the Viability Assessment (TRW 1998m, all), which also considered more detailed sensitivity studies concerned with ceramic waste forms, alternative waste package configurations, individual fuel assembly configurations, and mixed waste forms (DOE 1998a, Volume 3, Section 5.5).

Thirty-nine radionuclides were included in the initial estimates of total inventories using the ORIGEN2 program (Croff 1980, all). In the Viability Assessment and the EIS performance assessment model, the list of 39 radionuclides was reduced to nine, based on the screening criteria discussed in this section and observing the nuclides that contributed most to total radiological dose as calculated in the performance assessment models. These nine radionuclides are carbon-14, iodine-129, neptunium-237, protactinium-231, plutonium-239, plutonium-242, selenium-79, technetium-99, and uranium-234.

This section discusses the inventories of waterborne radioactive materials used to model impacts and of some nonradioactive, chemically toxic waterborne materials used in the repository environment that could present health hazards. This section also discusses the inventory of atmospheric radioactive materials.

I.3.1 WATERBORNE RADIOACTIVE MATERIALS

There would be more than 200 radionuclides in the materials to be placed in the repository (see Appendix A). Because some of the radionuclides have a small inventory and some have short half-lives, this analysis did not need to consider all of these radionuclides when estimating long-term repository performance. Therefore, a screening analysis was performed to choose a subset of these radionuclides for further analysis.

I.3.1.1 Reduction of the List of Radionuclides for Performance Assessment Modeling

This evaluation of postclosure performance reduced the number of radionuclides considered by eliminating any radionuclides that:

- Have short half-lives and are not decay products of long-lived radionuclides
- Have high chemical sorption such that long travel times to a human exposure location would result in extremely low concentrations due to radioactive decay (unless the radionuclide has a large inventory and the potential for colloidal transport)
- Have low biosphere dose-conversion factors

Any one or any combination of these factors would result in a diminished contribution by the radionuclide to the total radiological dose; thus, eliminating that radionuclide from consideration would not reduce estimates of radioactive material impacts. Based on these considerations and previous performance analysis results (TRW 1995, all), DOE selected nine dominant radionuclides for analysis and focused on those radionuclides that would have the most impact on human health, thereby enhancing modeling efforts.

Two other factors were a part of the decision to reduce the list of radionuclides explicitly modeled in performance assessment calculations. First, there was a need to reduce the number of radionuclides in order to focus on only those radionuclides with the greatest impact on human health. Large multidimensional flow-and-transport models such as the unsaturated zone and saturated zone particle-tracking and transport models that are part of the repository integration program model require extensive computer time (days or weeks). Hence, it was necessary to focus on those radionuclides that would have the most impact on human health. The reduced list of radionuclides adequately characterized the impacts without requiring an unnecessary computer modeling effort. Second, knowledge and experience gained from earlier assessments (Wilson et al. 1994, all; TRW 1995, all), as well as the experience of other organizations (Wescott et al. 1995, all), were incorporated into the choice of radionuclides included for analysis. To be included for the Total System Performance Assessment – Viability Assessment, a radionuclide had to pass the elimination process performed under the basic criteria described above. It also had to have an overall larger inventory than a similar radionuclide with similar performance importance, or it had to have been identified as important in earlier studies.

The following is a discussion of the further rationale for the final selection of the specific radionuclides to model.

Selected Radionuclides

- *Carbon-14, technetium-99, and iodine-129.* These radionuclides are highly soluble and exhibit little or no chemical sorption. Technetium-99 and iodine-129 were major radiological dose contributors in previous Total System Performance Assessments (Barnard et al. 1992, all; Wilson et al. 1994, all). Carbon-14 and iodine-129 could be liberated from the waste packages as gases and subsequently dissolved in water.

- *Selenium-79, protactinium-231, uranium-234, and neptunium-237.* These radionuclides are relatively soluble and have relatively low chemical sorption. Selenium-79 is the major radiological dose contributor through a cow's liver pathway. Protactinium-231 has a relatively high sorption coefficient, but because it is a decay product of uranium-235, it should be transported relatively quickly and have a long residence time. Uranium-234 has a large inventory, is a decay product of uranium-238, and has a high biosphere dose conversion factor. Neptunium-237 has been the most important radionuclide in previous Total System Performance Assessments for exposure periods between 20,000 and 1,000,000 years after repository closure.

- *Plutonium-239 and plutonium-242.* Although these plutonium isotopes are highly sorbing, they were included on the list because of their large inventory and the possibility that they might migrate by colloidal transport. These radionuclides would be among the most important radionuclides involved in colloid-facilitated transport, if colloidal transport of plutonium were determined to be important. Plutonium-242 was selected over plutonium-240 because of its longer half-life, thus making it more likely to reach the accessible environment (especially via colloidal transport).

Radionuclides Not Selected

- *Curium-246, curium-245, americium-241, americium-243, plutonium-240, uranium-238, thorium-230, radium-226, lead-210, cesium-137, cesium-135, niobium-94, and nickel-59.* These radionuclides were among those selected by the U.S. Nuclear Regulatory Commission for its Iterative Performance Assessment (Wescott et al. 1995, page 5-5). The Viability Assessment did not include curium isotopes because of their similarity to plutonium. Americium isotopes were not included directly because they have short half-lives, americium-243 was included in the plutonium-239 inventory, and the activity of americium-241 was included in the neptunium-237 inventory. Plutonium-240 was not selected because it is highly sorbing (although plutonium-242 was selected to address colloidal transport). Uranium-238 was not selected because its decay product uranium-234 was chosen. Ingrowth of uranium-238 was compensated for by increasing the uranium-234 inventory. Thorium, radium, lead, cesium, niobium, and nickel were generally not included because they are highly sorbing. In addition, lead-210, cesium-137, and radium-226 have relatively short half-lives, while cesium-135, nickel-59, and niobium-94 have low inventories. For these reasons, none of these radionuclides would contribute significantly to radiological dose (that is, including these radionuclides in the calculations would not change the estimates of dose within the number of significant figures reported for results).

Using only a subset of the radionuclides leads to potential underestimates of impacts to humans. The modeling results reported in Chapters 5 and 8 show that in the first 10,000 years, the radiological dose is dominated by technetium-99, iodine-129, and carbon-14. These radionuclides all have relatively high solubility and little chemical sorption. There are no other radionuclides with a meaningful inventory in the proposed repository that share these characteristics. Thus, the error introduced by excluding other radionuclides is very small in the first 10,000 years after repository closure.

The potential for underestimating impacts increases with time periods greater than 10,000 years after repository closure. The possible error is largely due to the modeling of a few nuclides without modeling the entire decay chain for the nuclide. Based on decay equilibrium calculations for the first 1,000,000 years after repository closure, the error from neglecting all other nuclides is about 5 percent of the total radiological dose rate (DOE 1998a, Appendix C, page C6-2 and Figure C6-1).

The inventories for the categories of spent nuclear fuel and high-level radioactive waste described in the following paragraphs include these nine radionuclides. The inventories of these radionuclides were used in the performance assessment model to estimate the impacts to people.

The Viability Assessment and these EIS performance assessment calculations included only certain nuclides of prominent decay chains. To account for the lack of ingrowth of decay products, modifications were made to the nine radionuclide inventories for commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste. These modifications helped produce conservative estimates of the activities of these nuclides (that is, estimates of the inventory would be equal to or greater than the real inventory, so that any uncertainty would tend to overpredict impacts), which were then used by the performance assessment model to determine impacts to individuals at specific exposure locations. Three of the radionuclide inventories were modified as follows:

- The amount of protactinium-231 was entered in the repository integration program model as grams per waste package of protactinium-231 rather than as curies per waste package, which allowed the inventory of protactinium-231 to be modeled in secular equilibrium with its parent nuclide uranium-235.

- The estimated activities of neptunium-237 and uranium-234 were increased by 58 percent and 13 percent, respectively. The increase in the activity of neptunium included the activity of the precursors californium-249, curium-245, plutonium-241, and americium-241 in the performance assessment model. Neptunium-237 transports faster than the precursor radionuclides, so putting the entire inventory in neptunium-237 would not underestimate the radiological dose. The increase of activity in uranium-234 included the activity of precursors such as californium-250, curium-246, plutonium-242, americium-242, curium-242, uranium-238, and plutonium-238.

I.3.1.2 Radionuclide Inventory Used in the Performance Assessment Model

Radioactive material inventories were included in the performance assessment model for Total System Performance Assessment calculations by the following waste categories: commercial spent nuclear fuel, high-level radioactive waste, and DOE spent nuclear fuel. For each waste category, an *abstracted waste package* was represented with an average radionuclide inventory for the nine radionuclides selected in the screening analysis (see Section I.3.1.1).

The quantity of abstracted packages was determined, in part, by averaging the characteristics of the several different types of actual waste packages planned for each waste category and, in part, by demands for a symmetrical, replicating arrangement of waste packages necessary for efficient thermal-hydrologic modeling. Therefore, the quantity of abstracted packages in the performance assessment model differed slightly from the actual quantity of waste packages identified in Appendix A and elsewhere. Other inventory differences between the performance assessment model and Appendix A, and the associated implications, are discussed in this section.

ABSTRACTED WASTE PACKAGES

The number of waste packages used in the performance assessment simulations do not exactly match the number of actual waste packages specified in TRW (1998n, all).

The performance assessment model uses three types of *abstracted waste packages,* representing the averaged inventory of all the actual waste packages used for a particular waste category (commercial spent nuclear fuel, DOE spent nuclear fuel, or high-level radioactive waste).

While the number of abstracted waste packages might vary from TRW (1998n, all), the total radionuclide inventory (activity) represented by all of the abstracted waste packages collectively is equivalent to the total inventory given in Appendix A, unless otherwise noted.

I.3.1.2.1 *Commercial Spent Nuclear Fuel*

The commercial spent nuclear fuel inventory is discussed in detail in Appendix A. The quantities and activities were weighted according to the contributors and the expected waste package configurations. Using these data, the analysis established an abstracted waste package commercial spent nuclear fuel radionuclide inventory for the Total System Performance Assessment – Viability Assessment and EIS performance assessment modeling (TRW 1998m, page 5-10). Table I-1 lists the radionuclide inventory for commercial spent nuclear fuel used for both the EIS and Viability Assessment analyses.

Table I-1. Performance assessment model radionuclide inventory (curies per waste package) for commercial spent nuclear fuel.[a]

Nuclide	Inventory
Carbon-14	12
Iodine-129	0.29
Neptunium-237	11
Protactinium-231[b]	5.1
Plutonium-239	3,100
Plutonium-242	17
Selenium-79	3.7
Technetium-99	120
Uranium-234	21

a. Source: DOE (1998a, Volume 3, page 3-96).

b. Protactinium-231 is listed in grams per package to facilitate modeling as an equilibrium decay product of uranium-235. The specific activity of protactinium-231 is 0.0000022 curies per gram.

I.3.1.2.2 *DOE Spent Nuclear Fuel*

The DOE spent nuclear fuel inventory is discussed in detail in Appendix A. Table I-2 lists the abstracted waste package radionuclide inventory for DOE spent nuclear fuel used for the Viability Assessment and the EIS analyses for the Proposed Action.

I.3.1.2.3 *High-Level Radioactive Waste*

High-level radioactive waste is the highly radioactive material resulting from the reprocessing of spent nuclear fuel, and the inventory for its disposal is presented in Appendix A. The high-level radioactive waste inventory assembled for Total System Performance Assessment – Viability Assessment and EIS performance assessment modeling was derived from the inventories of high-level radioactive waste at the Hanford Site, Savannah River Site, Idaho National Engineering and Environmental Laboratory, and West

Table I-2. Performance assessment model radionuclide inventory (curies per waste package) for DOE spent nuclear fuel.[a]

Nuclide	Inventory
Carbon-14	0.31
Iodine-129	0.0057
Neptunium-237	0.15
Protactinium-231[b]	0.66
Plutonium-239[c]	155
Plutonium-242	0.11
Selenium-79	0.089
Technetium-99	2.6
Uranium-234	0.54

a. Source: DOE (1998a, Volume 3, page 3-96).

b. Protactinium-231 is listed in grams per package to facilitate modeling as an equilibrium decay product of uranium-235. The specific activity of protactinium-231 is 0.0000022 curies per gram.

c. Inventory for plutonium-239 is correct; DOE (1998a, Volume 3, page 3-96) contains a typographical error.

Valley Demonstration Project. This inventory was established from the National Low-Level Waste Database and weighted for the expected contributions from the four principal high-level radioactive waste sites listed above using quantities calculated in the *Waste Quantity, Mix and Throughput Report* (TRW 1997a, all). This inventory is listed in Table I-3 for the nine modeled radionuclides.

Table I-3. High-level radioactive waste mass and volume summary.

Parameter	EIS analyses	Appendix A
Mass (metric tons)	NA[a]	58,000
Volume (cubic meters)	18,000	21,000
Number of canisters	19,234	22,280
Waste packages (5-packs)	3,848	4,456[b]

a. NA = not applicable.

b. Derived from data presented in Appendix A.

These data were included in the high-level radioactive waste inventory for the Viability Assessment base case (TRW 1998o, all); long-term performance assessment analyses for this EIS used this same inventory.

Recent updates of the waste inventories from the DOE sites are in Appendix A. The most recent estimates from these sites indicated a higher total volume of high-level radioactive waste but with an overall lower activity. Appendix A provides a 1998 summary of the potential total mass, volume, and number of canisters of high-level radioactive waste that would be available to the Yucca Mountain Repository from the principal waste sites.

These performance assessment analyses did not use the most recent information reported in Appendix A, because the more recent estimates of high-level radioactive waste activity were received too late for inclusion in the Viability Assessment and EIS performance assessment calculations (see TRW 1998f, page 6-16). A sensitivity analysis of high-level radioactive waste was performed by comparing the high-level radioactive waste inventory used in EIS analyses to the inventory in Appendix A. The results of the analysis showed that the estimate of total radiological dose to maximally exposed individuals at 20 kilometers (12 miles) from the Yucca Mountain Repository, using the high-level radioactive waste base case inventory for the Viability Assessment, led to higher amounts of radionuclides contributing to radiological dose than those calculated using the revised data from Appendix A. Therefore, actual impacts would be lower than estimated if the more recent information were used. Table I-4 compares the nine radionuclide inventories used in the Viability Assessment and EIS analyses with those used in the Appendix A inventory. Note that the nine modeled radionuclides do not contribute equally to radiological

Table I-4. Comparison of high-level radioactive waste inventories (curies per package).

Nuclide	TSPA-VA inventory [a] (3,848 packages)	Appendix A inventory (4,456 packages)
Carbon-14	0	0.032
Iodine-129	0.000042	0.0085
Neptunium-237	0.74	0.13
Protactinium-231[b]	0.036	0.82
Plutonium-239	24	68
Plutonium-242	0.02	0.014
Selenium-79	0.29	0.49
Technetium-99	30	13
Uranium-234	0.9	0.15

a. Source: TSPA-VA = (Total Systems Performance Assessment – Viability Assessment); DOE (1998a, Volume 3, page 3-96).

b. Protactinium-231 is listed in grams per package to facilitate modeling as an equilibrium decay product of uranium-235. The specific activity of protactinium-231 is 0.0000022 curies per gram.

dose, so a comparison of the inventories in Table I-4 can be misleading. For example, neptunium-237 typically contributes more than 90 percent of the dose in the 1-million-year period, so the larger inventory of neptunium-237 in the Total Systems Performance Assessment – Viability Assessment inventory column is more important that the smaller inventory of other radionuclides relative to the Appendix A inventory column. Similarly, iodine-129 and technetium-99 inventories contribute most of the dose in the 10,000-year period, so difference in those inventories are most important in that case.

The source used for the Viability Assessment to establish the inventory of high-level radioactive waste was the Characteristics Database (DOE 1992, all). Appendix A contains data submitted by the individual sites in response to an EIS data call. The differences in the data from each source are listed below by site.

Discussion of differences is limited to the nine radionuclides modeled in the performance assessment analyses.

Hanford Site

- The Characteristics Database (DOE 1992, all) assumes 1,650 kilograms (3,630 pounds) of glass per canister.

- Appendix A reports the mass of glass per canister as 3,040 kilograms (6,700 pounds). Values in Appendix A are generally higher than those presented in the Characteristics Database (DOE 1992, all); these values are listed in Table I-5. Nuclide values which are generally lower in Appendix A than the Characteristics Database are presented in Table I-6.

Table I-5. Nuclides at the Hanford Site for which Appendix A presents values greater than those in the Characteristics Database.[a]

Nuclide	Factor
Iodine-129	100
Protactinium-231	100,000
Plutonium-239	2.5
Selenium-79	8
Uranium-234	5

a. Source: DOE (1992, all).

Table I-6. Nuclides for which Appendix A presents values lower than those in the Characteristics Database.[a]

Nuclide	Factor
Neptunium-237	100
Technetium-99	3

a. Source: DOE (1992, all).

Idaho National Environmental and Engineering Laboratory

- The Characteristics Database (DOE 1992, all) inventory numbers do not include the projected high-level radioactive waste inventory from the Argonne National Laboratory-West ceramic and metal waste matrices (approximately 102 canisters).

- Appendix A reported values for carbon-14 and iodine-129 (0.000083 and 0.017 curie per canister, respectively), while the Characteristics Database (DOE 1992, all) reported no values for these nuclides.

- The Characteristics Database (DOE 1992, all) reported 0.08 curie per canister for selenium-79; however, no value is reported for use in Appendix A.

- For the other nuclides, the values reported in Appendix A are greater by a variety of factors, as listed in Table I-7.

Table I-7. Nuclides at the Idaho National Engineering and Environmental Laboratory for which Appendix A presents values greater than those in the Characteristics Database.[a]

Nuclide	Factor
Neptunium-237	270
Plutonium-239	2.25
Plutonium-242	1.65
Technetium-99	3.7
Uranium-234	200,000

a. Source: DOE (1992, all).

Savannah River Site

- In general, the Appendix A values for the other nuclides are slightly smaller (generally less than 1 percent) than those presented in the Characteristics Database (DOE 1992, all). The uranium-234 value reported in Appendix A is 77 percent less; however, most of the other nuclides are within 1 percent of the values in the Characteristics Database.

West Valley Demonstration Project

- The Characteristics Database (DOE 1992, all) does not include data for carbon-14 or iodine-129; Appendix A uses approximately 0.53 and 0.00081 curie per canister, respectively, for these nuclides.

- Neptunium-237, plutonium-239, plutonium-242, and protactinium-231 differ slightly in Appendix A (by about 1 percent) due largely to the difference in reporting accuracy (Appendix A reports two significant figures; the Characteristics Database reports three).

- Uranium-234 is increased by about 15 percent in Appendix A.

- Technetium-99 and selenium-79 are both higher in Appendix A by a factor of approximately 15.

I.3.1.2.4 *Greater-Than-Class-C and Special-Performance-Assessment-Required Wastes*

Wastes with concentrations above Class-C limits (shown in 10 CFR Part 61.55, Tables 1 and 2 for long and short half-life radionuclides, respectively) are called Greater-Than-Class-C low-level waste. These wastes generally are not suitable for near-surface disposal. The Greater-Than-Class-C waste inventory is discussed in detail in Appendix A.

DOE Special-Performance-Assessment-Required low-level radioactive waste could include production reactor operating wastes, production and research reactor decommissioning wastes, non-fuel-bearing components of naval reactors, sealed radioisotope sources that exceed Class-C limits for waste classification, DOE isotope production related wastes, and research reactor fuel assembly hardware. The Special-Performance-Assessment-Required waste inventory is discussed in detail in Appendix A.

The final disposition method for Greater-Than-Class-C and Special-Performance-Assessment-Required low-level radioactive waste is not known. If these wastes were to be placed in a repository, they would be placed in canisters before shipment. This appendix assumes the use of a canister similar to the naval dual-purpose canister described in Section A.2.2.5.6.

Table I-8 lists existing and projected volumes through 2055 for the three Greater-Than-Class-C waste sources. DOE conservatively assumes 2055 because that year would include all Greater-Than-Class-C low-level waste resulting from the decontamination and decommissioning of commercial nuclear reactors. The projected volumes conservatively reflect the highest potential volume and activity expected based on inventories, surveys, and industry production rates.

Table I-8. Greater-Than-Class-C low-level waste volumes (cubic meters)[a] by source.[b]

Source	1993	2055
Nuclear electric utility	26	1,300
Sealed sources	40	240
Other	74	470
Totals	**140**	**2,010**

a. To convert cubic meters to cubic feet, multiply by 35.314.
b. Source: DOE (1994, Tables 6-1 and 6-3).

The data concerning the volumes and projections of Greater-Than-Class-C low-level waste are from Appendix A-1 of the *Greater-Than-Class-C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclide Activities, and Other Characteristics* (DOE 1994, all). This appendix provides detailed radioactivity reports for such waste currently stored at nuclear utilities. Table I-9 summarizes the radioactivity data for the nine radionuclides modeled in performance assessment calculations, decayed to 2055.

I.3.2 WATERBORNE CHEMICALLY TOXIC MATERIALS

Waterborne chemically toxic materials that could present a human health risk would be present in materials disposed of in the repository. The most abundant of these chemically toxic materials would be nickel, chromium, and molybdenum, which would be used in the waste package, and uranium in the disposed waste. Uranium is both a chemically toxic and radiological material. Screening studies were conducted to determine which, if any, of these or other materials could be released in sufficient quantities to have a meaningful impact on groundwater quality.

Table I-9. Performance assessment model radionuclide inventory (curies per waste package) for Greater-Than-Class-C and Special-Performance-Assessment-Required waste.[a]

Nuclide	Inventory
Carbon-14	38
Iodine-129	0.000000012
Neptunium-237	0.000000052
Protactinium-231[b]	0.0000015
Plutonium-239	48
Plutonium-242	0.0000040
Selenium-79	0.0000010
Technetium-99	2.6
Uranium-234	0.00000062

a. Source: TRW (1999a, Table 2.2-6, page 2-10).

b. Protactinium-231 is listed in grams per package to facilitate modeling as an equilibrium decay product of uranium-235. The specific activity of protactinium-231 is 0.0000022 curies per gram.

I.3.2.1 Identification of Waterborne Chemically Toxic Materials

An inventory of chemical materials to be placed in the repository under the Proposed Action was prepared. The inventories of the chemical components in the repository were combined into four groups:

- Materials outside the waste packages (concrete, copper bus bars, structural members, emplacement tracks and supports, etc.)
- Carbon steel in the outer layer of the waste packages
- Alloy-22 in the inner layer of the waste packages
- Materials internal to the waste packages

These materials were organized into groups with similar release times for use in the screening study. Table I-10 lists the chemical inventories. Plutonium is not listed in Table I-10 because, while it is a heavy metal and therefore could have toxic effects, its radiological toxicity far exceeds its chemical toxicity (DOE 1998b, Section 2.6.1) (see Section I.5 for more information). Also, while there are radiological limits set for exposure to plutonium, no chemical toxicity benchmarks have been developed. Therefore, because of this lack of data to analyze chemical toxicity, plutonium was not analyzed for the chemical screening.

I.3.2.2 Screening Criteria

Only those chemicals likely to be toxic to humans were carried forward in the screening study. Uranium was an exception; it was carried forward due to its high inventory and also to serve as a check on the screening study. Chemicals included in the substance list for the U.S. Environmental Protection Agency's Integrated Risk Information System (EPA 1999, all) were evaluated further to determine a concentration that would be found in drinking water in a well downgradient from the repository. The chemicals on the Integrated Risk Information System substance list that would be in the repository are barium, boron, cadmium, chromium, copper, lead, manganese, mercury, molybdenum, nickel, selenium, uranium, vanadium, and zinc.

Table I-10. Inventory (kilograms)[a] of chemical materials placed in the repository under the Proposed Action.

Element	Inventory: Outside package	Carbon steel	Alloy-22	Internal	High-level radioactive waste	Totals
Aluminum	0	0	0	1,205,000	0	1,205,000
Barium	0	0	0	0	19,000	19,000
Boron	0	0	0	223,000	0	223,000
Cadmium	0	0	0	0	43,000	43,000
Carbon	286,000	796,000	8,000	5,000	0	1,096,000
Chromium	0	0	9,670,000	3,903,000	0	13,573,000
Cobalt	0	0	1,357,000	27,000	0	1,384,000
Copper	1,135,000	0	0	3,000	0	1,139,000
Iron	91,482,000	320,089,000	2,171,000	9,000	0	413,751,000
Lead	0	0	0	0	2,000	2,000
Magnesium	0	0	0	12,000	0	12,000
Manganese	234,000	3,007,000	271,000	2,000	0	3,514,000
Mercury	0	0	0	0	200	200
Molybdenum	0	0	5,934,000	302,000	0	6,236,000
Nickel	0	0	29,727,000	5,563,000	0	35,290,000
Phosphorus	37,000	114,000	11,000	0	0	161,000
Selenium	0	0	0	0	300	300
Silicon	361,000	943,000	43,000	7,000	0	1,354,000
Sulfur	46,000	114,000	11,000	0	0	170,000
Titanium	0	0	0	2,000	0	2,000
Tungsten	0	0	1,628,000	0	0	1,628,000
Uranium	0	0	0	70,000,000	0	70,000,000
Vanadium	0	0	190,000	0	0	190,000
Zinc	0	0	0	3,000	0	3,000

a. To convert kilograms to pounds, multiply by 2.2046.

I.3.2.3 Screening Application

The screening calculations for chemically toxic materials assume that groundwater would move through the repository, dissolving and transporting the potentially chemically toxic materials. This analysis treated the repository materials and the carbon-steel layer of the waste package as simultaneously degrading in the groundwater. After the carbon-steel layer of the waste degraded, the Alloy-22 corrosion-resistant material would start degrading. Finally, once the waste package was breached, the materials inside the waste packages would become available for dissolution and transport.

I.3.2.3.1 *Solubility of Chemically Toxic Materials in the Repository*

The release of chemically toxic materials to the accessible environment depends on the solubility of the materials in water. Table I-11 lists the solubility values used for the screening study.

Maximum source concentrations for materials in the repository that are not a part of the waste package materials were calculated as solubilities of an element in repository water. This calculation would provide the maximum possible concentration of that element in water entering the unsaturated zone if it dissolved at a sufficiently high rate. The solubilities were obtained by modeling with the EQ3 code (Wolery 1992, all). The simulations were started with water from well J-13 near the Yucca Mountain site (Harrar et al. 1990, all). EQ3 calculates chemical equilibrium of a system so that by making successive runs with gradually increasing aqueous concentrations of an element, eventually a result will show the saturation of a mineral in that element. That concentration at which the first mineral saturates is said to be

SCREENING ANALYSIS

A *screening analysis* is a method applied to avoid unnecessary calculations and focus on potentially large impacts.

The repository would contain many materials that could result in impacts to human health. However, most of these materials would either not be present in large enough quantities or not dissolve readily enough in water to pose a risk.

To evaluate the potential risk posed by so many materials, an analysis could either rigorously evaluate every material at great cost, or could apply a screening analysis to identify those materials with too little inventory or too little solubility to be of concern. The screening analysis applied for the EIS was a simplified scoping calculation which resulted in a short list of materials that merited further consideration. Any preliminary concentrations predicted under the simplified assumptions of the screening analysis were treated as conservative estimates used only to determine if the material should be rigorously modeled again using the performance assessment model. For those materials that the screening analysis indicated must be evaluated further, more realistic concentrations and impacts were computed with the performance assessment model and are reported in Sections I.5 and I.6.

Table I-11. Source concentrations[a] (milligrams per liter)[b] of waterborne chemically toxic materials for screening purposes.

Element	Concentration	Aqueous species	Reference
Boron	6,400	B(OH)3aq	Solubility in repository water by EQ3[c] simulation
Chromium	300	CrO_4^{--}	EQ6[d] simulation of Alloy 22 corrosion
Copper	0.018	$CuOH^+$, $Cu(CO_3)aq$, Cu^{++}	Solubility in repository water by EQ3[c] simulation
Manganese	4.40×10^{-11}	Mn^{++}	EQ6[d] simulation of Alloy 22 corrosion
Molybdenum	218	MoO_4^{--}	EQ6[d] simulation of Alloy 22 corrosion
Nickel	1.00×10^{-6}	Ni^{++}	EQ6[d] simulation of Alloy 22 corrosion
Uranium	0.6	$UO_2(OH)_2aq$	Derived from TRW (1997b), Figure C-3, page C-8[e]
Vanadium	4.8	VO_3OH^{--}, HVO_4^{--}	EQ6[d] simulation of Alloy 22 corrosion
Zinc	63	Zn++	Solubility in repository water by EQ3[c] simulation

a. Concentration at the point where the chemical enters unsaturated zone water, controlled by solubility or local chemistry of dissolution and interaction with tuff. Note that these concentrations are not used for transport modeling (which is discussed in Section I.6) but are used only for screening analysis purposes. Refer to Section I.6 for groundwater concentrations of chemically toxic materials that were selected for further consideration based on the screening analysis.

b. To convert milligrams per liter to pounds per cubic foot, multiply by 0.00000624.

c. EQ6 code, Version 7.2b (Wolery and Daveler 1992, all).

d. EQ3 code, Version 7.2b (Wolery 1992, all).

e. For ph=8 and $Co_2=10^{-3}$ atmospheric partial pressure.

the "solubility." For example, the solubility of copper (from the bus bars left in the tunnels) would be obtained by increasing copper concentrations in successive runs of EQ3. At a concentration of 0.01811 milligram per liter, tenorite (CuO) would be saturated. This mineral would then be in equilibrium with dissolved copper existing in approximately equal molar parts as $CuOH^+$, $Cu(CO_3)aq$, and Cu^{++}. The aqueous concentration was then reported in Table I-11 as a "solubility" of copper for the purposes of screening the potentially toxic chemicals.

The largest quantities of potentially toxic materials come from the construction materials of the waste packages themselves. The main source is the Alloy-22 material used in the corrosion-resistant layer. The possible maximum concentrations of these materials (chromium, nickel, molybdenum, manganese, and vanadium) were developed by examining the corrosion process. Corrosion was modeled in the EQ6 code

(Wolery and Daveler 1992, all), starting with the same repository water as used in the solubility calculations described above. In the corrosion step, EQ6 was run in the titration mode (that is, a confined area in which essentially stagnant water reacts with iron from existing corrosion-allowance material fragments and Alloy-22). Oxygen is fixed at atmospheric fugacity (which is analogous to partial pressure adjusted for nonidealities). After a few hundred years, the chemistry of the resultant solution stays relatively constant for a long period. Following that, ionic strength eventually exceeds limits for +EQ6. The chemistry during this "flat period" was used as the resultant solution, which contained very high quantities of dissolved chromium (as hexavalent chromium), nickel, and molybdenum, and small dissolved quantities of manganese and vanadium. The reaction of this solution with tuff was then modeled. The resultant solution showed that essentially all of the nickel and manganese were precipitated and that the original dissolved concentrations of chromium, molybdenum, and vanadium remained.

Two types of geochemical analyses were performed. The first was an analysis of the solution concentration obtained when J-13 water, adjusted for the presence of repository materials such as concrete (that is, the same water chemistry used for other process modeling work supporting the Total System Performance Assessment-Viability Assessment), reacts with a large mass of carbon steel and Alloy-22 for an extended period. The second was an analysis of the reaction of the solution from the first analysis with volcanic tuff. The resultant solution from the second analysis would represent a bounding value for the source term solution at the floor of the emplacement drift.

At each step of the reaction progress in which the titration mode of EQ6 was used, a small quantity of reactants (steel and Alloy-22) was added to the solution (starting as J-13 water). After each addition, the increment of reactant dissolves and all product phases would reequilibrate with the aqueous solution. After a long time, this process would produce a bounding concentration for the solution. This would be the case if the water had a very long contact time with the metals and a very limited amount of water was used.

The composition of J-13 water was taken from earlier studies (TRW 1997b, page A-5). The carbon dioxide and oxygen levels are maintained at atmospheric conditions during the reaction. This process promotes the formation of the chromate (CrO_{4--}) ion, which represents the hexavalent (and most toxic) state of chromium. The complete oxidation of chromium and the formation of chromate creates a very low pH environment in the area immediately adjacent to the corrosion process. The result of a low pH level in the presence of sufficient oxygen would be dissolved chromium existing in the hexavalent state. Large amounts of soluble hexavalent molybdenum are also formed.

Once the corrosion solution left the waste package, it would quickly encounter rock material. The second analysis evaluated the effect of rock on the solution. The analysis used the option for a "Fluid-Centered Flow-Through Open System" in EQ6. In this type of simulation the solution is permitted to react with solid materials (in this case, the tuff) for some specified interval (either time or reaction progress). The solution is then moved away from the solid reaction products that would be created and allowed to react with the same initial solids for a further interval. In this way, the model simulates reaction of the solution as it percolates through a rock.

This analysis simulated the tuff rock with the elemental composition characteristics of volcanic tuff. Earlier waste package criticality studies used this formulation for tuff reactants (TRW 1997c, page 17).

The resultant solution from the simulated reaction of J-13 water with carbon steel and Alloy-22 has a very low pH and a high concentration of dissolved chromium, molybdenum, and nickel. The resulting pH 2.0 solution would have the elemental concentrations listed in the second column of Table I-12. When the solution from corrosion contacts the rock, it would be neutralized to a pH of 8. The availability of silica in the rock would promote the formation of silicates, which would precipitate most of the nickel and manganese but virtually none of the chromium, molybdenum, or vanadium. Some chromium would change to $Cr_2O_7^{--}$ (still hexavalent and very soluble). The molybdenum would behave in a very similar

Table I-12. EQ6-modeled concentrations (milligrams per liter)[a] in solution from reaction of J-13 water with carbon steel and Alloy-22.

Element	After corrosion of Alloy-22	After reaction with tuff rock
Chromium	299	299
Manganese	32	4.40×10^{-11}
Molybdenum	218	218
Nickel	750	9.9×10^{-5}
Vanadium	4.8	4.8

a. To convert milligrams per liter to pounds per cubic foot, multiply by 0.00000624.

fashion and remain in solution as hexavalent species. The resultant solution would have the elemental concentrations listed in the third column of Table I-12.

The mechanism for mass loss of the Alloy-22 remains an issue at this time. There is no reliable evidence to support or refute the idea that the chromium that is carried away from Alloy-22 is dissolved hexavalent chromium. What is known fairly well is that trivalent chromium is the likely constituent (as Cr_2O_3) of the passivation film and that it has a very low solubility. It is not known whether the film grows thick until it sloughs off or if the film oxidizes in place so that it loses hexavalent chromium into solution. It is also not known if the film would oxidize and dissolve if it did slough off. EQ6 simulates a process whereby the trivalent chromium oxidizes to hexavalent chromium by reaction with O_2. It is well known that if chromium is in solution, the predominant species will be hexavalent chromium, especially in oxidizing conditions. At the Eh for atmospheric oxygen, it is known that the ratio of hexavalent chromium to For purposes of analysis, DOE assumes hexavalent chromium is mobilized as a dissolved constituent, and its source term is represented by 0.22 times the bulk loss rate of Alloy-22. A parallel assumption has been made about hexavalent molybdenum, which is also present in meaningful quantities in the results of the corrosion simulation.

I.3.2.3.2 *Well Concentration of Chemically Toxic Materials*

After the materials would begin to be released from the repository, they would be transported through the unsaturated zone to the saturated zone and on to the accessible environment. The screening study assumed that the chemicals would flow to a well from which an individual received all of their drinking water. Table I-13 lists the concentrations for the chemically toxic materials.

The well concentrations listed in Table I-13 were based on a series of simple calculations. First, the release concentrations for each material were calculated. The release rate for the material in the carbon steel is based on a degradation rate of 0.025 millimeter (0.001 inch) per year and a thickness of 100 millimeters (3.9 inches); thus, the annual fractional release rate for carbon steel is 0.00025. The degradation rate for Alloy-22 is 0.000006 millimeter (0.00000024 inch) per year and the material thickness is 20 millimeters (0.79 inch); the resulting annual fractional release rate is 0.0000003. The internal materials were assumed to be released at the same rate as the carbon steel (a conservative assumption). The release rate for the high-level radioactive waste was taken from earlier studies (TRW 1998f, Section 6.4). The annual fractional release rate for the high-level radioactive waste is 0.000054. The well concentrations in Table I-13 are very conservative concentration estimates that are not used directly for impact estimates. Instead, they are used to screen potentially toxic chemicals for more detailed analyses. These estimates were then compared to the Maximum Contaminant Levels for each material, if available (40 CFR 141.2). Some of the estimated concentrations were orders of magnitude below their respective Maximum Contaminant Levels. As a result of this screening study, barium, copper, lead, mercury, and selenium were eliminated from further detailed analysis. All the other chemically toxic materials, including boron, cadmium, chromium, manganese, molybdenum, nickel, uranium, vanadium, and zinc, were carried forward for further detailed analysis (see Chapter 5, Section 5.6.1).

Table I-13. Concentrations (milligrams per liter)[a] of waterborne chemically toxic materials for screening purposes.[b]

Element	Concentration limit	Release concentration: Non-package	Carbon steel	Alloy-22	Internal	HLW	Maximum	Well concentration	Maximum contaminant level[c]
Barium	0.00412	0	0	0	0	0.99	0.00412	1.5×10^{-5}	2.0
Boron	6,400	0	0	0	50	0	52	1.9×10^{-1}	NA[d]
Cadmium	23	0	0	0	0	2.2	2.2	7.7×10^{-3}	0.005
Chromium	300	0	0	2.7	940	0	300	1.1	0.1
Copper	0.018	0.018	0	0	0	0	0.018	6.4×10^{-5}	1.3
Lead	NA	0	0	0	0	0.09	0.09	3.2×10^{-4}	0.015
Manganese	4.4×10^{-11}	4.4×10^{-11}	707	0.077	0.44	0	4.4×10^{-11}	1.6×10^{-13}	NA
Mercury	NA	0	0	0	0	0.01	0.01	3.6×10^{-5}	0.002
Molybdenum	218	0	0	2.07	71	0	71	2.5×10^{-1}	NA
Nickel	1.0×10^{-6}	0	0	8.4	1,310	0	1.0×10^{-6}	3.5×10^{-9}	NA
Selenium	NA	0	0	0	0	0.014	0.014	4.9×10^{-5}	0.05
Uranium	0.0023	0	0	0	16,500	0	0.0023	8.2×10^{-6}	NA
Vanadium	4.8	0	0	0.054	0	0	0.054	1.9×10^{-4}	NA
Zinc	63	0	0	0	0.73	0	0.73	2.6×10^{-3}	NA

a. To convert grams per cubic meter to pounds per cubic foot, multiply by 0.00000624.

b. Note that these concentrations are not used for transport modeling (as discussed in Section I.6), but only for screening analysis purposes. Refer to Section I.6 for groundwater concentrations of chemically toxic materials that were selected for further consideration based on the screening analysis.

c. Maximum contaminant levels are specified in 40 CFR 141.2.

d. NA = not available (no Maximum Contaminant Level established by the U.S. Environmental Protection Agency for this element).

For the chemicals in the nonpackaged materials, the degradation was assumed to be limited by the solubility of the chemical in water. The release concentration (in grams per cubic meter) was assumed to be equal to the elemental solubility for those chemicals with a nonzero inventory in the nonpackaged materials. For the remaining material categories, all part of the waste packages, the release concentration was calculated based on the per-package inventory and the release rate from a waste package.

The per-package inventory (in grams for each material category) was calculated by dividing the total inventory (in grams) of the material type by the total number of waste packages in the repository (assumed to be 11,969). The release of material per cubic meter would be the fractional release rate divided by the rate of water flow past a waste package, based on an average 20-millimeter (0.79-inch) annual water flow rate through the repository. The release concentration is the per-package inventory in grams multiplied by the release per cubic meter.

To estimate the concentration in a well, two steps were performed. First, the maximum release concentration from the four material groups was selected. Then, two dilution factors were applied to the maximum release concentration. An unsaturated zone dilution factor was calculated as the ratio of the total cross-sectional area of all waste packages to the total surface area of the repository. Each of the 11,969 waste packages would have a cross-sectional area of 8.9 square meters (96 square feet), and the assumed repository surface area would be about 3 square kilometers (740 acres). This calculation resulted in an unsaturated zone dilution factor of 0.035. A dilution factor of 10 was applied to the saturated zone so the dilution factor, when combined for the unsaturated and saturated zones, would be 0.0035.

I.3.2.3.3 *Health Effects Screening for Chemically Toxic Materials*

The potential for human health impacts was estimated using a hazard index. The hazard index was determined by dividing the intake of a chemical by the *oral reference dose* for that chemical. A hazard index of 1.0 or above indicated the potential for human health impacts. Table I-14 lists the human health hazard indices.

ORAL REFERENCE DOSE

The *oral reference dose* is based on the assumption that thresholds exist for certain toxic effects such as cellular necrosis. This dose is expressed in units of milligrams per kilogram per day. In general, the oral reference dose is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (EPA 1999, all).

Table I-14. Human health hazard indices for chemically toxic materials.

Element	Intake (milligram per kilogram per day)	Oral reference dose[a] (milligram per kilogram per day)	Hazard index
Boron	0.0053	0.09	0.059
Cadmium	0.00022	0.0005	0.44
Chromium	0.030	0.005	6.1
Manganese	4.5×10^{-15}	0.14	3.2×10^{-14}
Molybdenum	0.0072	0.005	1.4
Nickel	1.0×10^{-10}	0.02	5.1×10^{-9}
Uranium	0.00000023	0.003	0.000078
Vanadium	0.0000054	0.007	0.00078
Zinc	0.000074	0.3	0.00025

a. Source: EPA (1999, all).

Intake was based on a 2-liter (0.53-gallon) daily consumption rate of drinking water, at the concentrations in the well, by a 70-kilogram (154-pound) adult. The oral reference doses were from the Integrated Risk Information System (EPA 1999, all), with the exception of doses for uranium (EPA 1994, all) and vanadium (International Consultants 1997, all).

Of the proposed chemically toxic materials in the repository, only chromium and molybdenum have a hazard index above 1.0. Because the inventories of a given material category in the repository should no more than double under any of the inventory modules, all chemically toxic materials (except chromium and molybdenum) can be eliminated from detailed analyses. However, the analysis also considered uranium in recognition of the special attention this element attracts and as a check for the screening analyses.

I.3.2.4 Chromium Inventory for Use in the Performance Assessment Model

The Alloy-22 that would comprise the inner corrosion-resistant material layer of the waste packages for the Yucca Mountain Repository design would contain 21.25 percent chromium and 55 percent nickel. In addition, stainless-steel containers and fuel cladding would contribute a meaningful but much smaller quantity of chromium. Table I-15 lists the chromium that would be present in the waste packages under the Proposed Action. Tables I-16 and I-17 list the chromium that would be present in the waste packages under Inventory Modules 1 and 2, respectively.

The performance assessment model simulates a number of abstracted waste packages for each waste category with a generalized inventory. Tables I-18 and I-19 summarize the assignment of the chromium inventory under the Proposed Action derived from the actual inventory listed in Table I-15 to the number of abstracted waste packages simulated with the model. The inventory is separated between interior stainless steel (Table I-18) and waste package Alloy-22 (Table I-19) because these two portions of the chromium inventory are modeled separately in a two-step process (see Section I.6 for details). Similarly, Tables I-20 and I-21 summarize the assignment of the chromium inventory derived from the actual inventory under Inventory Module 1, listed in Table I-16, to the number of abstracted waste packages

Table I-15. Chromium content (kilograms) of waste packages for the Proposed Action.[a]

			Alloy-22 per waste package		SS/B[b] alloy per waste package		
Waste category	Waste package type[c]	Quantity actual waste packages[d]	Alloy mass	Chromium mass[e]	Alloy mass	Chromium mass[f]	Chromium mass per waste package type
Commercial spent nuclear fuel	21 PWR UCF (no absorber)	1,369	4,458	947	0	0	1,296,888
	21 PWR UCF (absorber plates)	2,641	4,458	947	1,883	546	3,944,056
	21 PWR UCF (control rods)	169	4,458	947	0	0	160,098
	12 PWR UCF (high heat)	394	3,282	697	0	0	274,785
	12 PWR UCF (South Texas)	179	3,717	790	1,071	311	196,981
	44 BWR UCF (no absorber)	773	4,261	905	0	0	699,923
	44 BWR UCF (absorber plates)	2,024	4,261	905	3,999	1,160	4,179,909
	24 BWR UCF (thick absorber)	93	3,342	710	2,141	621	123,789
High-level radioactive waste	5 HLW co-disposal	1,270	4,066	864	0	0	1,097,312
	5 HLW long co-disposal	1,007	5,687	1,208	0	0	1,216,947
DOE spent nuclear fuel	Navy SNF long	300[g]	6,306	1,340	0	0	381,907
Totals		**10,204**					**13,572,595**

a. To convert kilograms to pounds, multiply by 2.2046.

b. SS/B = stainless-steel boron.

c. Abbreviations: PWR = pressurized-water reactor; UCF = uncanistered fuel; BWR = boiling-water reactor; HLW = defense high-level radioactive waste; SNF = spent nuclear fuel.

d. Source: TRW (1999b, pages 6-5 to 6-12); quantities of waste packages modeled for results reported in Section I.6 differ slightly (because of the use of earlier estimates), resulting in a total chromium inventory about 1 percent less than indicated in this table. Final chromium impacts were not expected to differ because the inventory would not be exhausted during the period simulated.

e. Chromium constitutes 21.25 percent of Alloy-22.

f. Chromium constitutes 29 percent of SS/B alloy.

g. The analysis used 285 Navy SNF long waste packages in models for results discussed in Section I.6. The difference resulted in a chromium inventory that was about an additional 0.02 percent less than indicated in this table.

Table I-16. Chromium content (kilograms) of waste packages for Inventory Module 1.[a]

			Alloy-22 per waste package		SS/B[b] alloy per waste package		
Waste category	Waste package type[c]	Quantity actual waste packages[d]	Alloy mass	Chromium mass[e]	Alloy mass	Chromium mass[f]	Chromium mass per waste package type
Commercial spent nuclear fuel	21 PWR UCF (no absorber)	2,339	4,458	947	0	0	2,215,793
	21 PWR UCF (absorber plates)	4,228	4,458	947	1,883	546	6,314,074
	21 PWR UCF (control rods)	314	4,458	947	0	0	297,460
	12 PWR UCF (high heat)	646	3,282	697	0	0	450,537
	12 PWR UCF (South Texas)	428	3,717	790	1,071	311	470,994
	44 BWR UCF (no absorber)	1,242	4,261	905	0	0	1,124,584
	44 BWR UCF (absorber plates)	3,195	4,261	905	3,999	1,160	6,598,226
	24 BWR UCF (thick absorber)	186	3,342	710	2,141	621	247,578
High-level radioactive waste	5 HLW co-disposal	1,557	4,066	864	0	0	1,345,287
	5 HLW long co-disposal	3,000	5,687	1,208	0	0	3,625,463
DOE spent nuclear fuel	Navy SNF Long	300	6,306	1,340	0	0	402,008
Totals		**17,435**					**23,092,003**

a. To convert kilograms to pounds, multiply by 2.2046.

b. SS/B = stainless-steel boron.

c. Abbreviations: PWR = pressurized-water reactor; UCF = uncanistered fuel; BWR = boiling-water reactor; HLW = defense high-level radioactive waste; SNF = spent nuclear fuel.

d. Source: TRW (1999b, pages 6-5 to 6-12); quantities of waste packages modeled for results reported in Section I.6 differ slightly (because of the use of earlier estimates), resulting in a total chromium inventory about 1 percent less than indicated in this table. Final chromium impacts were not expected to differ because the inventory would not be exhausted during the period simulated.

e. Chromium constitutes 21.25 percent of Alloy-22.

f. Chromium constitutes 29 percent of SS/B alloy.

Table I-17. Chromium content (kilograms) of waste packages for Inventory Module 2.[a]

Waste category	Waste package type[c]	Quantity actual waste packages[d]	Alloy-22 per waste package: Alloy mass	Alloy-22 per waste package: Chromium mass[e]	SS/B[b] alloy per waste package: Alloy mass	SS/B[b] alloy per waste package: Chromium mass[f]	Chromium mass per waste package type
Commercial spent nuclear fuel	21 PWR UCF (no absorber)	2,339	4,458	947	0	0	2,215,793
	21 PWR UCF (absorber plates)	4,228	4,458	947	1,883	546	6,314,074
	21 PWR UCF (control rods)	314	4,458	947	0	0	297,460
	12 PWR UCF (high heat)	646	3,282	697	0	0	450,537
	12 PWR UCF (South Texas)	428	3,717	790	1,071	311	470,994
	44 BWR UCF (no absorber)	1,242	4,261	905	0	0	1,124,584
	44 BWR UCF (absorber plates)	3,195	4,261	905	3,999	1,160	6,598,226
	24 BWR UCF (thick absorber)	186	3,342	710	2,141	621	247,578
High-level radioactive waste	5 HLW co-disposal	1,557	4,066	864	0	0	1,345,287
	5 HLW long co-disposal	3,000	5,687	1,208	0	0	3,625,463
DOE spent nuclear fuel	Navy SNF long	300	6,306	1,340	0	0	402,008
GTCC and SPAR[g]	5 HLW long co-disposal	608	5,687	1,208	0	0	734,760
Totals		**18,043**					**23,826,763**

a. To convert kilograms to pounds, multiply by 2.2046.

b. SS/B = stainless-steel boron.

c. Abbreviations: PWR = pressurized-water reactor; UCF = uncanistered fuel; BWR = boiling-water reactor; HLW = defense high-level radioactive waste; SNF = spent nuclear fuel.

d. Source: TRW (1999b, pages 6-5 to 6-12); quantities of waste packages modeled for results reported in Section I.6 differ slightly (because of the use of earlier estimates), resulting in a total chromium inventory about 1 percent less than indicated in this table. Final chromium impacts were not expected to differ because the inventory would not be exhausted during the period simulated.

e. Chromium constitutes 21.25 percent of Alloy-22.

f. Chromium constitutes 29 percent of SS/B alloy.

g. GTCC = Greater-Than-Class-C waste; SPAR = Special-Performance-Assessment-Required waste.

Table I-18. Modeled waste package interior chromium inventory for Proposed Action (kilograms).[a]

Waste category	Waste package type[b]	Mass per waste package type[c]	Mass per waste category	Number of abstracted waste packages	Mass per abstracted waste package
Commercial spent nuclear fuel	21 PWR UCF (no absorber)	0	3,902,762	7,760	503
	21 PWR UCF (absorber plates)	1,442,171			
	21 PWR UCF (control rods)	0			
	12 PWR UCF (high heat)	0			
	12 PWR UCF (South Texas)	55,596			
	44 BWR UCF (no absorber)	0			
	44 BWR UCF (absorber plates)	2,347,253			
	24 BWR UCF (thick absorber)	57,743			
High-level radioactive waste	5 HLW co-disposal	0	0	1,663	0
	5 HLW long co-disposal	0			
DOE spent nuclear fuel	Navy SNF long	0	0	2,546	0
Totals		**3,902,762**	**3,902,762**	**11,969**	

a. To convert kilograms to pounds, multiply by 2.2046.

b. Abbreviations: PWR = pressurized-water reactor; UCF = uncanistered fuel; BWR = boiling-water reactor; HLW = defense high-level radioactive waste; SNF = spent nuclear fuel.

c. Source: Table I-15.

Table I-19. Modeled corrosion-resistant material (Alloy-22) chromium inventory (kilograms) for Proposed Action.[a]

Waste category	Waste package type[b]	Mass per waste package type[c]	Mass per waste category	Number of abstracted waste packages	Mass per abstracted waste package
Commercial spent nuclear fuel	21 PWR UCF (no absorber)	1,296,888	6,973,667	7,760	899
	21 PWR UCF (absorber plates)	2,501,885			
	21 PWR UCF (control rods)	160,098			
	12 PWR UCF (high heat)	274,785			
	12 PWR UCF (South Texas)	141,385			
	44 BWR UCF (no absorber)	699,923			
	44 BWR UCF (absorber plates)	1,832,656			
	24 BWR UCF (thick absorber)	66,046			
High-level radioactive waste	5 HLW co-disposal	1,097,312	2,314,259	1,663	1,392
	5 HLW long co-disposal	1,216,947			
DOE spent nuclear fuel	Navy SNF long	381,907	381,907	2,546	150
Totals		**9,669,833**	**9,669,833**	**11,969**	

a. To convert kilograms to pounds, multiply by 2.2046.

b. Abbreviations: PWR = pressurized-water reactor; UCF = uncanistered fuel; BWR = boiling-water reactor; HLW = defense high-level radioactive waste; SNF = spent nuclear fuel.

c. Source: Table I-15.

Table I-20. Modeled waste package interior chromium inventory (kilograms) for Inventory Module 1.[a]

Waste category	Waste package type[b]	Mass per waste package type[c]	Mass per waste category	Number of abstracted waste packages	Mass per abstracted waste package
Commercial spent nuclear fuel	21 PWR UCF (no absorber)	0	6,262,475	12,932	484
	21 PWR UCF (absorber plates)	2,308,784			
	21 PWR UCF (control rods)	0			
	12 PWR UCF (high heat)	0			
	12 PWR UCF (South Texas)	132,933			
	44 BWR UCF (no absorber)	0			
	44 BWR UCF (absorber plates)	3,705,273			
	24 BWR UCF (thick absorber)	115,486			
High-level radioactive waste	5 HLW co-disposal	0	0	4,456	0
	5 HLW long co-disposal	0			
DOE spent nuclear fuel	Navy SNF long	0	0	4,340	0
Totals		**6,262,475**	**6,262,475**	**21,728**	

a. To convert kilograms to pounds, multiply by 2.2046.

b. Abbreviations: PWR = pressurized-water reactor; UCF = uncanistered fuel; BWR = boiling-water reactor; HLW = defense high-level radioactive waste; SNF = spent nuclear fuel.

c. Source: Table I-16.

simulated with the performance assessment model for interior stainless steel and corrosion-resistant material, respectively.

Inventory Module 2 is simulated as an incremental impact over Inventory Module 1, where the difference is in the Greater-Than-Class-C and Special-Performance-Assessment-Required wastes added under Inventory Module 2. Table I-22 summarizes the assignment of the additional chromium inventory derived from the actual inventory for Inventory Module 2 to the number of abstracted waste packages simulated with the performance assessment model. No interior stainless steel would be included in the additional waste packages under Inventory Module 2.

Table I-21. Modeled corrosion-resistant material (Alloy-22) chromium inventory (kilograms) for Inventory Module 1.[a]

Waste category	Waste package type[b]	Mass per waste package type[c]	Mass per waste category	Number of abstracted waste packages	Mass per abstracted waste package
Commercial spent nuclear fuel	21 PWR UCF (no absorber)	2,215,793	11,456,771	12,932	886
	21 PWR UCF (absorber plates)	4,005,290			
	21 PWR UCF (control rods)	297,460			
	12 PWR UCF (high heat)	450,537			
	12 PWR UCF (South Texas)	338,061			
	44 BWR UCF (no absorber)	1,124,584			
	44 BWR UCF (absorber plates)	2,892,953			
	24 BWR UCF (thick absorber)	132,093			
High-level radioactive waste	5 HLW co-disposal	1,345,287	4,970,749	4,456	1,116
	5 HLW long co-disposal	3,625,463			
DOE spent nuclear fuel	Navy SNF long	402,008	402,008	4,340	93
Totals		**16,829,528**	**16,829,528**	**21,728**	

a. To convert kilograms to pounds, multiply by 2.2046.

b. Abbreviations: PWR = pressurized-water reactor; UCF = uncanistered fuel; BWR = boiling-water reactor; HLW = high-level radioactive waste; SNF = spent nuclear fuel.

c. Source: Table I-17.

Table I-22. Additional corrosion-resistant material (Alloy-22) chromium inventory for Inventory Module 2 in excess of inventory for Module 1 (kilograms).[a]

Waste category	Waste package type[b]	Mass per waste package type[c]	Mass per waste category	Number of abstracted waste packages	Mass per abstracted waste package
GTCC+SPAR[d]	5 HLW long co-disposal	734,760	734,760	1,642	447

a. To convert kilograms to pounds, multiply by 2.2046.

b. Abbreviations: HLW = high-level radioactive waste.

c. Source: Table I-17.

d. GTCC = Greater-Than-Class-C waste; SPAR = Special-Performance-Assessment-Required waste.

I.3.2.5 Elemental Uranium Inventory for Use in the Performance Assessment Model

Table I-23 lists the total inventory of elemental uranium (that is, all isotopes of uranium) for consideration as a chemically toxic material for the Proposed Action and Inventory Modules 1 and 2. The total uranium inventory for both Inventory Modules 1 and 2 would be about 70 percent greater than that for the Proposed Action. The uranium content in high-level radioactive waste was set to the equivalent of metric tons of heavy metal (MTHM) for this analysis, though much of the uranium would have been removed during reprocessing operations. The elemental uranium inventory for Modules 1 and 2 would be essentially equivalent because Greater-Than-Class-C and Special-Performance-Assessment-Required wastes (the only additional waste in Module 2 over Module 1) do not contain substantial quantities of uranium.

I.3.2.6 Molybdenum Inventory

The Alloy-22 used for the corrosion-resistant material contains 13.5 percent molybdenum. During the corrosion of the Alloy-22, molybdenum behaves almost the same as chromium. Due to the corrosion conditions, molybdenum also dissolves in a highly soluble hexavalent form. Therefore, the source term for molybdenum will be exactly 13.5/21.25 times the source term for chromium (or 64 percent) from Alloy-22 only.

Table I-23. Total elemental uranium inventory (kilograms)[a] for Proposed Action and Inventory Modules 1 and 2.[b,c,d]

Inventory	Commercial SNF[e]	HLW[f]	DOE SNF	Totals
Proposed Action	63,000,000	4,700,000	2,300,000	70,000,000
Modules 1 and 2[g]	105,000,000	13,000,000	2,500,000	120,000,000

a. To convert kilograms to pounds, multiply by 2.2046.

b. The uranium content in high-level radioactive waste was set to the MTHM equivalent for this analysis, even though much of the uranium would have been removed during reprocessing operations.

c. Rounded to two significant figures.

d. Source: Appendix A, Tables A-12, A-13, A-19, A-29 to A-34.

e. SNF = spent nuclear fuel.

f. HLW = high-level radioactive waste.

g. Inventory Module 1 and 2 will have the same total uranium inventory because Greater-Than-Class-C and Special-Performance-Assessment-Required waste (the only additional waste in Module 2 over Module 1) does not contain a substantial quantity of uranium.

I.3.3 ATMOSPHERIC RADIOACTIVE MATERIALS

The only radionuclide that would have a relatively large inventory and a potential for gas transport would be carbon-14. Iodine-129 can exist in a gas phase, but it is highly soluble and therefore likely to dissolve in groundwater rather than migrate as a gas. After carbon-14 escaped from the waste package, it could flow through the rock in the form of carbon dioxide. About 2 percent of the carbon-14 in commercial spent nuclear fuel occurs in a gas phase in the space (or *gap*) between the fuel and the cladding around the fuel (Oversby 1987, page 92). The gas-phase inventory consists of 0.23 curie of carbon-14 per commercial spent nuclear fuel waste package. Table I-24 lists the total carbon-14 inventory for the repository under the Proposed Action and Inventory Modules 1 and 2.

Table I-24. Total carbon-14 inventory (curies).[a]

Inventory	Solid[b]	Gaseous[c]	Totals[d]
Proposed Action	92,000	1,800	93,000
Module 1	150,000	3,200	160,000
Module 2	240,000	3,200	240,000

a. Source: Appendix A, Table A-10.

b. Impacts of carbon-14 in solid form are addressed as waterborne radioactive material impacts.

c. Based on 0.234 curie of carbon-14 per commercial spent nuclear fuel waste package.

d. Totals are rounded to two significant figures.

I.4 Extension of Total System Performance Assessment Methods and Models for EIS Analyses

DOE conducted analyses for the Total System Performance Assessment – Viability Assessment to evaluate potential long-term impacts to human health from the release of radioactive materials from the Yucca Mountain Repository. The analyses for this EIS were conducted in conjunction with, but distinct from, the calculations for the Viability Assessment (DOE 1998a, Volume 3, all). The methodologies and assumptions for the Viability Assessment are detailed in TRW (1998a,b,c,d,e,f,g,h,i,j,k, all). Extensions of the Viability Assessment analyses to meet distinct EIS requirements (for example, consideration of different thermal load scenarios or inventories) were made using the same overall methodology, and details of these extensions are provided in this section. Additional information on EIS performance-assessment analyses can be found in TRW (1999a, all).

I.4.1 REPOSITORY DESIGN FOR ALTERNATIVE THERMAL LOADS

The spatial density at which the waste packages are emplaced in the repository is generally quantified using *thermal load*, which is the MTHM emplaced per acre of repository area. The higher the thermal load, the smaller the spacing between waste packages, resulting in a higher thermal output per unit area.

The area required for emplacement is based on the target thermal loads attained by varying the spacing between the waste packages and the distance between the emplacement drifts. The commercial spent nuclear fuel heat output dominates the overall heat load and thus the total emplacement area required. Thus, for purposes of thermal modeling, the Proposed Action inventory implies the nominal value of 63,000 MTHM commercial spent nuclear fuel, whereas Inventory Modules 1 and 2 have the same expanded inventory of 105,000 MTHM commercial spent nuclear fuel.

Table I-25 gives the estimates of repository area required for the emplacement of wastes, ranging from a low of 740 acres for the high thermal load scenario with the Proposed Action inventory case to a high of 4,200 acres for the low thermal load scenario with the Inventory Module 1 or 2 case. Most of the options require waste emplacement in areas beyond the primary, or *upper,* emplacement block, which is juxtaposed between the Solitario Canyon Fault and the Ghost Dance Fault. The upper emplacement block is the reference repository region in the Viability Assessment base case facility design (63,000 MTHM high thermal load scenario). Selection of potential expansion blocks near the upper block was carried out using several criteria:

- Availability of 200 meters (660 feet) of overburden
- Consistency of elevation and dip with the upper block
- Distance from the saturated zone
- Favorable excavation characteristics

These considerations are described in detail in TRW (1999b, all).

Table I-25. Estimates of repository emplacement area.[a]

		Area (acres)[b]	
Thermal load (MTHM per acre)	Drift spacing (meters)[c]	Proposed Action	Inventory Modules 1 and 2
85	28	740	1,240
60	40	1,050	1,750
25	38[d]	2,520	4,200

a. Source: TRW (1999a, Table 2.3-1, page 2-12) based on 63,000 MTHM of commercial spent nuclear fuel.

b. To convert acres to square miles, divide by 640.

c. To convert meters to feet, multiply by 0.3048.

d. Under the low thermal load, the waste packages would be placed in an approximately square pattern so that the thermal load was distributed evenly. To accomplish this, the emplacement drift spacing and the spacing of the waste packages in the emplacement drift would be approximately equal (TRW 1999c, page F-2).

The selected inventory layouts for the Proposed Action and Inventory Modules 1 and 2 for the high, intermediate, and low thermal load scenarios are shown in Figures I-2 through I-7. These layouts, simplified from the original engineering layouts presented in TRW (1999c, Figures 3.3-1 through 3.3-6), indicate that the wastes for these thermal loads can be accommodated within the upper blocks, the lower block, and one additional region (Block 1a) to the west of the Solitario Canyon Fault.

As described in TRW (1999c, all), additional subsurface blocks for emplacement of waste according to intermediate and low thermal load scenarios were identified by:

- Expanding the upper block to the north and south
- Expanding the lower block to the north and east
- Lowering the elevation of Block 1a, combining it with Block 1b, and designating the combined area as Block 5
- Raising the elevation of Block 2 by 15 meters (50 feet) and designating it as Block 6
- Raising the elevation of Block 3 by 12 meters (39 feet) and designating it as Block 7
- Raising the elevation of Block 4 by 2 meters (6.6 feet), extending the area to the south, and designating it as Block 8

The corresponding layouts for the low thermal load scenario for the Proposed Action and for Inventory Modules 1 and 2 are shown in Figures I-6 and I-7, respectively. Figure I-8 shows the relationship between the early Proposed Action designs and the design areas considered in these EIS analyses.

I.4.2 THERMAL HYDROLOGY MODEL

Evaluation of the intermediate (60 MTHM per acre) and low (25 MTHM per acre) thermal load scenarios for this EIS diverged from the high thermal load base case evaluated in the Viability Assessment. Extensions of the thermal-hydrologic modeling supporting the total systems performance assessment model were required to evaluate these additional thermal load scenarios. These extensions are detailed in this section.

I.4.2.1 Thermal-Hydrologic Scenarios

The analysis of waste package degradation and engineered barrier system release for the EIS requires information regarding waste package temperature and relative humidity, and liquid saturation and temperature within the repository invert. These data were derived from the development and application of a suite of three-dimensional, drift-scale models for predicting the thermal-hydrologic environment near the waste packages. Six sets of calculations were carried out to handle the two inventory options (63,000 and 105,000 MTHM) and the three thermal load scenarios (85, 60, and 25 MTHM per acre). The simulations were performed using NUFT, an integrated finite-difference code capable of modeling multidimensional fluid flow, solute migration, and heat transfer in porous and/or fractured media (Nitao 1998, all).

These calculations closely parallel the thermal-hydrologic modeling study performed in support of Total System Performance Assessment – Viability Assessment (TRW 1998c, all). The main difference between the two studies is in the treatment of thermal-hydrologic conditions at the edge of the repository. In Total System Performance Assessment – Viability Assessment, a hybrid methodology with complementary thermal-hydrologic and thermal conduction models is used to delineate different thermal-hydrologic zones within the repository horizon (TRW 1998c, all). In this study, a less detailed scaling methodology is used to divide the repository into center and edge regions because of the computational complexities associated with larger inventories and expanded emplacement regions. This less detailed scaling methodology is not expected to adversely impact the results.

I.4.2.2 Waste Package and Drift Geometry

Following the approach taken in Total System Performance Assessment – Viability Assessment, the basic three-dimensional drift-scale model was developed around a discrete waste package symmetry element. This model extends:

- In the x-direction, from the drift centerline to the midpoint between adjacent drifts
- In the y-direction, over a representative number of packages to capture the package-to-package variability in heat output
- In the z-direction, from the ground surface to the water table

The vertical discretization between the ground surface and the water table was chosen to be consistent with the Lawrence Berkeley National Laboratory three-dimensional, site-scale unsaturated flow model (Bodvarsson, Bandurraga, and Wu 1997, all). The basis for the model discretization in the other two dimensions is described in the following paragraphs.

The Proposed Action inventory consists of 63,000 MTHM of commercial spent nuclear fuel, 4,667 MTHM of high-level radioactive waste, and 2,333 MTHM of DOE spent nuclear fuel. As described in DOE (1998a, Volume 3, Figure 3-18, page 3-31), the corresponding symmetry element contains seven packages:

- Three 21-pressurized-water-reactor waste packages
- Two 44-boiling-water-reactor waste packages
- One-half of a 12-pressurized-water-reactor waste package
- One-half of a direct-disposal waste package (containing four DOE spent nuclear fuel N-reactor canisters)
- One co-disposal waste package (containing five high-level radioactive waste glass-filled canisters with or without a DOE spent nuclear fuel canister)

Inventory Module 1 consists of 105,000 MTHM of commercial spent nuclear fuel, 12,600 MTHM of high-level radioactive waste (based on MTHM equivalency discussion in Section A.2.3.1 of Appendix A of this EIS), and 2,500 MTHM of DOE spent nuclear fuel. Accordingly, the expanded inventory symmetry element was created using a total of nine packages:

- Three and one-half 21-pressurized-water-reactor waste packages
- Two and one-half 44-boiling-water-reactor waste packages
- One 12-pressurized-water-reactor waste package
- Two co-disposal waste packages containing five high-level radioactive waste glass-filled canisters (with or without a DOE spent nuclear fuel canister)

Note that this symmetry element model maintains the relative percentage (and heat output) of different package types while minimizing the total number of discrete packages for computational convenience. This package discretization model was deemed adequate from the standpoint of thermal-hydrologic modeling, although it is only an approximation of the true inventory.

For the high (85 MTHM per acre) and intermediate (60 MTHM per acre) thermal load scenarios, the waste package arrangement within the drifts was kept constant, and the drift spacing was adjusted to attain the correct thermal load levels. Thus, the high thermal load scenario yields drift spacing of 28 meters (about 92 feet) and the intermediate thermal load scenario yields drift spacing of 40 meters (about 130 feet). For the low (25 MTHM per acre) thermal load scenario, maintaining the same waste package arrangement as for the high and intermediate thermal load scenarios would have required the drifts to be spaced too far apart in the x-direction, resulting in localized heating effects. Therefore, the package-to-package spacing in the y-direction was increased for the low thermal load scenario to create an approximately square symmetry element, including drift spacing of 38 meters (about 120 feet). Waste package spacing for the Proposed Action and for Inventory Modules 1 and 2 is summarized in Table I-26 and Table I-27, respectively.

Table I-26. Waste package spacing for the Proposed Action inventory.[a]

		Spacing of gap after given package (meters)[b]	
Waste package type	Waste package width (meters)	High and intermediate thermal load	Low thermal load
12-PWR	½ (5.87)	6.021	26.424
21-PWR	5.3	9.276	31.215
21-PWR	5.3	2.949	15.415
Co-disposal	5.37	2.2535	13.676
21-PWR	5.3	8.929	30.345
44-PWR	5.3	7.98	27.969
44-BWR	5.3	1.305	11.2996
Direct-disposal	½ (5.37)		

a. Source: TRW (1999a, Table 3.2-1, page 3-3).
b. To convert meters to feet, multiply by 0.3048.

Table I-27. Waste package spacing for Inventory Modules 1 and 2.[a]

		Spacing of gap after given package (meters)[b]	
Waste package type	Waste package width (meters)	High and intermediate thermal load	Low thermal load
21-PWR	½ (5.3)	2.949	11.3055
Co-disposal	5.37	2.2535	17.79
21-PWR	5.3	9.95	32.902
21-PWR	5.3	10.02	33.081
21-PWR	5.3	7.39	26.9175
12-PWR	5.87	6.368	24.3615
44-PWR	5.3	7.98	27.969
44-BWR	5.3	1.305	12.599
Direct-disposal	5.37	1.305	10.0
44-BWR	½ (5.3)		

a. Source: TRW (1999a, Table 3.2-2, page 3-4).
b. To convert meters to feet, multiply by 0.3048.

I.4.2.3 Selection of Submodels

Engineering layouts developed for waste emplacement were shown in Figures I-2 through I-7. These layouts suggest that multiple, discontinuous heated regions will develop in the postclosure period for some of the options. A full three-dimensional representation of all heated regions (such as emplacement areas) was not considered computationally practical. Therefore, for modeling purposes each region was treated as an isolated entity by assuming that boundaries existed for no heat flow and no fluid flow between the regions. Furthermore, to capture the effects of varying stratigraphy and variable surface infiltration on the thermal-hydrology response at the repository, each emplacement block was modeled by a representative stratigraphic column or submodel. These submodel solution assumptions are unlikely to affect adversely the results reported in this EIS.

Based on the original design layouts (see Figure I-2), each thermal load scenario was to be modeled using some combination of each of the following seven stratigraphic columns:

- Upper Block (stratigraphic column 1)
- Lower Block (stratigraphic column 2)
- Block 1a (stratigraphic column 3)
- Block 1b (stratigraphic column 7)
- Block 2 (stratigraphic column 5)
- Block 3 (stratigraphic column 6)
- Block 4 (stratigraphic column 4)

These submodels were used for the high and intermediate thermal load scenarios. However, because of the large areal extent required for the low thermal load scenario, the engineering layout changed for those two design options. In the new design layout, Block 1b has been combined with part of Block 1a to form Block 5, while part of Block 1a has been combined with Block 4 to form Block 8. These two new areas can be represented by two existing submodels: stratigraphic column 7 for Block 5 and stratigraphic column 4 for Block 8. This information is summarized in Table I-28 and shown on Figure I-8.

Table I-28. Areas of submodels (stratigraphic columns) used in thermal-hydrologic calculations.[a]

Thermal-hydrologic scenario	Loading (MTHM per acre)	Waste package inventory module	Emplacement block	Stratigraphic column number	Actual area (acres)	Percent of area
1	85	Proposed Action	Upper Block	1	740	100.0
2	60	Proposed Action	Upper Block	1	1,050	100.0
3	25	Proposed Action	Upper Block	1	1,110	44.0
			Lower Block	2	596	23.7
			Block 5	7	814	32.3
4	85	Inventory Modules 1 and 2	Upper Block	1	1,180	95.5
			Lower Block	2	55	4.5
5	60	Inventory Modules 1 and 2	Upper Block	1	1,180	67.4
			Lower Block	2	380	21.7
			Block 1a	3	190	10.9
6	25	Inventory Modules 1 and 2	Upper Block	1	1,110	26.4
			Lower Block	2	596	14.2
			Block 5	7	814	19.4
			Block 6	5	420	10.0
			Block 7	6	440	10.5
			Block 8	4	820	19.5

a. Source: TRW (1999a, Table 3.2-3, page 3-5).

For all submodels, the vertical stratigraphic data for the model stratigraphic columns were extracted from the Lawrence Berkeley National Laboratory site-scale model (Bodvarsson, Bandurraga, and Wu 1997, all), with the exception of Block 2 and Block 3, which lie outside the boundaries of the site-scale model. The geologic framework model (TRW 1997d, all) was used to develop the stratigraphy for the columns corresponding to Block 2 and Block 3 even though very little information is available regarding the stratigraphy, hydrology, and infiltration conditions in this sector of the Yucca Mountain site. Thermal-hydrologic simulations were carried out with these two submodels for the low thermal load with expanded inventory scenario, but the simulations were not used for the subsequent total-system calculations. It was assumed that the thermal-hydrologic results for these regions could be approximated by the neighboring regions within the Berkeley model domain. Thus, the submodel for Block 8 (stratigraphic column 4) was assumed also to represent Block 3, and the submodel for Block 5 (stratigraphic column 7) was assumed also to represent Block 2.

I.4.2.4 Hydrology and Climate Regime

Hydrologic properties for the thermal-hydrologic models were taken to be the same as the Total System Performance Assessment – Viability Assessment base case (TRW 1998c, Section 3.5). These properties include matrix and fracture characteristics describing capillary retention and relative permeability for a dual-permeability model, including fracture-matrix-interaction area-reduction factor terms that were adjusted to match observed borehole saturations. As described in RamaRao, Ogintz, and Mishra (1998, pages 116 to 118), the dual-permeability model parameters have been adjusted for the present study using the "satiated saturation" concept in the generalized equivalent continuum model. Using a porosity-weighted average, the dual-permeability model fracture and matrix parameters (porosity and permeability) are combined to create corresponding parameters for the generalized equivalent continuum model, while the satiated saturation concept is used to set the threshold for the initiation of flow in fractures (before the attainment of full matrix saturation). Subsequently, the composite medium capillary characteristics are generated by a porosity-weighted average of the individual media curves. These hydrologic properties, as well as other thermal properties used in the thermal-hydrologic calculations, are discussed in TRW (1998c, Section 3.2.1, pages 3-21 to 3-26).

This EIS performance assessment considered three climate scenarios: *present-day*, *long-term average* (wetter than the present-day climate), and *superpluvial*, which are added at short-duration, fixed intervals on a periodic basis during the 100,000-year period after waste emplacement. In the performance assessment model, the initial conditions (that is, the present-day climate) are multiplied by 5.45 to obtain the long-term average climate and by 14.30 to obtain the super-pluvial climate (DOE 1998a, Volume 3, Figure 4.2, page 4-4). The climate changes are measured in step-changes for the duration of the climate periods, and the sequence lengths are 10,000 years for the present-day dry climate and the super-pluvial climate, and 90,000 years for the long-term average climate. The sequence of climate changes used for expected-value simulations (which use the mean value of probabilistically defined input variables) is:

- 0 to 5,000 years - present-day (dry) climate
- 5,001 to 95,000 years - long-term average climate
- 95,001 to 105,000 years - present-day (dry) climate
- 105,001 to 195,000 years - long-term average climate
- 195,001 to 205,000 years - present-day (dry) climate
- 205,001 to 285,000 years - long-term average climate
- 285,001 to 295,000 years - super-pluvial climate
- 295,001 to 305,000 years - present-day (dry) climate

This sequence is repeated for the duration of the simulation period.

Expected-value simulations were carried out for the first 1 million years after closure, to include the complete decay of waste heat caused by radioactive decay and a return to ambient conditions. To establish appropriate initial conditions for the thermal-hydrologic simulations, the nominal present-day (dry) climate scenario, as used in the Viability Assessment base case (TRW 1998c, Section 3.5), was used for the ambient hydrologic calculations. A separate set of thermal-hydrologic simulations was then performed for each climate condition, as required. This approach is consistent with that used in the Viability Assessment, in which climate effects on thermal hydrology for the entire period were included by making three sets of calculations (for present-day, long-term average, and superpluvial climates). The influence of climate change on thermal-hydrologic system response was then approximated in the performance assessment model total-system simulator by switching from one set of results to the other at the time of climate change.

For both the present-day and long-term average climate, the infiltration flux at the top of each representative column was extracted from the flux associated with the nearest element in the Lawrence Berkeley National Laboratory site-scale model (Bodvarsson, Bandurraga, and Wu 1997, all). However, there was no infiltration information available for stratigraphic columns 5 and 6, which are located outside the Berkeley model boundary. Therefore, the infiltration fluxes for these columns were assumed to be equal to the fluxes at the nearest element within the Berkeley model boundary. Note that these infiltration rates were assumed to be constant throughout the 1-million-year postemplacement period with climate changes implemented by multiplying the infiltration rate as described above.

I.4.2.5 Treatment of Edge Effects

The drift-scale modeling results, developed using a representative symmetry element with periodic lateral boundary conditions, best represents the conditions at the center of the repository. To account for the edge-cooling effects experienced by exterior drifts located near unheated rock mass, a scaling methodology was developed based on the hypothesis that the repository can be divided into at least two thermal-hydrologic regions for grouping waste packages, a center region and an edge region. The center region was designed so periodic boundary conditions (no-flow thermal and hydrologic boundaries) could be assigned in a lateral direction. The edge region has a more complicated response because of edge-cooling effects. However, it is believed that the thermal-hydrologic response at the edge is similar to that for the center, albeit at a lower thermal load. Thus, the objective of the scaling methodology was two-fold:

1. Devise a strategy for generating the thermal load scale factors so models representative of the center can be used to simulate the edge response.

2. Estimate the fraction of the repository area enclosed within the center or edge regions.

The following sections briefly describe the development and testing of the components of this scaling methodology.

I.4.2.5.1 *Scaling Factors for Edge Effects*

Based on the conceptual model that the edge response is similar to the center response at a lower thermal load, two-dimensional results from an east-west cross-section scale model of the mountain were compared to a set of one-dimensional runs representing the edge at a series of different thermal loads. The objective was to find a scaling factor for the thermal loads which would provide agreement between the two-dimensional and one-dimensional runs with respect to (1) time history of temperature, liquid saturation, and the mass fraction of air at the repository horizon; and (2) vertical profiles of temperature, liquid saturation, and the mass fraction of air at different points in time.

These calculations were carried out for the base case hydrologic properties and infiltration regime described earlier. The selection of the optimal scaling factor was performed by visual examination and restricted to one scaling factor for the early-time period (0 to 1,000 years) and a second scaling factor for the late-time period (1,000 years to 100,000 years).

Figure I-9 shows the comparison between the two-dimensional and one-dimensional model results using scale factors of 0.8 and 0.6. This comparison suggests that a scale factor of 0.8 is more appropriate for the early-time period, and a scale factor of 0.6 is more suitable for the late-time period. Although not shown here, examining vertical profiles of the primary variables at two different points in time (100 years and 10,000 years) yielded similar observations. Note that a single scaling factor can only provide a gross average match of all stated variables; thus, the match between two-dimensional and scaled one-dimensional results is never perfect. Furthermore, categorization of only two scale factors (early-time and late-time periods) is primarily for computational convenience. These simplifications notwithstanding, the scaling methodology appears to be a reasonable and practical strategy for generating the edge response without resorting to more complex three-dimensional models containing both heated drifts and unheated rock mass.

I.4.2.5.2 *Definition of Thermal-Hydrologic Zones*

The spatial division of the repository into center and edge regions is based on the approximation of the diffusive temperature profile at the repository by a step function. The temperature profile at selected time steps was extracted and fitted with equivalent step functions. The fraction of area enclosed within the temperature discontinuity was then taken as the fraction of repository belonging to the center region. This process is schematically demonstrated for the high thermal load scenario in Figure I-10.

The fractional areas were found to be time-dependent. For the high thermal load scenario, the thermal-hydrologic response is nearly the same for the entire repository as long as the boiling period is active. Thereafter, for all practical purposes, the fraction belonging to the center stabilizes at about 0.66 (this is the recommended fraction to be used at all times for waste package degradation calculations). For the intermediate thermal load scenario, the fractional area belonging to the center region is found to be close to unity at early- and late-time periods, dropping to approximately 0.6 at intermediate times. Therefore, a time-averaged value of 0.8 is recommended as the fractional area belonging to the center for this thermal load. Edge effects are not considered important for the low thermal load scenario, because the use of multiple emplacement blocks will tend to elevate the temperature between adjacent blocks, thus minimizing edge-cooling effects.

I.4.2.6 Results

As mentioned earlier, thermal-hydrologic modeling results in the form of waste package temperature and relative humidity are required for waste package degradation calculations in WAPDEG. In addition, temperature and liquid saturation within the invert supporting the waste packages is required for Engineered Barrier System release calculations in the repository integration program model. Such information is extracted from NUFT output files and archived in tabular form for input to WAPDEG and the repository integration program model. In this section, a brief discussion of the sensitivity of the thermal-hydrologic simulation results to various design options and natural-system uncertainties will be presented.

I.4.2.6.1 *Variability Among the Waste Packages*

Figures I-11 and I-12 show the temperature and relative humidity histories for the various waste package types for the Proposed Action inventory at high and low thermal loads, respectively. For the high thermal load scenario, the highest peak temperature would result from the use of the 21-pressurized-water-reactor design package, whereas the lowest peak temperature would result from the use of the direct disposal package. These peaks differ by approximately 80°C (176°F). The temperature history for the 21-pressurized-water-reactor average waste package falls near the middle of this range. Note, however, the convergence in temperature and relative humidity for all packages as the temperature drops below the nominal boiling point [100°C (212°F)]. The small differences in temperature and relative humidity histories for the waste packages from this time onward would not affect the WAPDEG-predicted package degradation rates in a meaningful manner. Therefore, results from only the 21-pressurized-water-reactor average waste package are provided as representative inputs to WAPDEG.

I.4.2.6.2 *Sensitivity to Thermal Loads*

Figure I-13 shows the temperature and relative humidity histories for the three thermal loads and both Proposed Action and Inventory Modules 1 and 2 scenarios. As expected, the relative peak temperatures correspond to the magnitude of the thermal loads. For each thermal load, the expanded inventory gives a slightly higher peak temperature result, but the two inventories converge quickly at later times. Calculations for the high and intermediate thermal load scenarios result in similar curves, both in terms of temperature and relative humidity. For the low thermal load scenario, the shape of the curve is much flatter and the temperature drops below 100°C (212°F) much earlier than the other scenarios.

I.4.2.6.3 *Comparison Between Center and Edge Locations*

Figure I-14 shows a comparison between temperature and relative humidity histories calculated for the high thermal load scenario using both center and edge models. The edge model is essentially the center model with a lower heat load. As described in Section I.4.2.5, the heat flux for the center model is scaled by 0.8 prior to 1,000 years and by 0.6 after 1,000 years, to provide the thermal input for the edge model. As expected, the temperature history for the edge model falls below, and the relative-humidity history lies above, the response for the center model.

I.4.3 WASTE PACKAGE DEGRADATION MODEL

Evaluation of Inventory Modules 1 and 2 for this EIS diverged from the Proposed Action, or base case, inventory evaluated in the Viability Assessment. Extensions of the waste package degradation modeling supporting the total systems performance assessment model were required to evaluate the additional inventories. These extensions are detailed in this section.

One component of the EIS and Total System Performance Assessment – Viability Assessment performance assessments pertains to quantifying the degradation of the metallic waste packages. A waste package would be a double-walled disposal container consisting of an outer 10-centimeter (4-inch)-thick layer of carbon steel (the corrosion-allowance material), and an inner 2-centimeter (0.8-inch)-thick layer of chromium-molybdenum Alloy-22 (the corrosion-resistant material) (DOE 1998a, Volume 3, page 3-74). A statistically based waste package degradation numerical code, WAPDEG (TRW 1998l, all), was developed to quantify the ranges in expected degradation of the waste packages. The corrosion rates for the corrosion-allowance materials and corrosion-resistant materials included in the code were abstracted from several sources (TRW 1998e, pages 5-11 to 5-16). The development of WAPDEG indicated that the major environmental factors in waste package degradation were temperature and moisture availability. These data were input into WAPDEG after conducting thermal-hydrologic modeling to establish the temperature and relative humidity histories, as described in Section I.4.2.

I.4.3.1 WAPDEG Development and Application to Total System Performance Assessment – Viability Assessment

The EIS WAPDEG calculations were based on the Total System Performance Assessment – Viability Assessment model configuration of this code (TRW 1998e, page 5-3). The performance assessment analysis conducted for the Total System Performance Assessment – Viability Assessment considered a repository thermal load of 85 MTHM per acre, with the base case waste inventory of 63,000 MTHM commercial spent nuclear fuel and 7,000 MTHM DOE spent nuclear fuel and high-level radioactive waste. Numerical thermal-hydrologic modeling was conducted to generate transient temperature and relative humidity histories within the emplacement drift. These histories were then used as input into the WAPDEG code to determine the time of initiation, type, and rate of waste package corrosion during a 100,000-year simulation. The WAPDEG simulations generated a suite of waste package failure distributions that were incorporated into the Total System Performance Assessment – Viability Assessment model.

Two corrosion modes were implemented by the WAPDEG code for each waste package, general corrosion and localized corrosion. These modes were applicable to both the corrosion-allowance-material outer wall/barrier and the corrosion-resistant-material inner wall/barrier. The conditions under which the corrosion modes applied in WAPDEG depended primarily on temperature, relative humidity, the geochemistry of the water, and the presence or absence of dripping or pooled water.

The corrosion-allowance material undergoes general corrosion according to one of two models, a humid-air corrosion model and an aqueous corrosion model, depending on the relative humidity at the waste package surface. Both models are based on statistical analysis of corrosion data observed for carbon-steel corrosion (DOE 1998a, Volume 3, pages 3-81 to 3-82). However, neither corrosion model will be applicable if the temperature at the waste package surface is too high. The thermal calculations for the potential repository typically show an initial postclosure increase in repository temperature due to radioactive decay, followed by a cooling period that eventually reaches ambient temperature. Laboratory and modeling studies indicate that general corrosion of the corrosion-allowance material can only start when the temperature cools to a value near the boiling point of water (DOE 1998a, Volume 3, page 3-82). The temperature-dependent corrosion data are input into the model and applied to waste packages based on a user-defined temperature threshold either in the form of a fixed value or a probability distribution that is sampled for each package.

Relative humidity generally increases as the temperature cools and vaporized moisture condenses. If the relative humidity is sufficiently high and the temperature threshold is met, the corrosion-allowance material can undergo humid-air corrosion. An input to the model is the relative humidity threshold sufficient for initiation of humid-air general corrosion either as a fixed value or a probability distribution that is sampled for each package.

The relative humidity may rise sufficiently to cause a thin film of water to form on the waste package surface. At that point, the aqueous corrosion model more appropriately describes general corrosion. The relative humidity threshold is input either as a fixed value or a probability distribution that is sampled for each package. When the relative humidity exceeds the threshold, WAPDEG transitions from the humid-air corrosion model to the aqueous corrosion model.

Neither general corrosion model for corrosion-allowance materials is expected to behave in a uniform manner over the entire waste package surface. WAPDEG includes a provision for nonuniform corrosion in two ways; it discretizes the waste package surface into segments called *patches* with roughness factors applied to each patch. The number of patches per waste package and the roughness factors are input, with the latter either as a fixed value or a probability distribution. WAPDEG obtains a statistical sample of the distribution (if provided) to be used for each patch on the package. The product of the general corrosion depth at a given time and the roughness factor gives the total corroded depth at a particular location on the patch at that time. When the corroded depth at any point on a patch equals or exceeds the thickness of the corrosion-allowance material, WAPDEG assumes that the patch has failed.

When a patch is breached on the corrosion-allowance material, WAPDEG assumes that part of the surface area of the corrosion-resistant material is then subject to corrosion. In fact, there is a one-to-one correspondence of patches for corrosion-allowance material and corrosion-resistant material. Even though only a fraction of the corrosion-allowance material patch may be breached, the crevice between the two materials will likely grow over time to allow water and air to access the entire corrosion-resistant material patch. WAPDEG conservatively assumes that the entire area of this patch is immediately subject to corrosion upon breach of its overlying corrosion-allowance material patch.

The general corrosion of the two materials differs due to the composition of the two waste package wall materials. The general corrosion rate applied by WAPDEG to the corrosion-resistant material was derived from data gained from the Waste Package Degradation Expert Elicitation. A compilation of the elicited results was then used to create a cumulative distribution function for general corrosion rates of corrosion-resistant materials at temperatures of 25°C, 50°C, and 100°C (77°F, 122°F, and 212°F, respectively) (DOE 1998a, Volume 3, pages 3-85 to 3-88). WAPDEG samples a corrosion rate from each cumulative distribution function for a package in such a manner that, if the points were joined on a plot comparing corrosion rates and temperatures, the curve for a waste package is parallel to the curves for all the other waste packages. When WAPDEG encounters a temperature between the specified temperatures, it linearly interpolates the logarithm of the corrosion rate versus the reciprocal of the temperature to estimate the corrosion rate at the given temperature.

According to a follow-up question for the Waste Package Degradation Expert Elicitation, the spread of the general corrosion rates at a given temperature was due to a combination of uncertainty and natural variability. Waste Package Degradation Expert Elicitation panelists estimated the Alloy-22 general corrosion rate and the allocation of the total variance to its variability and uncertainty. The effect of the corrosion rate variability among waste packages, patches, and the corrosion rate uncertainty on waste package failure and, ultimately, radiological dose was evaluated by splitting the total variance into three different variability and uncertainty combinations: 75-percent variability and 25-percent uncertainty; 50-percent variability and 50-percent uncertainty; and 25-percent variability and 75-percent uncertainty. Uncertainty was interpreted as the uncertainty of the mean of the distribution. To capture this uncertainty, a given percentage was used to establish three possible values for the mean which were based on the 5th, 50th, and 95th percentiles of the uncertainty about the global mean. Three uncertainty splits, combined with these three estimates of the mean, produced nine new cumulative distribution functions for general corrosion rate, which implied nine WAPDEG runs. These runs are summarized in Table I-29.

Table I-29. Uncertainty/variability splitting sets for corrosion rate of corrosion-resistant material[a]

	Uncertainty/variability splitting ratios		
Percentile	25% and 75%	50% and 50%	75% and 25%
5th	Set 1	Set 2	Set 3
50th	Set 4	Set 5	Set 6
95th	Set 7	Set 8	Set 9

a. Source: TRW (1999a, Table 3.3-1, page 3-12).

In the presence of water or water vapor, localized corrosion could occur on the corrosion-resistant material in the form of pitting or crevice corrosion. Information from the Waste Package Degradation Expert Elicitation indicates that localized corrosion would begin only if the temperature was sufficiently high. The user supplies the temperature threshold for initiating pitting either in the form of a fixed value or a probability distribution that is sampled for each waste package. If pitting is allowed to begin as the result of sufficient water and heat levels, WAPDEG implements an Arhennius model for pit growth. Thus, the corrosion-resistant material could be breached either by the general corrosion of patches on the waste package surface or by pit penetration. WAPDEG output files indicate the number of patch failures and pit penetrations over time for each waste package.

The local environment in the waste-emplacement areas could differ from package to package, a factor treated as variability in WAPDEG. To implement this concept, WAPDEG assumes that the variances of the probability distributions that describe general corrosion are due to spatial variability and the variances should be allocated. Using the treatment described above for splitting the cumulative distribution functions for general corrosion of the corrosion-resistant material, the variance of each of the resulting nine distributions is due to natural variability. Some variance accounts for package-to-package variability, and the rest accounts for variable conditions along a waste package (patch-to-patch variability). The user supplies the fraction of variance to be shared by the waste packages, and the remaining fraction is applied to patches. In the Viability Assessment analysis, variance between packages and between patches is 35 percent/65 percent for patches dripped on and 50 percent/50 percent otherwise.

In practice, WAPDEG samples a corrosion parameter using the global distribution but with only a fraction of its variance. The sampled value is then treated as the mean value for the patches on that waste package. For each patch, WAPDEG samples the distribution using the waste package mean and the remaining variance. The results are used to model general corrosion for the patch. WAPDEG also applies this variance-sharing technique to the general corrosion of the corrosion-allowance material and to the temperature threshold for pitting initiation on the corrosion-resistant material.

One difference between waste package environments would be the presence or absence of dripping or pooled water. WAPDEG allows the user to specify the fraction of patches that contact such water, either as a fixed value or using a probability distribution. The user can also specify when drips start, stop, or experience a change in water chemistry. For dripping conditions, model inputs can be used to specify roughness factors on the corrosion-allowance material, the cumulative distribution functions of general corrosion rates for corrosion-resistant material, and all the temperature and relative humidity thresholds as different from those for nondripping conditions. WAPDEG determines if an individual patch is dripped on or not and uses the appropriate model parameters.

For the Total System Performance Assessment – Viability Assessment configuration, waste package failure distributions were generated based on always-dripping or no-dripping conditions. For each infiltration (I) case where I varied from I multiplied by 3 to I divided by 3 (I, I × 3, and I) 3), nine simulations were conducted based on the always-dripping corrosion rates. Because of the small number of failures for the no-dripping case, only one case was simulated (Set 6).

I.4.3.2 Application of WAPDEG for the EIS

This EIS analyzes the effects of three different thermal loads (high, intermediate, and low) and three waste inventories (Proposed Action, Inventory Module 1, and Inventory Module 2) to determine their impact, if any, on total system performance. The comparison of thermal output versus time for the Inventory Module 1 and Inventory Module 2 waste inventories were considered identical for the thermal-hydrologic modeling (see Section I.4.2). Therefore, only the Proposed Action inventory and Inventory Module 1 (the expanded inventory) were considered.

Section I.4.2 describes the number of repository regions that were simulated depending on the thermal load requirements for each scenario. To incorporate the potential cooling effects around the edges of a repository region, some regions were simulated using a conceptualized center and edge, resulting in multiple NUFT simulations for certain regions. Table I-30 lists the number of individual simulations conducted for each thermal load/inventory combination, for each climate scenario.

As with the Total System Performance Assessment-Viability Assessment analyses, only the long-term average climate scenario was used in the EIS WAPDEG simulations. Therefore, the six thermal-hydrologic scenarios listed in Table I-30 were used in the generation of an equal suite of WAPDEG simulations that assumed long-term average infiltration conditions. Table I-30 lists 18 total individual thermal-hydrologic simulations for the six scenarios. WAPDEG simulations were performed using the temperature and relative humidity histories generated from each of the 18 simulations. Each set of WAPDEG simulations consisted of nine always-dripping and one no-dripping case, based on uncertainty/variability splitting.

The EIS analyses used one always-dripping case and the no-dripping base case input files from the Total System Performance Assessment – Viability Assessment as starting points. The EIS models used the same corrosion model configuration and the same corrosion rate probability distribution functions as those used in the Total System Performance Assessment – Viability Assessment base case configuration. However, the EIS analysis used a lower, fixed relative humidity threshold for corrosion initiation of the corrosion-resistant material than that used in the Total System Performance Assessment – Viability Assessment analysis. The threshold used in the EIS analysis is based on a better understanding of the factors that initiate corrosion. This difference resulted in an earlier estimate of failure of the corrosion-resistant material for the EIS analysis. This earlier failure is evident in the results of the 10,000-year analysis but does not affect the 1-million-year analysis.

Table I-30. Thermal-hydrologic and waste package degradation simulation matrix.[a]

Thermal-hydrology scenario	Inventory module	Thermal load (MTHM per acre)	Repository block(s)	Stratigraphic column	Block simulation location	WAPDEG simulation number
1	Proposed Action	85	Upper Block	1	Center	1-10
					Edge	11-20
2	Proposed Action	60	Upper Block	1	Center	21-30
					Edge	31-40
3	Proposed Action	25	Upper Block	1	Center	41-50
			Lower Block	2	Center	51-60
			Block 5	7	Center	61-70
4	Inventory Modules 1 and 2	85	Upper Block	1	Center	71-80
					Edge	81-90
			Lower Block	2	Center	91-100
					Edge	101-110
5	Inventory Modules 1 and 2	60	Upper Block	1	Center	111-120
			Lower Block	2	Center	121-130
			Block 1a	3	Center	131-140
6	Inventory Modules 1 and 2	25	Upper Block	1	Center	141-150
			Lower Block	2	Center	151-160
			Block 8	4	Center	161-170
			Block 5	7	Center	171-180

a. Source: TRW (1999a, Table 3.3-2, page 3-13).

Each WAPDEG run generated a failure curve that contained a probability distribution function of the first corrosion-resistance-material breach, average pit failures, and average patch failures (as a function of time). These files were transferred to the repository integration program model.

I.4.3.3 Results

Figure I-15 shows the temperature and drift relative humidity history curves, respectively, for all three thermal loads (high, intermediate, and low) with the Proposed Action inventory. Figure I-16 shows the temperature and relative humidity history curves, respectively, for all three thermal load scenarios with the expanded inventory (Inventory Modules 1 and 2). These figures show that when the temperature threshold [100°C (212°F)] for corrosion initiation is met, the relative humidity within the drifts for most of the runs is within the range of aqueous corrosion (80 to 100 percent). The time to reach the temperature threshold is less for the low thermal load scenario (less than 100 years) than for the high and intermediate thermal load scenarios (200 to 700 years). Corrosion of the corrosion-allowance material for the low thermal load scenario is initiated sooner but only by a few hundred years. This difference will become relatively small when discussing the differences in package failure rates at times greater than 10,000 years.

The thermal histories generated from the thermal-hydrologic modeling indicate that the hottest and coolest thermal histories correspond to the high thermal load, expanded-inventory scenario and the low thermal load, Proposed Action inventory scenarios, respectively. Thus, the results from these two configurations bound the range of potential WAPDEG failure responses. In addition, the waste package failure results were dominated by the packages that were dripped on; therefore, the failure results for the packages that were not dripped on are not presented.

WAPDEG simulations for the low thermal load with Proposed Action inventory case were generated for three repository regions corresponding to the upper (primary) block, lower block, and Block 5. The thermal output for this layout did not include edge effects (see Section I.4.2); therefore, only one thermal simulation per repository block was generated. Temperature and relative humidity histories generated from each repository block were used to define the conditions within the drifts. Figure I-17 shows the time to first breach or failure of the corrosion-allowance material for the always-dripping packages in each of the three emplacement blocks. The failures of the corrosion-allowance material are very similar for all three stratigraphic columns, with failures starting at approximately 800 years and extending approximately 4,000 years. Figure I-18 shows the time to first breach of the corrosion-resistant material for the always-dripping packages in each of the three emplacement blocks, for each of the nine uncertainty/variability splitting sets (defined in Table I-29). The failure of the corrosion-resistant material barriers in the three regions were very similar, given the same uncertainty/variability splitting set (set 5). For example, the responses observed for stratigraphic columns 2 and 7 overlie each other. The variability in the failure of the corrosion-resistant material in a particular region (for example, stratigraphic column 1), due to the introduction of the uncertainty/variability splitting, ranges from a few thousand years (set 7) to no failures within 1 million years (set 3).

Given the relatively cool thermal history for the low thermal load scenario and the 70,000 MTHM inventory, no pits (localized corrosion) would penetrate through the corrosion-resistant material for the always-dripping packages for all three emplacement blocks. All failures (see Figure I-18) would be due to general corrosion because the temperature threshold for localized corrosion was not reached. Figure I-19 shows the average number of patches penetrated through the corrosion-resistant material as a function of time for the always-dripping packages, all three emplacement blocks, and the uncertainty/variability splitting sets. Figures I-20 through I-22 show that the variability in the results of the failure for the three emplacement blocks is dominated by the corrosion rate uncertainty/variability splitting of corrosion-resistant material, with little variability attributed to the different thermal-hydrologic inputs.

WAPDEG simulations for the high thermal load scenario with the expanded inventory were generated for the upper (primary) and lower repository blocks. The repository blocks were simulated with both a center and an edge region (see Section I.2). Figure I-20 shows the time to first breach or failure of the corrosion-allowance material for the always-dripping packages, for all four simulations, and the uncertainty/variability splitting sets. Figure I-21 shows the time to first breach of the corrosion-resistant material. Figure I-22 shows the average number of patches penetrated through the corrosion-resistant material as a function of time. Previous analyses have shown that the releases from the waste packages are dominated by advection through the patch. Therefore, the patch failure history is a representative indicator of the overall performance. The results shown in Figure I-22 also show that the variability in the failures for the four center and edge simulations is dominated by the uncertainty/variability splitting, with little variability attributed to the different thermal-hydrologic inputs.

These results show that the variability in the corrosion-resistant material failures as a function of time has a greater dependency on the variability/uncertainty splitting associated with the corrosion-resistant material corrosion rate than on the variation in the temperature and relative humidity histories. The results for the high and intermediate thermal load scenarios for the Proposed Action inventory and the intermediate and low thermal load scenarios for the expanded inventory simulations showed similar behavior to the results discussed above.

I.4.3.4 Discussion

Corrosion of the corrosion-allowance material is not initiated until the waste package temperature decreases below the thermal threshold selected for the model [100°C (212°F)]. For the majority of the thermal-hydrologic simulations conducted for the EIS, once the thermal threshold is satisfied, the humid-air corrosion is initiated. Figure I-23 shows the time to the first breach of the corrosion-allowance material for all expected-value always-dripping WAPDEG simulations (Set 5). The time to first breach of the corrosion-allowance material is earliest for the low thermal load scenarios as expected from the temperature profiles shown in Figures I-15 and I-16. Because the thermal threshold is satisfied sooner, corrosion of the corrosion-allowance material is initiated sooner.

Figure I-23 also shows that by 5,000 years, almost each waste package has had at least a single corrosion-allowance material failure, thereby allowing corrosion of corrosion-resistant material. Figure I-24 shows the time to the first breach of the corrosion-resistant material for all expected-value always-dripping WAPDEG simulations (Set 5). The first corrosion-resistant-material breach for most scenarios occurs between 20,000 to 30,000 years, with the high thermal load, expanded-inventory scenario having a very low fraction of packages failing within 10,000 years. Figure I-24 also shows that the higher thermal loads generate the earliest corrosion-resistant material failures, even with later corrosion-allowance material failures. This behavior is due to the temperature-dependent, corrosion-resistant-material corrosion models, which have higher corrosion rates at higher temperatures. The thermal profiles in Figures I-23 and I-24 show that temperature is lower for the lower thermal load scenarios, resulting in slower corrosion rates and delayed failure relative to the higher loads.

Figure I-25 shows the average number of patches that failed per package as a function of time for all thermal loads and inventories, all regions, always-dripping, and uncertainty/variability splitting (set 9). Figure I-26 shows the average number of patches that failed per package as a function of time for all thermal loads and inventories, all regions, always-dripping, and uncertainty/variability splitting (set 5). These plots show a factor-of-five difference between the failure results for the two different uncertainty/variability-splitting sets.

The degradation results show that for each thermal-hydrologic scenario, the variability in the failures due to the uncertainty/variability splitting in the corrosion rate of the corrosion-resistant material would be considerably greater than the variability due to the different thermal histories. Therefore, for each thermal and inventory scenario, a set of -failure distributions from a single region was selected and included in the RIP model simulations.

I.4.4 WASTE FORM DISSOLUTION MODELS

Evaluation of Inventory Modules 1 and 2 for this EIS diverged from the Proposed Action, or base case, inventory evaluated in the Viability Assessment. Specifically, additional waste forms were included in Inventory Modules 1 and 2 that were not considered in the Viability Assessment base case, and waste form dissolution models were required to model these additional waste forms. Extensions of the waste form dissolution modeling that supported the Total Systems Performance Assessment model were required to evaluate the additional inventories. These extensions are detailed in this section.

I.4.4.1 Spent-Fuel Dissolution Model

A semi-empirical model for intrinsic dissolution (alteration) rate of the spent fuel matrix was developed from experimental data (TRW 1995, page 6-2). If the postclosure environment inside the potential repository can be assumed to maintain the atmospheric oxygen partial pressure of 0.2 atmosphere (TRW 1995, page 6-1), the dissolution model becomes a function of temperature, total carbonate concentration, and pH of contacting water. The dissolution rate strongly depends on temperature and total carbonate concentration but is less influenced by pH. The spent fuel dissolution rate increases with temperature and is enhanced by the total carbonate concentration of the contacting water, although to a smaller extent than by temperature. The mixed oxide spent nuclear fuel from plutonium disposition was modeled as commercial spent nuclear fuel.

I.4.4.2 High-Level Radioactive Waste Glass

As in the spent fuel alteration/dissolution modeling discussed above, the entire surface area of defense high-level radioactive waste in the glass waste form is assumed to be exposed to the near-field environment as soon as the first pit penetrates the waste package. The waste forms are assumed to be covered by a "thin" water film when the water contacts the glass and the alteration/dissolution processes are initiated. The "can-in-canister" ceramic from plutonium disposition was modeled as high-level radioactive waste.

High-Level Radioactive Waste Glass Dissolution Model

Details concerning the intrinsic glass dissolution rate model, as a function of temperature and pH, are presented along with rate data (TRW 1995, pages 6-4, 6-5, and 6-37). The relationship indicates that the rate model represented by the equation predicts a monotonically increasing dissolution rate with temperature.

This dissolution conceptualization contains several assumptions and limitations. The radionuclides are assumed to be released as fast as the glass structure breaks down, which is a conservative assumption because it does not account for solubility-limited radionuclides. No credit is taken for the fact that "experiments have shown that the actinides more commonly are included in alteration phases at the surface of the glass either as minor components of other phases or as phases made up predominantly of actinides" (TRW 1995, page 6-5). The model includes neither solution chemistry (other than pH and dissolved-silica concentration) nor vapor-phase alteration of the glass. Glass has been observed to undergo hydration in a humid environment and, on subsequent contact with water, radionuclide releases from a hydrated glass layer were several orders of magnitude higher than those from an unhydrated (fresh) glass waste form (TRW 1995, page 6-5).

I.4.4.3 Greater-Than-Class-C and Special-Performance-Assessment-Required Waste

The alteration/dissolution processes for Greater-Than-Class-C and Special-Performance-Assessment-Required waste forms were assumed to be similar to those for high-level radioactive waste glass.

I.4.5 RIP MODEL MODIFICATIONS

The EIS RIP model simulations are based on the Total System Performance Assessment – Viability Assessment (Revision 1) base case RIP model (TRW 1998n, all). To perform the EIS performance assessment analyses, the base case model was modified primarily to allow input of the different repository areas corresponding to the thermal load scenarios and the expanded waste inventories of Modules 1 and 2, and the repository-block configurations used in the thermal-hydrologic modeling. The EIS analysis also considered the impact to individuals at distances other than the 20 kilometers (12 miles) used for the Viability Assessment. Therefore, the analysis expanded the saturated-zone convolution model used in the Viability Assessment to include development of convolution stream tubes from the repository to distances of 30 kilometers (19 miles) and 80 kilometers (50 miles) and postprocessing of the 20-kilometer output to extract the radiological dose to individuals at the 5-kilometer (3-mile) distance described in Section I.4.5.4. This section describes the modifications. Knowledge and understanding of the RIP model (Golder 1998, all) and the Viability Assessment model (TRW 1998a,b,c,d,e,f,g,h,i,j,k, all) are necessary to fully understand the differences discussed in this section.

I.4.5.1 Modifications to the RIP Model in the Repository Environment

The RIP model conceptualization for the Yucca Mountain Repository performance assessment considers waste forms in discrete regions of the repository as source terms for flow and transport. The RIP model conceptualization for the Viability Assessment considered the primary repository block, corresponding to the high thermal load scenario, to be comprised of six regions. For any particular case analyzed for the

EIS, the EIS thermohydrologic simulations were used to determine the number of repository regions used. In adapting the Viability Assessment base case as the model for the EIS analyses, the repository regions had to conform to the center/edge model conceptualization. For each of the unused Viability Assessment regions, the source terms (commercial spent nuclear fuel, high-level radioactive waste, and DOE spent nuclear fuel) and all associated RIP model cells were removed from the model, and the remaining source terms and associated connecting cells were adapted to the center/edge model. In all cases, a total of 60 concentration parameters and all of the "connection" groups, except the 10 groups that provided total radiological dose at various points, were removed from the model. Then, the new region-specific connection groups were added as appropriate to account for the calculation of advective and diffusive releases from the center and edge regions of the EIS simulations. The calculated flux data, developed from the Lawrence Berkeley National Laboratory hydrologic model of the repository area (Bodvarsson, Bandurraga, and Wu 1997, all), was used to modify the flux into and fluid saturations applicable to the various source terms in the EIS RIP model.

Another modification resulted from the fact that although the Total System Performance Assessment – Viability Assessment considered sensitivity variations in the infiltration to the repository, the EIS simulations used only the infiltration (I) option. This was done to reduce the number of calculations, because the three thermal loads and two extra inventories greatly multiplied the number of cases to be simulated. The (I × 3) and (I × 3) options of the Total System Performance Assessment – Viability Assessment were not considered. Therefore, only the WAPDEG results for the "always-dripping" and "no-drip" scenarios were selected for model input. This change resulted in appropriate changes to the fraction-of-packages-failed parameters to allow the appropriate (I) WAPDEG to be incorporated into the model. To accommodate these differences to the RIP model, the fraction-of-packages-failed parameters for the (I × 3) and (I × 3) options were redirected to call the applicable WAPDEG tables for the long-term average climate case. The effect of neglecting this variation is minor. Sensitivity studies with the Viability Assessment model for the high thermal load scenario (DOE 1998a, Volume 3, pages 5-3 to 5-5) showed that the 10,000-year peak dose is actually decreased by 30 percent for the I × 3 case, while the peak is moved back from 10,000 years to about 5,000 years and the 1-million-year peak dose is increased about 30 percent.

The EIS simulations used only one thermal table rather than the six used in the Viability Assessment base case. Therefore, the thermal parameters were updated to refer to only one unique thermal table for each of the thermal load scenarios and inventory combinations:

- High thermal load, Proposed Action inventory
- Intermediate thermal load, Proposed Action inventory
- Low thermal load, Proposed Action inventory
- High thermal load, Inventory Modules 1 and 2
- Intermediate thermal load, Inventory Modules 1 and 2
- Low thermal load, Inventory Modules 1 and 2

The thermal hydrology modeling indicated that a single invert saturation was sufficient for all regions and all layers of the invert. Based on this information, all invert saturation parameters were fixed to a value of 0.993.

I.4.5.2 Modifications to Input and Output FEHM Model

The particle-tracking files used in the Viability Assessment (TRW 1998g, all) were modified for each EIS case to allow a different number of FEHM input regions to be used, depending on the number of input regions used in the engineered barrier system model. The "Zone 6" interface file was modified for each EIS case by changing the FEHM nodes to be used for input of mass from the engineered barrier system. The FEHM nodes were chosen to correspond to the coordinates of the EIS repository emplacement blocks. For the low thermal load scenario for Inventory Modules 1 and 2 shown in Figure I-7, proposed Blocks 6 and 7 fell outside the model boundaries. To allow the unsaturated zone particle tracker in the FEHM model to account for all mass in the repository, the mass from areas 6 and 7 were allocated to Blocks 5 and 8, respectively. Figures I-27 through I-32 show the repository emplacement blocks used for each case.

The "Zone 6" interface file was also modified for each EIS case by defining the saturated zone area that would capture the mass coming out of the FEHM model. It was necessary to modify the capture regions in order to ensure inclusion of all of the mass and to distribute the mass amongst the six stream tubes based on its repository emplacement block of origin. For the high and intermediate thermal load scenarios with Proposed Action inventories, the same regions were used for this EIS as were used for the Viability Assessment base case (Figure I-33). Figure I-34 shows the capture regions used for the low thermal load scenario with the Proposed Action inventory; the low thermal load scenario with Inventory Modules 1 and 2, and the intermediate thermal load scenario with Inventory Modules 1 and 2. Figure I-35 shows the capture regions used for the high thermal load scenario with Inventory Modules 1 and 2.

I.4.5.3 Modifications to Saturated Zone Stream Tubes for Different Repository Areas

The saturated zone stream tubes consist of a unit-breakthrough curve and a scaling factor. The unit-breakthrough curves are all the same for a given radionuclide at a given distance. The scaling factor is the product of the flux coming from the repository and a dilution factor. The dilution factor is a lumped parameter that is used to account for mixing and lateral dispersion. For the multiple-realization cases, the dilution factor is assumed to have lognormal distribution with a mean value of ten.

In order to use the stream tubes for different repository regions, flux multiplier values were calculated for each stream tube. The flux multiplier value is the ratio of the new flux into a stream tube to the flux into that stream tube in the base case (Proposed Action inventory, high thermal load scenario). The saturated zone module of RIP requires the concentration of water entering the saturated zone from the unsaturated zone, so the water flux at this interface is needed to compute the mass concentration of contaminants in the water. The resulting flux multiplier is used to scale the water flux predicted by the FEHM transport module in RIP to properly account for the larger capture zone areas for other cases. Each stream tube is associated with one of the unsaturated zone capture regions described above. The flux into a given stream tube is the sum of the fluxes from the repository regions that are in that capture region. The high thermal load scenario with Proposed Action-inventory used the same fluxes as the Viability Assessment base case. Tables I-31 and I-32 list the contribution to each of the stream tubes from each of the repository areas for the intermediate and low thermal load scenarios with Proposed Action inventory, respectively. The same information is provided for the high, intermediate, and low thermal load scenarios with Inventory Modules 1 and 2 inventory, respectively, in Tables I-33 through I-35. The fluxes used in these tables were obtained from the results of the base case Lawrence Berkeley National Laboratory site-scale unsaturated zone flow model (Bodvarsson, Bandurraga, and Wu 1997, all).

Table I-31. Summary of fluxes (cubic meters per year) from repository area to convolution stream tubes for intermediate thermal load scenario with Proposed Action inventory.[a]

	Flux from each repository area into each stream tube						
Stream tube	Upper block	Lower block	Blocks 5 & 6	Blocks 7 & 8	Total flux	85-MTHM-per acre, base case inventory flux	Flux multiplier
1	6,410	0	0	0	6,410	3,162	2.03
2	3,480	0	0	0	3,480	3,482	1.00
3	3,990	0	0	0	3,990	3,993	1.00
4	4,060	0	0	0	4,060	4,060	1.00
5	8,090	0	0	0	8,090	10,103	0.801
6	5,320	0	0	0	5,320	2,077	2.56

a. Source: TRW (1999a, Table 3.5-1, page 3-19).

Table I-32. Summary of fluxes (cubic meters per year) from repository area to convolution stream tubes for low thermal load scenario with Proposed Action inventory.[a]

Stream tube	Flux from each repository area into each stream tube: Upper block	Lower block	Blocks 5 & 6	Blocks 7 & 8	Total flux	85-MTHM-per acre, base case inventory flux	Flux multiplier
1	16,570	0	0	0	16,570	3,162	5.24
2	16,570	0	0	0	16,570	3,482	4.76
3	0	5,250[b]	0	0	5,250[b]	3,993	0.131
4	0	5,250[b]	0	0	5,250[b]	4,060	0.129
5	0	0	6,750	0	6,750	10,103	0.668
6	0	0	6,750	0	6,750	2,077	3.25

a. Source: TRW (1999a, Table 3.5-2, page 3-19).

b. Typographical error in source document.

Table I-33. Summary of fluxes (cubic meters per year) from repository area to convolution stream tubes for high thermal load scenario with Inventory Modules 1 and 2.[a]

Stream tube	Flux from each repository area into each stream tube: Upper block	Lower block	Blocks 5 & 6	Blocks 7 & 8	Total flux	85-MTHM-per acre, base case inventory flux	Flux multiplier
1	7,050	0	0	0	7,050	3,162	2.23
2	7,050	0	0	0	7,050	3,482	2.02
3	7,050	0	0	0	7,050	3,993	1.77
4	7,050	0	0	0	7,050	4,060	1.74
5	7,050	0	0	0	7,050	10,103	0.698
6	0	969	0	0	969	2,077	0.466

a. Source: TRW (1999a, Table 3.5-3, page 3-20).

Table I-34. Summary of fluxes (cubic meters per year) from repository area to convolution stream tubes for intermediate thermal load scenario with Inventory Modules 1 and 2.[a]

Stream tube	Flux from each repository area into each stream tube: Upper block	Lower block	Blocks 5 & 6	Blocks 7 & 8	Total flux	85-MTHM-per acre, base case inventory flux	Flux multiplier
1	17,620	0	0	0	17,620	3,162	5.57
2	17,620	0	0	0	17,620	3,482	5.06
3	0	3,350	0	0	3,350	3,993	0.838
4	0	3,350	0	0	3,350	4,060	0.824
5	0	0	0	4,090	4,090	10,103	0.404
6	0	0	0	4,090	4,090	2,077	1.97

a. Source: TRW (1999a, Table 3.5-5, page 3-20).

Table I-35. Summary of fluxes (cubic meters per year) from repository area to convolution stream tubes for low thermal load scenario with Inventory Modules 1 and 2.[a]

Stream tube	Flux from each repository area into each stream tube: Upper block	Lower block	Blocks 5 & 6	Blocks 7 & 8	Total flux	85-MTHM-per acre, base case inventory flux	Flux multiplier
1	17,620	0	0	0	17,620	3,162	5.57
2	17,620	0	0	0	17,620	3,482	5.06
3	0	5,250	0	0	5,250	3,993	1.31
4	0	5,250	0	0	5,250	4,060	1.29
5	0	0	10,240	0	10,240	10,103	1.01
6	0	0	10,240	54,200	64,440	2,077	31.0

a. Source: TRW (1999a, Table 3.5-4, page 3-20).

REPOSITORY SIZE AND SATURATED ZONE DILUTION FACTORS

Increasing repository size could cause either a reduction or no change in the relative lateral dispersive effects of saturated zone transport. Consider a rectangular repository oriented normal to the direction of flow in the saturated zone. The cross-sectional area of the resultant contaminant plume at a downstream well would be larger than that at the cross-sectional area of the plume at the source (below the repository), causing dilution of the radionuclide concentration at the downstream well. However, if the area of the repository was doubled, the plume at the exposure location would increase, but by less than twice. Hence, lower dilution factors would occur for larger repositories. Analytical modeling provides quantification for lower dilution factors.

The validity of using lower dilution factors for larger repositories can be illustrated by considering two hypothetical repositories with equal waste inventory, one having twice the emplacement area of the other. The concentration at the base of the unsaturated zone below the larger repository would be - half the concentration below the smaller repository (a direct result of different spacing of the waste). Using a one-dimensional saturated zone transport model without dilution, for times far greater than the groundwater travel time, the concentrations at a downstream well would be equal to those at the base of the unsaturated zone (provided the contaminant release was continuous). If the same dilution factor was applied in both cases, the downstream well concentrations for the larger repository would be half those in the smaller repository. On the other hand, if the repository was treated as a point source in each case, the dilution factor for the larger repository would be half that of the smaller repository, resulting in equal concentrations at a downstream well. These two outcomes correspond to two alternative ways of doubling the repository area. Thus, the dilution factors for expanded area repositories can be lower or equal to those of the base-case repository.

I.4.5.4 Modifications to the Stream Tubes for Distances Other Than 20 Kilometers

One-dimensional stream-tube runs for the saturated zone were conducted for generating unit-breakthrough curves at distances of 30 and 80 kilometers (19 and 50 miles) downstream from the repository. This was accomplished using the Los Alamos National Laboratory simulator FEHM (Zyvoloski et al. 1995, all) and developing a finite-element mesh that extended beyond the 25-kilometer (16-mile) mesh previously used to develop the 20-kilometer (12 mile) stream tube used for the Viability Assessment. The sets of transport parameters used in the previous model runs were also applied in the extended mesh simulations for distances up to 25 kilometers. Beyond 25 kilometers, the model properties were made identical to those assigned to the undifferentiated valley fill. On completing the FEHM runs for each of nine radionuclides, model output was postprocessed to take into account mass loadings from the unsaturated zone to each of six different stream-tube capture areas and to adjust model results for dilution attributed to transverse dispersion. This last step involved the determination of distance-dependent dilution factors by using dilution information previously developed from exposure concentrations at the 20-kilometer distance. An analytical transport solution in the program 3DADE (Leij, Scaggs, and van Genuchten 1991, all) was used to determine dispersion coefficients that resulted in dilution factors of 10, 50, and 100 at 20 kilometers and to determine corresponding dilution factors at distances of 30 and 80 kilometers. The resulting data indicated a logarithmic relationship between the 20-kilometer dilution factors and those occurring at the longer distances, making it possible to determine appropriate dilution parameters used in postprocessing of the extended-distance FEHM runs.

The saturated zone transport in the Viability Assessment is essentially based on a one-dimensional analysis that precludes lateral dispersion in the *y* and *z* directions. To simulate the realistic results of three-dimensional transport, the results of the one-dimensional analysis are divided by a dilution factor. Thus, the dilution factor accounts for attenuation of concentrations caused by the spread of the contaminant plume as the result of lateral dispersion. The dilution factor approximates numerical dispersion for the one-dimensional saturated zone model, as can be achieved using a three-dimensional advective-dispersive numerical model. This simulates the real dilution in the system.

The Viability Assessment dilution factors were based on the results of the Expert Elicitation Panel Project (TRW 1998h, Section 8.2.3.2), which assigned a median value of 10, a maximum value of 100, and a minimum value of 1.0 (no dispersion). Consideration of Inventory Modules 1 and 2 and/or the reduced thermal load resulted in a larger-area repository than that considered in the Viability Assessment analysis. Simplified logical models were developed to study the impact of the larger-area repository configurations for this EIS. In general, a larger inventory at the same thermal load results in lower concentrations at the base of the unsaturated zone (barring some exceptionally adverse infiltration conditions) because the spacing between disposal blocks results in the additional amount of waste being spread over a larger area. The larger size of the repository also tends to cause a reduction in the lateral dispersive effects of saturated zone transport, implying lower dilution factors for larger repository configurations. If the dilution factors of the Viability Assessment were to be used in this EIS, the dose rates would be predicted (albeit erroneously) to be lower than their true values for cases with expanded repository areas.

The dilution factors appropriate for the larger-area repository configurations were computed for the EIS analyses. The analytical solution for the three-dimensional transport in a one-dimensional flow field (Leij, Scaggs, and van Genuchten 1991, all) was used to relate the lateral dispersion lengths (in the *y* and *z* directions) and the dilution factors. Considering a rectangular source oriented normally to the flow direction, the steady-state concentrations at the locations [5, 20, 30, and 80 kilometers (3, 12, 19, and 50 miles)] were computed based on the assumed dispersion lengths described below.

The ratio between the concentration from the one-dimensional and three-dimensional analyses gives the dilution factor, which enables a “translation” of the Saturated Zone Expert Elicitation Panel’s dilution factors to “dispersion lengths.” The Panel’s dilution estimates were for a 25-kilometer (16 miles) distance and the Viability Assessment adjusted this estimate for estimates at 20 kilometers (12 miles). The dispersion lengths so derived for the Viability Assessment are assumed to remain the same for larger repository configurations. Using the same dispersion lengths, as implied in the Viability Assessment, the dilution factors for the larger repository configurations were computed using the analytical solution. The Darcy flux used in the calculations for the saturated zone flow fields was the same 0.6 meters (2 feet) per year used in the Viability Assessment (DOE 1998a, Volume 3, page 3-138). The actual repository geometry was a rectangular source with an area equivalent to that of the repository configuration for the appropriate thermal load. The larger dimension of the rectangular source was normal to the flow direction and assumed equal in the unsaturated and saturated zones. The smaller dimension of the rectangular source, parallel to the flow in the saturated zone, was modified in the saturated zone to fulfill the continuity of flow requirement (that is, to reconcile large differences in the flow velocities in the unsaturated and saturated zones).

The matrix of dilution factors (given in Table I-36), calculated using the 3DADE computer code (Leij, Scaggs, and van Genuchten 1991, all), was dependent on the major influences on the calculated dilution factors, namely:

- The orientation of each repository configuration relative to the direction of groundwater flow
- The total area of each repository configuration
- The average percolation flux of each sector (or block) of the repository based on the Lawrence Berkeley National Laboratory hydrologic model

Extension of the repository area in a direction orthogonal to that of groundwater flow had little effect on the calculated dilution factor. However, for dilution factors calculated for the repository and enlarged in the direction parallel to that of groundwater flow, there were changes on the order of factors of two or three. Thus, the intermediate thermal load scenario had the same dilution factor as the high thermal load Proposed Action scenario for the 20-kilometer (12-mile) distance, because the repository shape was relatively similar with essentially no changes parallel to the flow direction. In contrast, the low thermal

Table I-36. Dilution factors for three thermal load scenarios and four exposure locations.[a]

		Proposed Action			Inventory Modules 1 and 2		
	Thermal load (MTHM per acre)[b]	High (85)	Intermediate (60)	Low (25)	High (85)	Intermediate (60)	Low (25)
Distance	Repository area (acres)	740	1,050	2,520	1,240	1,750	4,200
5 kilometers[c]	Minimum	1.0	1.0	1.0	1.0	1.0	1.0
	Median	5.15	5.15	2.9	5.15	3.8	2.5
	Maximum	50.02	50.02	24.6	50.02	354	19.2
20 kilometers	Minimum	1.0	1.0	1.0	1.0	1.0	1.0
	Median	10.0	10.0	5.1	10.0	7.2	4.1
	Maximum	100.0	100.0	49.2	100.0	70.8	38.4
30 kilometers	Minimum	1.0	1.0	1.0	1.0	1.0	1.0
	Median	12.2	12.2	6.2	12.2	8.8	4.9
	Maximum	122.0	122.0	60.2	122	86.7	47
80 kilometers	Minimum	1.0	1.0	1.0	1.0	1.0	1.0
	Median	19.894	19.84	9.9	19.84	14.2	7.8
	Maximum	200.04	200.04	98.4	200.04	141.6	76.7

a. Source: TRW (1999a, Table 4.1-1, page 4-6).
b. To convert acres to square miles, multiply by 0.0015625.
c. To convert kilometers to miles, multiply by 0.62137.

load Proposed Action scenario has almost double the area of the intermediate thermal load Proposed Action scenario. The repository is approximately twice the distance in the direction parallel to flow, resulting in a dilution factor almost twice that of the intermediate thermal load Proposed Action scenario. Thus, because of the repository geometry, the differences in the dilution factors between the low and intermediate thermal load Proposed Action scenarios resulted in less dilution in the low thermal load Proposed Action scenario.

I.4.5.5 Modifications to the RIP Model to Account for Unsaturated Zone and Saturated Zone Particle Transport

Transport through the unsaturated zone is modeled in RIP using particles that are assigned a “start location” at the level of the repository. The Viability Assessment analysis considered particle releases only in the upper block of the repository. For the EIS analyses, the Lawrence Berkeley National Laboratory model (Bodvarsson, Bandurraga, and Wu 1997, all) element centroids were mapped to the outline of the upper block, and particles were released from these locations.

Because the EIS analysis considered expanded areas for the emplacement of waste, additional particle coverage was needed to represent transport throughout the entire region of interest. This region included the additional repository blocks for the expanded waste inventories considered in Inventory Modules 1 and 2. An orthogonal grid was mapped for each of the emplacement zones within the area covered by the Lawrence Berkeley National Laboratory model, and this grid was use to determine the coordinates of particle start points at the repository horizon. These coordinates were then converted to the centroid of the nearest Lawrence Berkeley National Laboratory model elements. In this way, a file containing Lawrence Berkeley National Laboratory element numbers was created for each waste emplacement zone for the particle-start coordinates. From this functional area of the RIP model, both the EIS and Viability Assessment performance assessment analyses used the FEHM model (Zyvoloski et al. 1995, all) to model particle transport through the unsaturated zone.

At the base of the unsaturated zone, a corresponding change of coordinates was used to collect and distribute the mass transported through the unsaturated zone to the saturated zone convolution stream tubes that carried dissolved radionuclides to the various exposure locations. The unsaturated and saturated zone capture regions for the EIS analysis were scaled-up modifications of the six regions used by the Total System Performance Assessment – Viability Assessment analysis, as extended to the edge of the Lawrence Berkeley National Laboratory model area. The nodes at the bottom of the unsaturated zone were calculated to ensure complete capture of the mass coming out of the unsaturated zone and to appropriately distribute that mass among the six stream tubes, based on those six repository regions being modified and applied to the expanded areas addressed by the EIS analysis.

Table I-37 lists the ranges of stochastic parameters that were included in the analysis of saturated zone flow and transport.

Table I-37. Stochastic parameters for saturated zone flow and transport.[a]

Parameter	Distribution type	Distribution statistics [bounds]
Effective porosity, alluvium	Truncated normal	Mean = 0.25, SD[b] = 0.075 [0, 1.0]
Effective porosity, upper volcanic aquifer	Log triangular	[1×10^{-5}, 0.02, 0.16]
Effective porosity, middle volcanic aquifer	Log triangular	[1×10^{-5}, 0.02, 0.23]
Effective porosity, middle volcanic confining unit	Log triangular	[1×10^{-5}, 0.02, 0.30]
Effective porosity [plutonium], volcanic units	Log uniform	[1×10^{-5}, 1×10^{-3}]
Distribution coefficient K_d (milliliters per gram) for:		
Neptunium (alluvium)	Uniform	[5, 15]
Neptunium (volcanic units)	Beta (approx. exp.)	Mean = 1.5, SD= 1.3 [0, 15]
Protactinium (alluvium)	Uniform	[0, 550]
Protactinium (volcanic units)	Uniform	[0, 100]
Selenium (alluvium)	Uniform	[0, 150]
Selenium (volcanic units)	Beta (approx. exp.)	Mean = 2.0, SD = 1.7, [0, 15]
Uranium (alluvium)	Uniform	[5, 15]
Uranium (volcanic units)	Uniform	[0, 4.]
Plutonium (all units)	Log uniform	[1×10^{-5}, 10]
Longitudinal dispersivity, all units (meters)	Log-normal	Log(mean) = 2.0, log(SD) = 0.753
Fraction of flow path in alluvium	Discrete CDF[c]	[0, 0.3] (see text)

a. Source: DOE (1998a, Volume 3, Table 3-20, page 3-140).
b. SD = standard deviation.
c. CDF = cumulative distribution function.

I.4.5.6 Biosphere Dose Conversion Factors for Waterborne Radionuclides

A biosphere dose conversion factor for groundwater is a number used to convert the annual average concentration of a radionuclide in the groundwater to an annual radiological dose for humans. The calculation of a biosphere dose conversion factor requires knowledge about the pathway the radionuclide would follow from the well to humans and the lifestyle and eating habits of humans. Figure I-36 illustrates the biosphere modeling components.

The approach used in this long-term performance assessment calculated the health consequences for a reference person living in the Amargosa Valley. The reference person would be an adult who lived year-round on a farm in the Amargosa Valley, grew a garden, raised livestock, and ate locally grown food. Because future human technologies, lifestyles, and activities are inherently unpredictable, the analysis assumed that the future inhabitants of the region would be similar to present-day inhabitants. This assumption has been accepted in similar international efforts at biosphere modeling and is preferable to developing a model for a future society (National Research Council 1995, all).

A lifestyle survey of people living in the area was completed in 1997 (TRW 1998i, Section 9.4, pages 9-25 to 9-35). Among other functions, the survey was intended to give an accurate representation of dietary patterns and lifestyle characteristics of residents within 80 kilometers (50 miles) of the Yucca

Mountain site. Of special interest was the proportion of locally grown foodstuff consumed by local residents and details about regularly consumed food types.

The Amargosa Valley region is primarily rural agrarian in nature and the local vegetation is primarily desert scrub and grasses. Agriculture consists mainly of growing livestock feed (for example, alfalfa); however, gardening and animal husbandry are common. Water for household uses, agriculture, horticulture, and animal husbandry is primarily from local wells.

Another component of the dose to people would be the inadvertent ingestion of contaminated soil, usually from vegetables. The inhalation pathways would include breathing small soil particles that became airborne during outdoor activities, especially farming, mining, and construction activities that would disturb the soil or bedrock. Proximity to a radiation source external to the body would result in an external pathway. This pathway is called “groundshine” when the contaminants are on the ground, “submersion” when they are in the atmosphere, and “immersion” when they are in water.

The analysis calculated biosphere dose conversion factors for the exposure pathways described above. Although many of the input parameters were derived from site-specific data obtained from the Yucca Mountain regional survey and weather data tabulations, some were from other published sources. The input parameters used in the biosphere modeling are described in the Viability Assessment (DOE 1998a, Volume 3, Section 3.8). The estimated consumption rates for vegetables, fruits, grains, beef, poultry, milk, eggs, and water were from the results of the survey (TRW 1998i, Tables 9-14 through 9-20, pages T9-20 to T9-26). Generic food-transfer factors were from IAEA (1994, pages 5 to 58). The amount of plant uptake of radionuclides used in the calculations was taken from LaPlante and Poor (1997, pages 2-12 to 2-14).

The analysis calculated the dose from each radionuclide that would reach the reference person by multiplying the amount of radionuclide ingested, inhaled, or deposited near that person by the dose conversion factor for that radionuclide. Dose conversion factors have important uncertainties associated with them. However (as is customary for radiological compliance evaluations and EISs), this analysis used only fixed values derived by methods from the *International Commission on Radiological Protection Publication 30* (ICRP 1979, all). These methods are similar to those specified by the Environmental Protection Agency (Eckerman, Wolbarst, and Richardson 1988, all).

The long-term performance assessment calculations used the statistical distributions of biosphere dose conversion factors. When the postulated climate change occurred during the model run, the biosphere dose conversion factors changed to reflect the precipitation patterns associated with the new climate. The major impact of a wetter climate would be to reduce the amount of well water required for irrigation. The analysis did not consider other climate-related effects such as the appearance of springs, seeps, or other surface water, because they would be unlikely to cause a large change in the consequences for a maximally exposed individual. The result was the annual dose rate that the reference person would receive from that radionuclide at a given time. The reference person (referred to in this EIS as a maximally exposed individual) was developed from a series of lifestyle assumptions based on the surveys of lifestyles in the region. Details on the reference person development are in the Viability Assessment (DOE 1998a, Volume 3, pages 3-150 to 3-155).

In the analyses for this EIS, the same biosphere dose conversion factors were used for the four locations considered [5, 20, 30, and 80 kilometers (3, 12, 19, and 50 miles)]. The biosphere dose conversion factors are appropriate for the 30-kilometer location due to its similarity to the 20-kilometer location. However, using the same factors for the other locations resulted in a systematic dose overestimation at 5 and 80 kilometers. This overestimate resulted because not all of the exposure pathways considered in the calculation of biosphere dose conversion factors for the 20-kilometer location were appropriate for the 5-and 80-kilometer locations. The 5-kilometer location would be a drinking-water-only pathway (ingestion dose only) because this location is not suitable to irrigation or farming. The 80-kilometer location is a lake playa, where evaporating contaminated water would result in deposits of contaminated dust. Resuspension of the contaminated dust present the only exposure pathway for this location (that is, drinking water and irrigation water pathways would not be relevant). However, development and use of location-specific biosphere dose conversion factors for 5 and 80 kilometers would only serve to reduce the calculated impacts reported in this EIS. Therefore, using the biosphere dose conversion factors developed for the Viability Assessment (DOE 1998a, Volume 3, pages 3-158 to 3-161) for the 20-kilometer location at all other locations evaluated in this EIS is considered conservative.

I.5 Waterborne Radioactive Material Impacts

This section presents the total radiological dose to maximally exposed individuals, as calculated by the RIP model, at the following four groundwater withdrawal or discharge locations downgradient from the Yucca Mountain site where contaminated water could reach the accessible environment:

- A potential well 5 kilometers (3 miles) from the repository
- A potential well 20 kilometers (12 miles) from the repository
- A potential well 30 kilometers (19 miles) from the repository
- Franklin Lake Playa, the closest potential groundwater discharge point downstream from the repository [80 kilometers (50 miles)]

The total radiological dose was calculated from repository closure to 10,000 years following closure and at a time when the peak radiological dose would be observable. RIP model simulations carried out to 1 million years after repository closure also will include the peak radiological dose. These results are provided in Section I.5.1.

Apparent anomalous behavior of total radiological dose results predicted by the RIP model for the low and intermediate thermal load scenario under the Proposed Action inventory is explained in Section I.5.2.

The sensitivity of the estimates of waterborne radioactive material impacts to the fuel cladding model is examined in Section I.5.3.

I.5.1 TOTAL RELEASES DURING 10,000 YEARS AND 1 MILLION YEARS

The RIP model calculated radionuclide releases and radiological doses from individual nuclides and the total radiological dose due to all nine modeled radionuclides released from the repository from failed waste packages. The model calculated total radiological dose in either of two ways: as a single run using expected values of variable parameters, or in multiple realizations (runs) using randomly selected values for distributed parameters. The model can calculate the total radiological dose as the expected value of individual nuclides or the sum of all nuclides, for which sum the model chooses the mean value of all distributed parameters. In addition, the model can use the *Monte Carlo* code to stochastically, or randomly, perform any number of realizations or runs to select values of the distributed parameters. The stochastic nature of the predictions is shown by the complementary cumulative distribution function of the total radiological dose rate (that is, the sum of doses over all radionuclides) for 10,000 or 1 million years. The total radiological dose represents the radiological dose to a maximally exposed individual at the accessible environment using potentially affected groundwater for drinking water. The complementary cumulative distribution functions discussed in this section represent the result of 100 realizations of the RIP model.

The number of realizations used for a Monte Carlo simulation is an important issue with respect to the reliability of analysis results and proper allocation of resources. The number of runs required to reliably predict peak dose rates was examined (DOE 1998a, Volume 3, page 4-71). To verify that 100 realizations would be sufficient, 10,000-year and 100,000-year simulations for the high thermal load scenario with Proposed Action inventory were carried out with 1,000 and 300 realizations, respectively. The resulting distributions of peak individual radiological dose rates were compared with the 100-realization base case results for both periods. The complementary cumulative distribution functions for each time period were found to nearly match. The 100-realization complementary cumulative distribution functions did not go below a probability of 0.01 because each predicted dose rate has a probability of occurrence of one one-hundredth, or 0.01. Similarly, the 1,000- and 300-realization distributions display minimum probabilities of 0.001 and 0.003, respectively. Peak dose rates did continue to increase as probability decreased. Increased dose rates at these low probabilities were caused by combinations of extremely uncertain parameter values sampled from the tails of the parameter probability distributions. However, 100 realizations appear to be sufficient for a good compromise between cost and precision.

Figures I-37 through I-39 show the 10,000-year and 1-million-year complementary cumulative distribution functions of total peak radiological dose for the Proposed Action inventory (see Section I.3.1.2) at 5, 20, 30, and 80 kilometers (3, 12, 19, and 50 miles). In sequence, these figures show the total radiological dose at human exposure locations for the high, intermediate, and low thermal load scenarios and show that the maximum peak radiological dose (total for all nuclides) would occur well after 10,000 years. Further, the 10,000-year complementary cumulative distribution functions show that the distance (of the four distances analyzed) at which the highest total radiological dose would occur is 5 kilometers from the repository. As groundwater moves downgradient from the Yucca Mountain site, it flows from tuffaceous rocks to an alluvial aquifer. The pattern of the complementary cumulative distribution reflects the fact that there would be greater natural retardation in the alluvium than in the tuff portions of the hydrostratigraphic units.

Figures I-40 through I-42 show the 10,000-year and 1-million-year complementary cumulative distribution functions of total peak radiological doses for the Inventory Module 1 inventory at 5, 20, 30, and 80 kilometers (3, 12, 19, and 50 miles). In sequence, these figures show the total radiological doses at human exposure locations for the high, intermediate, and low thermal load scenarios. As for the Proposed Action inventory, these figures show that the maximum peak radiological dose (total, all nuclides) would occur well after 10,000 years. Again, the 10,000-year complementary cumulative distribution functions show that the distance (of the four distances analyzed) at which the highest total radiological dose would occur is 5 kilometers from the repository.

For the Viability Assessment and this EIS, the mean peak dose is the average peak dose of the 100 realizations of radiological dose to a maximally exposed individual (that is, the peak for each realization is determined and all peaks are averaged). The 95th-percentile peak dose is the average of the 95th- and 96th-highest ranked peak doses of the 100 realizations of radiological dose to a maximally exposed individual (that is, the peak for each realization is determined, those peaks are ordered from lowest to highest, and the average of the 95th- and 96th-highest is computed).

I.5.2 APPARENT ANOMALOUS BEHAVIOR BETWEEN LOW AND INTERMEDIATE THERMAL LOAD RESULTS FOR PROPOSED ACTION INVENTORY

Comparison of the expected-value simulations for the different thermal load scenarios at the same distance from the repository reveals apparent anomalous behavior. The differences between the scenarios involving low and intermediate thermal loads under the Proposed Action inventory, which show that the low thermal load curve crosses over the intermediate thermal load curve, require further explanation.

The analysis of three thermal load scenarios revealed some differences in performance as measured by the calculation of total radiological dose to maximally exposed individuals at various distances from the repository. In particular, there is an apparent inconsistent relationship between the total dose-rate history curves for the low and intermediate thermal load scenarios at 20 kilometers (12 miles) from the repository. The apparent differences can be explained by the following factors:

- The effect of repository-area shape on the calculation of the dilution factor using the 3DADE analytical solution (Leij, Scaggs, and van Genuchten 1991, all)
- Waste package degradation differences resulting in the solubility-limited transport, among the different repository blocks being considered for disposal, of neptunium-237 from waste-form degradation
- The correlative differences in the percolation flux

I.5.2.1 Effect of the Dilution Factor

The saturated zone dilution factors were presented and discussed in Section I.4.5.4. As noted in that section, the major influences on the calculated dilution factors were the geometry of the total repository, the orientation of the repository relative to the direction of groundwater flow, and the average estimated infiltration for each repository block. The important finding was that for each repository configuration, extension of the repository area in a direction orthogonal to that of groundwater flow had little effect on the calculated dilution factor. However, when calculated for an enlargement parallel to groundwater flow, there were changes in the range of two to three times the dilution factors.

Thus, the intermediate thermal load Proposed Action scenario for the 20-kilometer (12-mile) distance had the same dilution factor as the high thermal load Proposed Action scenario, because the repository shape was relatively similar with essentially no change orthogonally to the flow direction. In contrast, the low thermal load Proposed Action scenario for the 20-kilometer distance has almost double the area of the intermediate thermal load Proposed Action scenario. Moreover, the repository is approximately twice as long in the direction parallel to groundwater flow, resulting in a dilution factor almost two times less than that of the intermediate thermal load Proposed Action scenario. Thus, because of the repository geometry, the dilution factors between the low and intermediate thermal load Proposed Action scenarios would result in less dilution under the low thermal load scenario.

I.5.2.2 Effect of Waste Package Degradation

Figure I-43 shows the total-radiological-dose-history curve for the Proposed Action inventory for the intermediate and low thermal load scenarios. The peak radiological dose from the low thermal load scenario is slightly delayed compared to the intermediate thermal load scenario, due to the delay in package failure initiation for the low thermal load scenario. An examination of the waste package failure distribution between these two scenarios (Figure I-44) shows that after the initial juvenile package failure (one package fails early for every case) stipulated by the Viability Assessment analysis, the first failure of the intermediate thermal load scenario is about 9,000 years after repository closure, whereas the first failure of the low thermal load scenario is about 27,000 years after repository closure. Thus, the amount of neptunium-237 available for removal from the repository is less for the low thermal load scenario than for the intermediate thermal load scenario.

The disparity in amount of neptunium-237 available for removal persists until the time of the super-pluvial climate. Figure I-43 shows that until the super-pluvial climate cycle (about 300,000 years after repository closure) the low thermal load total radiological dose history curve lies below and later than the intermediate thermal load total radiological dose history curve. Essentially, the peak radiological doses occur at different times by that same amount of material removed. At this time, the number of waste package failures has increased to allow differences in removal rates from the repository due to the solubility limitations of neptunium-237. A larger proportion of the neptunium-237 is removed under the intermediate thermal load conditions because of the relatively higher amount of percolation flux and larger number of waste packages for the upper block for this scenario. However, more of the neptunium-237 remains in the repository under the low thermal load case because it can not all be removed from the larger repository area due to the reduced amount of water. The total-radiological-dose-to-receptor curve then crosses over the intermediate thermal load curve at about 300,000 years after closure. Thereafter, the two curves slowly approach one another during the remainder of the simulation but never recross during the simulated period.

I.5.2.3 Effect of Percolation Flux Distribution

The percolation flux differs across Yucca Mountain, especially in relation to the proposed areas. Figure I-45 shows the average percolation flux for the different repository areas. Note that Block 5 has the lowest percolation flux and Block 8 has the largest percolation flux. The intermediate thermal load Proposed Action scenario includes only the upper block (Block 1) and the capture areas are similar to the high thermal load Proposed Action scenario. The average infiltration flux for the upper block is larger than that for Block 8.

A sensitivity analysis using only the long-term average climate shows that the release rate of neptunium-237 at the top of the water table has two peaks. One is influenced by percolation flux in capture regions 1, 2, and 4, and the other is influenced by percolation flux in capture regions 3, 5, and 6. The reason for the two-peak aspect of the total release-rate curve is that neptunium-237 is solubility limited, and the lower percolation flux in the lower block and Block 8 does not completely remove all of the available neptunium-237 from these blocks at the same rate as in areas with greater percolation flux. The comparable curve for the intermediate thermal load Proposed Action scenario shows that all neptunium-237 is released at approximately the same time. Figures I-46 through I-49 show a comparison of the neptunium-237 radiological dose-rate histories for the low and intermediate thermal load scenarios for only the average long-term climate at the engineered barrier system and at the exposure location [20 kilometers (12 miles)]. These figures show that the difference in percolation flux is apparent at the engineered barrier system and accentuated in the saturated zone because of the retarded release of neptunium-237 under lower percolation flux. Because neptunium-237 is the dominant radionuclide contributing to the total radiological dose at times greater than 100,000 years, the curves indicating the low and intermediate thermal load total radiological-dose rate history cross. After crossing, the curves do not maintain their separation but tend to approach one another without recrossing for the remainder of the 1-million-year simulation period. It appears that they would likely cross again between 1 million and 1.5 million years at the observed rate of closure if the simulation were extended.

I.5.2.4 Conclusion

The analysis of the three thermal loads proposed for the planned repository configuration revealed anomalous differences in performance as measured by the calculation of total radiological dose to maximally exposed individuals at various distances from the repository. The apparent differences can be explained by three factors:

- The effect of repository area shape on the calculation of the saturated zone dilution factor using the 3DADE numerical code, based on an analytical solution to flow and transport from the repository
- Differences in waste package failure under the different thermal loads
- Differences in the percolation flux and the correlative neptunium-237 solubility-limited transport among the different repository blocks being considered for disposal

I.5.3 SENSITIVITY TO FUEL CLADDING MODEL

Section 5.4.4 of this EIS describes a sensitivity analysis DOE conducted to assess the importance of fuel pin cladding protection on radiological dose. This section contains additional details for the sensitivity analysis.

The average radionuclide inventory listed in Table I-1 for each commercial spent nuclear fuel waste package was used in the sensitivity analysis. Under the Proposed Action, approximately 1.2 percent of the spent nuclear fuel would have stainless-steel cladding rather than zirconium-alloy cladding. The stainless steel would degrade much faster than zirconium alloy, so the sensitivity analysis neglected stainless-steel cladding as a protective barrier. In addition, approximately 0.1 percent of the fuel pins are proposed to fail in the reactor environment. Thus, under the Proposed Action, 1.3 percent of the radionuclides in every spent nuclear fuel waste package would be available for degradation and transport as soon as the waste package failed.

For the purposes of comparison, the analysis performed additional stochastic runs for 10,000 and 1 million years after repository closure assuming the zirconium-alloy cladding would provide no resistance to water or radionuclide movement after the waste package failed. Table I-38 compares the peak radiological dose rate from groundwater transport of radionuclides for the base case and this case, which assures zirconium-alloy cladding would not be present. The analysis used data representing the high thermal load scenario to calculate individual exposures for a 20-kilometer (12-mile) distance only for purposes of comparison.

Table I-38. Comparison of consequences for a maximally exposed individual from groundwater releases of radionuclides using different fuel rod cladding models under the high thermal load scenario.

	Mean consequence[a]		95th-percentile consequence[b]	
Maximally exposed individual	Dose rate (millirem/year)	Probability of an LCF[c]	Dose rate (millirem/year)	Probability of an LCF
Peak at 20 kilometers[d] within 10,000 years after repository closure with cladding credit	0.22	7.6×10^{-6}	0.58	2.0×10^{-5}
Peak at 20 kilometers within 10,000 years after repository closure without cladding credit	5.4	1.9×10^{-4}	15	5.3×10^{-4}
Peak at 20 kilometers within 1 million years after repository closure with cladding credit	260	9.0×10^{-3}	1,400	5.0×10^{-2}
Peak at 20 kilometers within 1 million years after repository closure without cladding credit	3,000	1.1×10^{-1}	10,800	3.8×10^{-1}

a. Based on sets of 100 simulations of total system performance, each using random samples of uncertain parameters.
b. Represents a value for which 95 out of the 100 simulations yielded a smaller value.
c. LCF = latent cancer fatality; incremental lifetime (70 years) risk of contracting a fatal cancer for individuals, assuming a risk of 0.0005 latent cancer per rem for members of the public (NCRP 1993a, page 31).
d. To convert kilometers to miles, multiply by 0.62137.

Figure I-50 shows complementary cumulative distribution functions of the peak radiological dose rates for the four suites of model runs. Approximately 25 percent of the 10,000-year runs did not show any releases to the locations at a distance of 20 kilometers (12 miles). The zero releases are the reason the 10,000-year curves in Figure I-50 start at an exceedance probability of 0.73 and decrease with increasing radiological dose rate. All of the 1-million-year runs show releases at 20 kilometers.

The analysis assumed that the zirconium-alloy cladding would provide no barrier to water movement and radionuclide mobilization after the failure of the waste package. However, DOE expects that the zirconium alloy would provide some impediment to radionuclide mobilization when the waste package is breached. Therefore, the results for no cladding listed in Table I-38 should be viewed as an upper boundary.

I.6 Waterborne Chemically Toxic Material Impacts

Further transport analysis is warranted because the screening analysis (Section I.3.2.3.3) indicated that the repository could release chromium into groundwater in substantial quantities and thus could represent a human-health impact. Surrogate calculations were performed using the RIP model and inputs based on the radiological materials transport simulations. This approach selected a long-lived unretarded isotope (iodine-129) to serve as a surrogate for chromium. Iodine is highly soluble and exhibits little or no sorption so when corrected for radioactive decay, its movement represents scalar transport. This method avoided the extensive inputs necessary to define a new species for the RIP model and revision of the associated external function modules that the analysis had carefully constructed for the nine modeled radionuclides.

I.6.1 CHROMIUM

The screening analysis for chemically toxic materials (Section I.3.2.3) identified chromium from the waste packaging as a potential impact of concern. This section describes a chromium inventory for use in the RIP model and evaluates chromium impacts.

I.6.1.1 RIP Model Adaptations for Chromium Modeling

The following assumptions were applied to the chromium surrogate calculation approach:

1. Iodine-129 will serve adequately as a surrogate for chromium because it has a long radioactive half-life, lacks decay ingrowth by predecessors in a decay chain in the RIP model calculations, and is not retarded in groundwater (chromate is also unretarded). A small error introduced by the slight radioactive decay of iodine-129 during the model simulations can be corrected by an analytical expression as a postprocessing step.

2. Alloy-22 degradation and release is modeled using general corrosion depth of the corrosion-resistant material taken from WAPDEG modeling results (Mon 1999, all) for both dripping and nondripping conditions. The WAPDEG modeled the general corrosion depth (in millimeters per year) of corrosion-resistant material for 400 waste packages were averaged to produce a general degradation rate for dripping and nondripping conditions and converted to a fraction of corrosion-resistant material per year rate for use in the RIP model. The fractional degradation rate curves are show in Figure I-51.

3. Chromium associated with stainless-steel components used in many commercial spent nuclear fuel waste packages would be released proportionately with Alloy-22 chromium. This conservative assumption effectively assumes no credit for the delay of the onset of interior stainless-steel degradation or for the degradation rate of the interior stainless steel itself.

The treatment of Alloy-22 corrosion-resistant material degradation and chromium mobilization required the redefinition of the RIP container model. This calculation used the “Primary Container” in the RIP model to represent only the corrosion-allowance material (outer layer) of the waste package. The “Secondary Container” in the RIP model (used to represent cladding in the radiological material transport simulations) was not used. The waste matrix was used to represent the corrosion-resistant inner layer made of Alloy-22. These steps, with the proper material inventory and degradation coefficients, enabled the use of the current RIP model structure for this calculation.

The following additional changes were made to the radiological RIP model input files to conduct the surrogate chromium mobilization and migration calculation:

1. Iodine-129 solubility was specified as 1,976 grams per cubic meter (0.12 pounds per cubic foot), based on the near-field geochemistry screening study results for chromium (iodine-129 serving as a surrogate for chromium). Section I.3.2.3.1 contains details on determining this solubility limit.

2. For each source term, the inventory of all radionuclides (except iodine-129) received a value of zero.

3. The inventory of iodine-129 in each source term were specified in units of grams (rather than the original units of curies) per waste package using the values in Tables I-18 through I-22 in Section I.3. All inventory was assigned to the RIP model Waste Matrix Fraction (and none to the Primary or Secondary Container Fractions) in each source term.

4. The analysis assumed that mobilized chromium from the corrosion-resistant material would advect directly from the exposed corrosion-resistant material surface onto the invert (drift floor).

5. All secondary container definitions were all changed to a "degenerate" distribution at time zero, to eliminate the effects of any cladding protection from the calculation. A degenerate distribution simply results in all secondary containers failing at the specified time. The Alloy-22 corrosion-resistant material layer would be outside the cladding and, hence, not a barrier from this perspective.

6. The primary container definitions were changed to a "Degenerate" distribution at time zero, to eliminate the effects of corrosion-allowance material protection. This step is necessary because the protective benefits of the corrosion-allowance material are implicit in the WAPDEG results used to directly incorporate corrosion-resistant material degradation into the RIP model.

7. The waste-form-degradation rate for each source term was replaced with new variables representing weight-averaged Alloy-22 degradation. The definition of these degradation rates is detailed below.

8. RIP model output was requested in grams (mass) rather than curies (radioactivity).

To arrive at a weight-averaged fractional corrosion rate to apply to all waste packages of a given category (spent nuclear fuel, high-level radioactive waste, or DOE spent nuclear fuel) in a given repository region, the following steps were taken. The Alloy-22 generalized corrosion depth for dripping and nondripping conditions was converted to a fractional degradation rate, as described above. The Alloy-22 fractional corrosion rate was computed from a weighted average (with respect to the fraction of packages subject to dripping and nondripping conditions in the current climate) of dripping and nondripping generalized corrosion rates. This weight-averaged fractional degradation rate was then used to model the release of chromium from the waste package to the near-field environment.

For the Proposed Action, 30 percent of the chromium inventory would originate from interior stainless-steel components used in some commercial spent nuclear fuel waste packages (see Table I-16). Because the waste package would have to fail before degradation and transport of interior components could begin, simply adding the two chromium inventories together would yield artificially high results.

A two-stage scoping analysis, following the steps outlined above for using the RIP model to calculate chromate migration, was performed for the Proposed Action inventory under the high thermal load scenario to predict chromate concentrations at the 5-kilometer (3-mile) distance. In the first stage, the model was run with only the chromium inventory from the Alloy-22 corrosion-resistant material [904,000 grams (about 2,000 pounds) of chromium per commercial spent nuclear fuel waste package] following the steps outlined above for chromium modeling. In the second stage, the model was run again with only the interior stainless-steel inventory [514,000 grams (about 1,100 pounds) of chromium per commercial spent nuclear fuel waste package] but used the complete WAPDEG waste package model (as used in the Viability Assessment) to represent complete waste package containment. Only the commercial spent nuclear fuel packages would differ; no interior stainless-steel internal components would be used in high-level radioactive waste or DOE spent nuclear fuel containers. Each RIP model run was held to the same random number seed (used to "seed" the random number generator that is used to select random values of stochastic parameters) so the realizations would be replicated. The results of each simulation were summed, with respect to realization and time step, to calculate the total chromium concentration at 5 kilometers (3 miles). The results are listed in Table I-39.

Table I-39. Chromium groundwater concentrations (milligrams per liter)[a] at 5 kilometers (3 miles) under Proposed Action inventory using the high thermal load scenario and a two-stage RIP model.

	Peak chromium concentration	
Model	Mean	95th-percentile
RIP Stage 1: Corrosion-resistant material (Alloy-22) chromium inventory	0.0085	0.037
RIP Stage 2: Interior-to-waste package (SS/B[b] alloy) chromium inventory	0.000000086	0.00000048
Totals (Stage 1 + Stage 2, by realization; time step)	**0.0085**	**0.037**

a. To convert milligrams per liter to pounds per cubic foot, multiply by 0.00000624.
b. SS/B = stainless-steel boron.

The chromium concentrations obtained in this scoping analysis demonstrated that the inventory of chromium associated with interior stainless-steel components, although it would represent 30 percent of the total chromium inventory, would be small with respect to the peak chromium concentration in groundwater at the closest downgradient location considered. Including the interior stainless-steel chromium inventory increased the estimate of the mean peak chromium concentration by 0.00088 percent over modeling the corrosion-resistant material chromium alone. The 95th-percentile peak chromium concentration was increased by 0.000072 percent over modeling the corrosion-resistant material inventory of chromium alone. Therefore, an additional step to model the interior stainless-steel corrosion and transport was unnecessary to predict peak chromate concentrations.

Two factors would contribute to the inconsequential impact of the chromium inventory from the waste package interior. First, the Alloy-22 in the waste package would have to be breached before interior stainless steel was exposed to water and began to degrade. Thus, much of the chromium in the Alloy-22 would already have migrated before the interior stainless-steel chromium began to degrade and migrate. Second, the Alloy-22 degradation would depend strongly on the RIP model parameters controlling the fraction of packages exposed to dripping conditions. Packages that experienced dripping conditions would degrade much faster; only those that experienced dripping conditions would fail within 10,000 years and permit exposure of interior stainless steel. The vast majority of waste packages would not fail, so the interior chromium inventory would never be exposed for degradation and transport.

Based on this demonstration of the relative unimportance of the interior stainless-steel chromate inventory in calculating peak chromium concentrations within 10,000 years, only the corrosion-resistant material (Alloy-22) in the chromium inventory was simulated for analysis of chromium impacts as a waterborne chemically toxic material.

I.6.1.2 Results for the Proposed Action

The chromium-migration calculation was conducted for the Proposed Action inventory under the high, intermediate, and low thermal load scenarios using the same stochastic approach as that used for the waterborne radioactive material assessment. The 100 independent realizations, using randomly selected input parameter values chosen from assigned probability distributions of values, were simulated with the RIP model. Simulations were performed to estimate chromium concentrations at 5, 20, 30, and 80 kilometers (3, 12, 19, and 50 miles) for 10,000 years following closure. The resulting concentrations were decay-corrected to remove the slight radioactive decay calculated by the RIP model for the surrogate constituent, iodine-129.

The mean peak concentrations and 95th-percentile peak concentrations computed with the RIP model, using the surrogate chromium-migration calculation described above, are listed in Table I-40 for all thermal load scenarios under the Proposed Action. Figures I-52 through I-54 show the complementary cumulative distribution function for the 100 realizations of chromium concentration under the Proposed Action at each of the four locations for the low, intermediate, and high thermal load scenarios, respectively.

Table I-40. Peak chromium groundwater concentration (milligrams per liter)[a] under the Proposed Action inventory.[b]

Thermal load	Maximally exposed individual	Mean	95th-percentile
High	At 5 kilometers[c]	0.0085	0.037
	At 20 kilometers	0.0028	0.012
	At 30 kilometers	0.0018	0.0063
	At 80 kilometers	0.00022	0.00061
Intermediate	At 5 kilometers	0.0029	0.0096
	At 20 kilometers	0.0023	0.010
	At 30 kilometers	0.00080	0.0038
	At 80 kilometers	0.000031	0.00015
Low	At 5 kilometers	0.0046	0.016
	At 20 kilometers	0.0018	0.0083
	At 30 kilometers	0.00067	0.0033
	At 80 kilometers	0.000053	0.00034

a. To convert milligrams per liter to pounds per cubic foot, multiply by 0.0000624.
b. Based on 100 repeated simulations of total system performance, each using randomly sampled values of uncertain parameters.
c. To convert kilometers to miles, multiply by 0.62137.

A simple sensitivity run, reducing the solubility limit of the iodine-129 surrogate by one order of magnitude (from 1,976 to 197.6 milligrams per liter), demonstrated that the imposed value of the solubility limit did not affect the resulting concentration at the accessible environment. This demonstration suggests that the chromium degradation rate is a major controlling factor over the release of chromium.

There are two measures for comparing human health effects for chromium. When the Environmental Protection Agency established its Maximum Contaminant Level Goals, it considered safe levels of contaminants in drinking water and the ability to achieve these levels with the best available technology. The Maximum Contaminant Level Goal for chromium is 0.1 milligram per liter (0.0000062 pound per cubic foot) (40 CFR 141.51). The other measure for comparison is the reference dose factor for chromium, which is 0.005 milligram per kilogram (0.0004 ounce per pound) of body mass per day (EPA 1999, all). The reference dose factor represents a level of intake that has no adverse effect on humans. It can be converted to a threshold concentration level for drinking water. The conversion yields essentially the same concentration for the reference dose factor as the Maximum Contaminant Level Goal.

No attempt can be made at present to estimate the groundwater concentrations of hexavalent chromate in Table I-40, in terms of human health effects (for example, latent cancer fatalities). The carcinogenicity of hexavalent chromium by the oral route of exposure cannot be determined because of a lack of sufficient epidemiological or toxicological data (EPA 1999, all; EPA 1998, page 48).

I.6.1.3 Results for Inventory Modules 1 and 2

Chromium impacts were calculated for Inventory Modules 1 and 2 using the same approach as for the Proposed Action. Peak mean and 95th-percentile chromium concentrations for Inventory Modules 1 and 2 are listed in Tables I-41 and Table I-42, respectively. Figures I-55 through I-57 show the complementary cumulative distribution function for the 100 realizations of chromium concentration for Inventory Module 1 at each of the four locations for the low, intermediate, and high thermal load scenarios, respectively.

Table I-41. Peak chromium groundwater concentration (milligrams per liter)[a] for 10,000 years after closure under Inventory Module 1.[b]

Thermal load	Maximally exposed individual	Mean	95th-percentile
High	At 5 kilometers[c]	0.032	0.14
	At 20 kilometers	0.018	0.10
	At 30 kilometers	0.0057	0.027
	At 80 kilometers	0.00029	0.00070
Intermediate	At 5 kilometers	0.023	0.083
	At 20 kilometers	0.0089	0.042
	At 30 kilometers	0.0032	0.017
	At 80 kilometers	0.00019	0.00057
Low	At 5 kilometers	0.0093	0.0353
	At 20 kilometers	0.0050	0.022
	At 30 kilometers	0.0020	0.0084
	At 80 kilometers	0.000074	0.00026

a. To convert milligrams per liter to pounds per cubic foot, multiply by 0.0000624.
b. Based on 100 repeated simulations of total system performance, each using randomly sampled values of uncertain parameters.
c. To convert kilometers to miles, multiply by 0.62137.

Table I-42. Peak chromium groundwater concentration (milligrams per liter)[a] due only to Greater-Than-Class-C and Special-Performance-Assessment-Required wastes for 10,000 years after closure under Inventory Module 2.[b]

Thermal load	Maximally exposed individual	Expected Value
High	At 5 kilometers[c]	0.0014
	At 20 kilometers	0.00058
	At 30 kilometers	0.00021
	At 80 kilometers	0.000000012
Intermediate	At 5 kilometers	0.00080
	At 20 kilometers	0.00033
	At 30 kilometers	0.00012
	At 80 kilometers	0.0000000094
Low	At 5 kilometers	0.00060
	At 20 kilometers	0.00025
	At 30 kilometers	0.000086
	At 80 kilometers	0.000000010

a. To convert milligrams per liter to pounds per cubic foot, multiply by 0.0000624.
b. Based on an expected value simulation using the mean of all stochastic parameters for the additional inventory of Inventory Module 2 over Inventory Module 1.
c. To convert kilometers to miles, multiply by 0.62137.

There are two measures for comparing human health effects for chromium. When the Environmental Protection Agency established its Maximum Contaminant Level Goals, it considered safe levels of contaminants in drinking water and the ability to achieve these levels with the best available technology. The Maximum Contaminant Level Goal for chromium is 0.1 milligram per liter (0.0000062 pound per cubic foot) (40 CFR 141.51). The other measure for comparison is the reference dose factor for chromium, which is 0.005 milligram per kilogram (0.0004 ounce per pound) of body mass per day (EPA 1999, all). The reference dose factor represents a level of intake that has no adverse effect on humans. It can be converted to a threshold concentration level for drinking water. The conversion yields essentially the same concentration for the reference dose factor as the Maximum Contaminant Level Goal.

No attempt can be made at present to express the estimated groundwater concentrations of hexavalent chromate in Table I-42 in terms of human health effects (for example, latent cancer fatalities). The carcinogenicity of hexavalent chromium by the oral route of exposure cannot be determined because of a lack of sufficient epidemiological or toxicological data (EPA 1999, all; EPA 1998, page 48).

I.6.2 MOLYBDENUM

Alloy-22 used as a waste package inner barrier also contains 13.5 percent molybdenum (ASTM 1994, page 2). During the corrosion of Alloy-22, molybdenum behaves almost the same as the chromium. Due to the corrosion conditions, molybdenum also dissolves in a highly soluble hexavalent form. Therefore, the source term for molybdenum will be exactly 13.5/22 times (61.4 percent) the source term for chromium. All the mechanisms and parameters are the same as those used for chromium so modeling is unnecessary. It is reasonable to assume that molybdenum would be present in the water at concentrations 61.4 percent of those reported above for chromium.

There is currently no established toxicity standard for molybdenum (in particular, the Environmental Protection Agency has not established a Maximum Contaminant Level Goal for molybdenum), although this does not mean that molybdenum is not toxic. The concentrations of molybdenum would be very small, so no effect would be likely to result from the molybdenum released to the groundwater.

I.6.3 URANIUM

While the screening analysis indicated that elemental uranium would not pose a health risk as a waterborne chemically toxic material (see Section I.3.2.3.3), it was retained for consideration for other reasons. The total uranium inventory (all uranium isotopes) is listed for the inventory modules in Table I-23.

The reference dose for elemental uranium is 0.003 milligram per kilogram of body mass per day (EPA 1999, all). Assuming that a child would experience the maximum individual exposure from the drinking-water pathway, the analysis used a 1-liter (0.26-gallon) daily intake rate and a 16-kilogram (35-pound) body weight to convert the reference dose to a threshold concentration of 4.8×10^{-2} milligram per liter (2.9×10^{-6} pound per cubic foot).

I.6.3.1 RIP Model Adaptations for Elemental Uranium Modeling

To evaluate the consequences of total uranium migration, the mobilization and transport of the total uranium inventory for the Proposed Action listed in Table I-23 were simulated using the RIP model. The following steps were taken in the RIP model adaptation for the total uranium simulations:

1. The inventory of all radionuclides except uranium was set to zero (as a precaution and to prevent confusion with radiological runs).

2. The inventory of uranium (all isotopes) was changed to 8,119 kilograms (17,900 pounds) for commercial spent nuclear fuel packages, 786 kilograms (1,730 pounds) for DOE spent nuclear fuel packages, and 2,826 kilograms (6,220 pounds) for high-level radioactive waste packages.

3. Output from the RIP model was requested in grams rather than curies.

4. The radiological decay rate of uranium-234 was left to represent all uranium isotopes in the waste packages, although the resulting concentrations obtained from RIP model simulations were decay-corrected to provide undecayed concentrations. Various uranium isotopes have different half-lives, so the analysis ignored decay benefits in reducing impacts.

5. Because the chemical properties (such as sorption rate) are functions of the element and not the isotope, the other transport properties of uranium were left the same as those used for the radiological consequences simulations.

6. Use of the parameter FCSOLU, which is used in the RIP model to partition the solubility coefficient to account for the fact that radionuclide simulations model only one isotope of uranium, was omitted for full uranium elemental simulations.

DOE ran 100 simulations to model the release and transport of uranium. The Proposed Action inventory is approximately 70,000 MTHM (77,000 tons). Although a small percentage of the heavy metal in the spent fuel is not uranium, it was reasonable to assume all of it was because doing so had a very small effect on the result and would make the analysis more conservative. This assumption introduced an approximate 7-percent increase into the result. The runs are based on the high thermal load scenario, and the consequences are computed for 5 kilometers (3 miles) from the repository. In addition, the analysis neglected radioactive decay. Most of the uranium present has a very long half-life compared to the analysis period, so decay would have a very small conservative effect on the result.

I.6.3.2 Results for the Proposed Action

The Proposed Action inventory of elemental uranium would be approximately 65 million kilograms (72,000 tons) (see Table I-23). Total elemental uranium migration calculations were made using the RIP model code for the Proposed Action inventory under the high thermal load scenario for 10,000 years following closure for the 5-kilometer (3-mile) distance. The resulting concentrations of elemental uranium in groundwater at the 5-kilometer (3-mile) discharge location were obtained from the simulation results.

The reference dose for elemental uranium is 3.0×10^{-3} milligram per kilogram (4.8×10^{-8} ounce per pound) of food intake per day (EPA 1999, all). Assuming that a child would experience the maximum individual exposure for the drinking water scenario, the analysis used a 1-liter (0.26-gallon) daily intake rate and a 16-kilogram (35-pound) body weight to convert the reference dose to a threshold concentration. The threshold concentration would be 0.048 milligram per liter (3.0×10^{-6} pound per cubic foot).

The maximum uranium concentration over 10,000 years was extracted for each of the 100 sets of simulation results. The mean peak concentration of uranium would be 6.7×10^{-8} milligram per liter (5.2×10^{-9} pound per cubic foot), and the 95th-percentile peak concentration would be 2.2×10^{-8} milligram per liter (1.7×10^{-9} pound per cubic foot). These concentrations would be six orders of magnitude lower than the threshold concentration for the oral reference dose, so DOE expects no human health effects from the chemical effects of waterborne uranium under the high thermal load scenario.

Figure I-58 shows the complementary cumulative distribution function for elemental uranium concentrations at the 5-kilometer (3-mile) discharge location for 10,000 years following closure under the high thermal load scenario. The groundwater concentration information in this figure shows that uranium, as a chemically toxic material, would be far below the reference dose at any probability level.

Based on trends in waterborne radioactive material results, the concentrations of elemental uranium at locations that were more distant [20, 30, and 80 kilometers (12, 19, and 50 miles)] and for the intermediate and low thermal load scenarios at all distance would be even lower. Because of the extremely low concentrations from these simulations, further simulations were unnecessary to evaluate other thermal loads under the Proposed Action. Elemental uranium would not present a health risk as a chemically toxic material under the Proposed Action for any thermal load scenario.

I.6.4 RESULTS FOR INVENTORY MODULES 1 AND 2

Under Inventory Modules 1 and 2, the total uranium inventory would increase from the Proposed Action total of 70,000 MTHM to 120,000 MTHM (Table I-18). The 70-percent increase in elemental uranium inventory would be likely to increase the groundwater concentration at the discharge location (1) at most, if the percentage of the inventory was increased, or (2) by less, if solubility limits were exceeded along the transport paths in groundwater in any case. Even doubling the groundwater concentrations calculated for the Proposed Action inventory would result in concentration levels that would be several orders of magnitude below the reference dose concentration level. Therefore, elemental uranium would not present a substantial health risk as a chemically toxic material under Inventory Module 1 or 2 for any thermal load scenario.

I.7 Atmospheric Radioactive Material Impacts

After DOE closed the Yucca Mountain Repository, there would be limited potential for releases to the atmosphere because the waste would be isolated far below the ground surface. Still, the rock is porous and does allow gas to flow, so the analysis must consider possible airborne releases. The only radionuclide that would have a relatively large inventory and a potential for gas transport is carbon-14. Iodine-129 can exist in a gas phase, but it is highly soluble and therefore would be more likely to dissolve in groundwater rather than migrate as a gas. Other gas-phase isotopes were eliminated in the screening analysis (Section I.3), usually because of short half-lives and because they are not decay products of long-lived isotopes. After carbon-14 escaped from the waste package, it could flow through the rock in the form of carbon dioxide. Atmospheric pathway models were used to estimate human health impacts to the local population in the 84-kilometer (52-mile) region surrounding the repository.

About 2 percent of the carbon-14 in commercial spent nuclear fuel exists as a gas in the space (or *gap*) between the fuel and the cladding around the fuel (Oversby 1987, page 92). The average carbon-14 inventory in a commercial spent nuclear fuel waste package is approximately 12 curies (see Table I-1), so the analysis used a gas-phase inventory of 0.23 curie of carbon-14 per commercial spent nuclear fuel waste package to calculate impacts from the atmospheric release pathway. The analysis described in Section 5.4 included the entire inventory of the carbon-14 in the repository in the groundwater release models. Thus, the groundwater-based impacts would be overestimated slightly (by 2 percent) by this modeling approach.

Carbon is the second-most abundant element (by mass) in the human body, constituting 23 percent of Reference Man (ICRP 1975, page 377). Ninety-nine percent of the carbon comes from food ingestion (Killough and Rohwer 1978, page 141). Daily carbon intakes are approximately 300 grams (0.7 pound) and losses include 270 grams (0.6 pound) exhaled, 7 grams (0.02 pound) in feces, and 5 grams (0.01 pound) in urine (ICRP 1975, page 377).

Carbon-14 dosimetry can be performed assuming specific-activity equivalence. The primary human-intake pathway of carbon is food ingestion. The carbon-14 in food results from photosynthetic processing of atmospheric carbon dioxide, whether the food is the plant itself or an animal that feeds on the plant. Biotic systems, in general, do not differentiate between carbon isotopes. Therefore, the carbon-14 activity concentration in the atmosphere will be equivalent to the carbon-14 activity concentration in the plant, which in turn will result in an equivalent carbon-14 specific activity in human tissues.

I.7.1 CARBON-14 RELEASES TO THE ATMOSPHERE

The calculation of regional radiological doses requires estimation of the annual release rate of carbon-14. The analysis based the carbon-14 release rate on the predicted timeline of container failures for the high thermal load scenario, using average values for the stochastic parameters that were entered. The expected number of spent nuclear fuel waste package failures in 100-year intervals was used to estimate the carbon-14 release rate after repository closure. The estimated amount of material released from each package as a function of time was reduced to account for radiological decay.

As for the waterborne releases described in Section 5.4, some credit was taken for the intact zirconium-alloy cladding (on approximately 99 percent by volume of the spent nuclear fuel) delaying the release of gas-phase carbon-14. The remaining 1 percent by volume of the spent nuclear fuel either would have stainless-steel cladding (which degrades much more quickly than zirconium alloy) or would already have failed in the reactor. The RIP model uses a waste package failure model that conceptually divides the surface area of the waste packages into many *patches.* A corrosion future for each patch is then calculated. The zirconium-alloy cladding failure model is implemented in the same fashion, with the cladding corrosion rate set to a fraction of the corrosion rate of the Alloy-22 in the inner shell of the waste package. This analysis set the cladding corrosion rate for the zirconium alloy to the same value used in the Viability Assessment (DOE 1998a, Volume 3, page 3-101). A plot of the patch-area fraction of the zirconium-alloy cladding that has failed as a function of time after repository closure is shown in Figure I-59. Although difficult to see on the plot scale, no zirconium-alloy cladding would fail during the first 5,000 years after repository closure.

The amount (in curies) of carbon-14 that would be available for transport from a failed waste package, A_T, is calculated as:

$$A_T = (F_{IF} + F_{FC}) \times 0.23 \text{ curies per package}$$

where:

F_{IF} = fraction immediately failed (fuel with stainless-steel cladding or previously failed fuel pins)

F_{FC} = fraction of failed cladding (if the value shown in Figure I-59 is less than 0.01, then that value is used; if the value shown in Figure I-59 exceeds 0.01, then a value of 0.9875 is used)

The model uses the patch failure rate on the zirconium alloy as the fraction of the failed pins until the patch failure rate reaches 1 percent. After the patch failure rate reaches 1 percent, the release rate is reset to not take further credit for zirconium-alloy cladding reducing the transport rate of gas-phase carbon-14. Rather than conducting a detailed gas-flow model of the mountain, the analysis assumed that the carbon-14 from the failed waste package would be released to the ground surface uniformly over a 100-year interval. Thus, the release rate to the ground surface for a waste package would be A_T divided by 100 (curies per year).

Figure I-60 shows the estimated release rate of carbon-14 from the repository for 50,000 years after repository closure, assuming that the spent nuclear fuel with stainless-steel cladding had failed and released its gas-phase carbon-14 prior to being placed in a waste package. This assumption is represented by $F_{IF}=0$ in the calculation for A_T. The results in Figure I-60 are based on the Proposed Action inventory. Each symbol in the figure represents the carbon-14 release rate to the ground surface for a period of 100 years. The general downward slope of the symbols is due to radioactive decay (carbon-14 has a half-life of 5,730 years). The symbols marking zero releases (curies per year) indicate that no waste packages failed during some 100-year periods. The jagged nature of the plot indicates a different number of waste packages failing in different 100-year intervals. Only 97 of 7,760 spent nuclear fuel waste packages would have failed during the first 10,000 years after repository closure. By 40,000 years after repository closure, 676 of the 7,760 spent nuclear fuel waste packages would have failed. Using this expected-value representation of waste package lifetime, no more than three waste packages would have failed in any single 100-year interval before 30,000 years after repository closure. Between 30,000 and 50,000 years after repository closure, as many as five waste packages would fail in a single 100-year interval. The maximum release rate would occur about 19,000 years after repository closure. The estimated maximum release rate would be about 0.098 microcurie per year.

I.7.2 ATMOSPHERE CONSEQUENCES TO THE LOCAL POPULATION

DOE used the GENII-S code (Leigh et al. 1993, all) to model the atmospheric transport and human uptake of released carbon-14 for the 84-kilometer (52-mile) population radiological dose calculation. This calculation used 84 kilometers rather than the typical 80 kilometers (50 miles) used in an EIS to include the population of Pahrump, Nevada, in the impact estimate. Radiological doses to the regional population near Yucca Mountain from carbon-14 releases were estimated using the population distribution compiled from DOE (1998a, Volume 3, Figure 3-76), which indicates approximately 28,000 people would live in the region surrounding Yucca Mountain in the year 2000. The population by distance and sector used in the calculations are listed in Table I-43. The computation also used current (1993 to 1996) annual average meteorology. The joint frequency data are listed in Table I-44.

Table I-43. Population by sector and distance from Yucca Mountain used to calculate regional airborne consequences.[a]

	Distance from the repository (kilometers)[b]										
Direction	6[c]	16	24	32	40	48	56	64	72	84	*Totals*[d]
S	0	0	16	238	430	123	0	10	0	0	*817*
SSW	0	0	0	315	38	0	0	7	0	0	*360*
SW	0	0	0	0	0	0	868	0	0	0	*868*
WSW	0	0	0	0	0	0	0	0	87	0	*87*
W	0	0	0	638	17	0	0	0	0	0	*655*
WNW	0	0	0	936	0	0	0	0	0	20	*956*
NW	0	0	0	28	2	0	0	0	33	0	*63*
NNW	0	0	0	0	0	0	0	0	0	0	*0*
N	0	0	0	0	0	0	0	0	0	0	*0*
NNE	0	0	0	0	0	0	0	0	0	0	*0*
NE	0	0	0	0	0	0	0	0	0	0	*0*
ENE	0	0	0	0	0	0	0	0	0	0	*0*
E	0	0	0	0	0	0	0	0	0	0	*0*
ESE	0	0	0	0	0	0	0	0	1,055	0	*1,055*
SE	0	0	0	0	3	0	13	0	0	206	*222*
SSE	0	0	0	0	23	172	6	17	6,117	16,399	*22,734*
Totals	**0**	**0**	**16**	**2,155**	**513**	**295**	**887**	**34**	**7,292**	**16,625**	***27,817***

a. Source: Compiled from DOE (1998a, Volume 3, Figure 3-76).
b. To convert kilometers to miles, multiply by 0.62137.
c. The 80-kilometer (50-mile) distance typically used in an EIS analysis was increased to 84 kilometers (52 miles) in order to include the population of Pahrump in the SSE sector in the calculations.
d. Population figures are estimates for 2000.

A population radiological dose factor of 2.2×10^{-9} person-rem per microcurie per year of release was calculated by the GENII code. For a 0.098-microcurie-per-year release, this corresponds to a 7.8×10^{-15}-rem-per-year average radiological dose to individuals in the population. Thus, a maximum 84-kilometer (52-mile) population radiological dose rate would be 2.2×10^{-10} person-rem per year. This radiological dose rate represents 1.1×10^{-13} latent cancer fatalities in the regional population of 28,000

Table I-44. Meteorologic joint frequency data used for Yucca Mountain atmospheric releases (percent of time).[a]

Average wind speed (m/s)[b]	Atmospheric stability class	Direction (wind toward)															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.9	A	0.807	0.633	0.613	0.520	0.462	0.604	0.688	0.659	0.467	0.340	0.183	0.200	0.197	0.212	0.412	0.778
	B	0.279	0.479	0.392	0.325	0.372	0.540	1.243	2.279	1.484	0.499	0.290	0.192	0.105	0.070	0.087	0.305
	C	0.113	0.105	0.064	0.017	0.015	0.020	0.041	0.157	0.122	0.067	0.055	0.020	0.012	0.020	0.009	0.032
	D	0.003	0.003	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.55	A	0.099	0.073	0.026	0.020	0.026	0.017	0.023	0.061	0.041	0.029	0.023	0.017	0.029	0.029	0.052	0.096
	B	0.058	0.044	0.038	0.026	0.032	0.061	0.125	0.377	0.360	0.070	0.049	0.015	0.009	0	0.009	0.017
	C	0.229	0.267	0.256	0.116	0.110	0.105	0.328	1.193	2.404	0.909	0.671	0.302	0.157	0.142	0.125	0.174
	D	0.105	0.049	0.038	0.003	0.003	0.003	0.006	0.035	0.444	0.290	0.206	0.055	0.035	0.049	0.087	0.099
	E	0.003	0.006	0	0.003	0	0	0.003	0.003	0.003	0.006	0.003	0.003	0.003	0.003	0	0.003
	F	0	0.003	0	0	0	0	0	0	0.003	0.003	0	0	0	0	0	0.003
4.35	A	0.096	0.096	0.041	0.015	0.012	0.009	0.015	0.023	0.058	0.044	0.026	0.023	0.029	0.020	0.020	0.070
	B	0.052	0.087	0.041	0.023	0.006	0.026	0.078	0.261	0.305	0.131	0.076	0.017	0.006	0.003	0.009	0.032
	C	0.142	0.241	0.168	0.070	0.029	0.076	0.131	0.740	1.638	0.308	0.290	0.119	0.049	0.041	0.038	0.102
	D	0.253	0.264	0.163	0.049	0.020	0.020	0.020	0.392	2.375	0.447	0.285	0.081	0.046	0.058	0.139	0.346
	E	0.006	0.017	0	0	0	0	0	0.003	0.006	0.020	0.015	0.006	0.003	0.003	0.012	0.020
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.95	A	1.568	0.642	0.215	0.038	0.035	0.009	0.023	0.026	0.081	0.142	0.261	0.163	0.209	0.314	0.343	0.819
	B	0.682	0.552	0.067	0.003	0.006	0.006	0.023	0.058	0.348	0.325	0.267	0.131	0.078	0.093	0.078	0.256
	C	0.993	0.560	0.105	0.012	0.009	0.078	0.090	0.244	0.984	0.526	0.337	0.192	0.067	0.076	0.073	0.189
	D	1.594	0.912	0.183	0.020	0.020	0.006	0.035	0.566	3.368	0.430	0.160	0.128	0.035	0.044	0.142	0.598
	E	0.735	0.366	0.067	0.012	0.006	0	0	0.386	2.515	0.192	0.038	0.015	0	0.015	0.064	0.804
	F	0.238	0.096	0.003	0	0.003	0	0	0.142	1.641	0.055	0.032	0	0.003	0.003	0.029	0.796
9.75	A	2.134	0.935	0.218	0.078	0.029	0.041	0.026	0.070	0.163	0.232	0.203	0.232	0.267	0.372	0.587	1.388
	B	0.865	0.627	0.081	0.009	0.003	0.017	0.020	0.046	0.319	0.267	0.154	0.131	0.070	0.052	0.113	0.302
	C	0.720	0.261	0.038	0.012	0.020	0.020	0.009	0.076	0.502	0.299	0.148	0.229	0.078	0.032	0.041	0.157
	D	0.415	0.212	0.020	0.003	0.003	0.003	0.003	0.046	0.627	0.154	0.044	0.032	0.029	0.009	0.026	0.145
	E	0.029	0.006	0	0	0.003	0	0	0	0.006	0.003	0.003	0	0	0.003	0	0.003
	F	0	0.003	0	0	0	0	0	0	0	0	0	0	0	0.003	0	0.003
12.98	A	1.661	0.706	0.418	0.322	0.247	0.244	0.366	0.343	0.407	0.380	0.302	0.299	0.357	0.537	1.083	2.038
	B	0.836	0.668	0.253	0.107	0.157	0.116	0.264	0.499	0.674	0.404	0.270	0.171	0.122	0.096	0.232	0.950
	C	0.322	0.267	0.087	0.017	0.006	0.012	0.026	0.136	0.311	0.107	0.032	0.029	0.020	0.009	0.015	0.038
	D	0.006	0.006	0	0	0	0	0	0.003	0.012	0.003	0	0	0	0	0	0.003
	E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

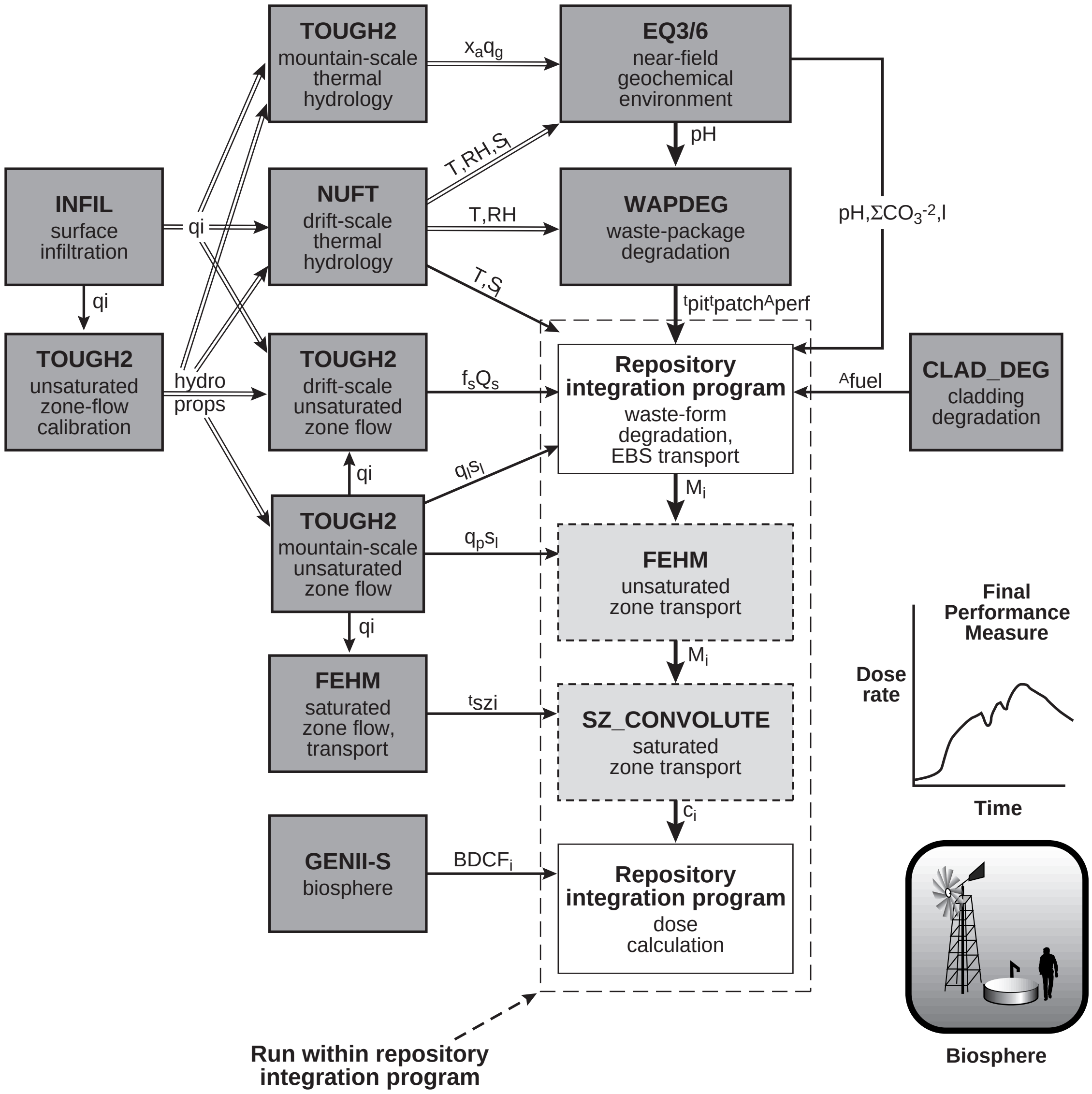
a. Source: Adapted from data in TRW (1999d, Appendix B, all)

b. To convert meters per second to feet per second, multiply by 3.2808.

persons each year at the maximum release rate. This annual population radiological dose rate corresponds to a lifetime radiological dose of 1.5×10^{-8} rem over a 70-year lifetime, which corresponds to 7.6×10^{-12} latent cancer fatalities during the 70-year period of the maximum release.

I.7.3 SENSITIVITY TO THE FRACTION OF EARLY-FAILED CLADDING

DOE performed a sensitivity analysis in which all of the cladding on commercial spent nuclear fuel that had stainless-steel cladding (about 1.3 percent of the fuel by volume) was assumed to fail immediately as the waste package failed. The commercial spent nuclear fuel with zirconium-alloy cladding was assumed to fail as shown in Figure I-57. The number of latent cancer fatalities per year in the local population at the time of maximum release would increase from 1.1×10^{-13} to 4.0×10^{-11} under the sensitivity analysis assumptions. The time of maximum release would be 2,000 years after repository closure rather than 19,000 years after repository closure.



OUTPUT Parameters

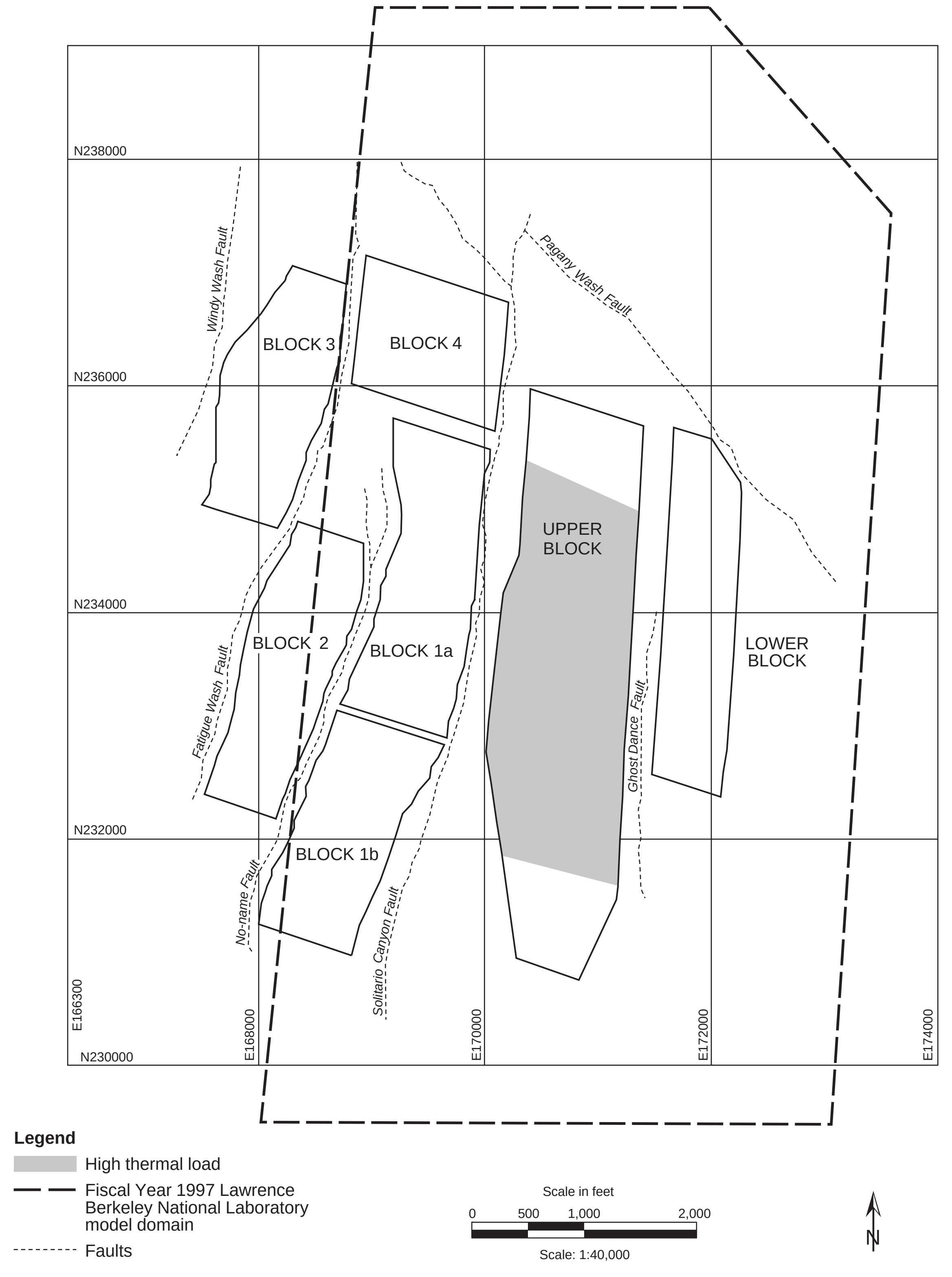
T	Temperature	Q^s	Seep flow rate
RH	Relative humidity	pH	pH
S_l	Liquid saturation	ΣCO_3^{-2}	Carbonate concentration
X_a	Air mass fraction	I	Ionic strength
q_g	Gas flux	^{t}pit	Initial-pit-penetration time
q_l	Liquid flux	^{t}patch	Initial-patch-penetration time
qi	Infiltration flux	^{A}perf	Perforated container area
M_i	Radionuclide mass flux	^{A}fuel	Exposed fuel area
C_i	Radionuclide concentration	^{t}szi	Saturated zone transport time
f_s	Fraction of WPs with seeps	$BDCF_i$	Biosphere dose conversion factor
		EBS	Engineered Barrier System

Legend

▨ External Process Model
☐ Repository Integration Program Cells
⬚ Repository Integration Program Calls External Code
⇒ Response Surface Between Process Models
→ Response Surface from Process Model to RIP
➞ Between RIP Cells and External Code

Source: Modified from DOE (1998a, Volume 3, Figure 2-13).

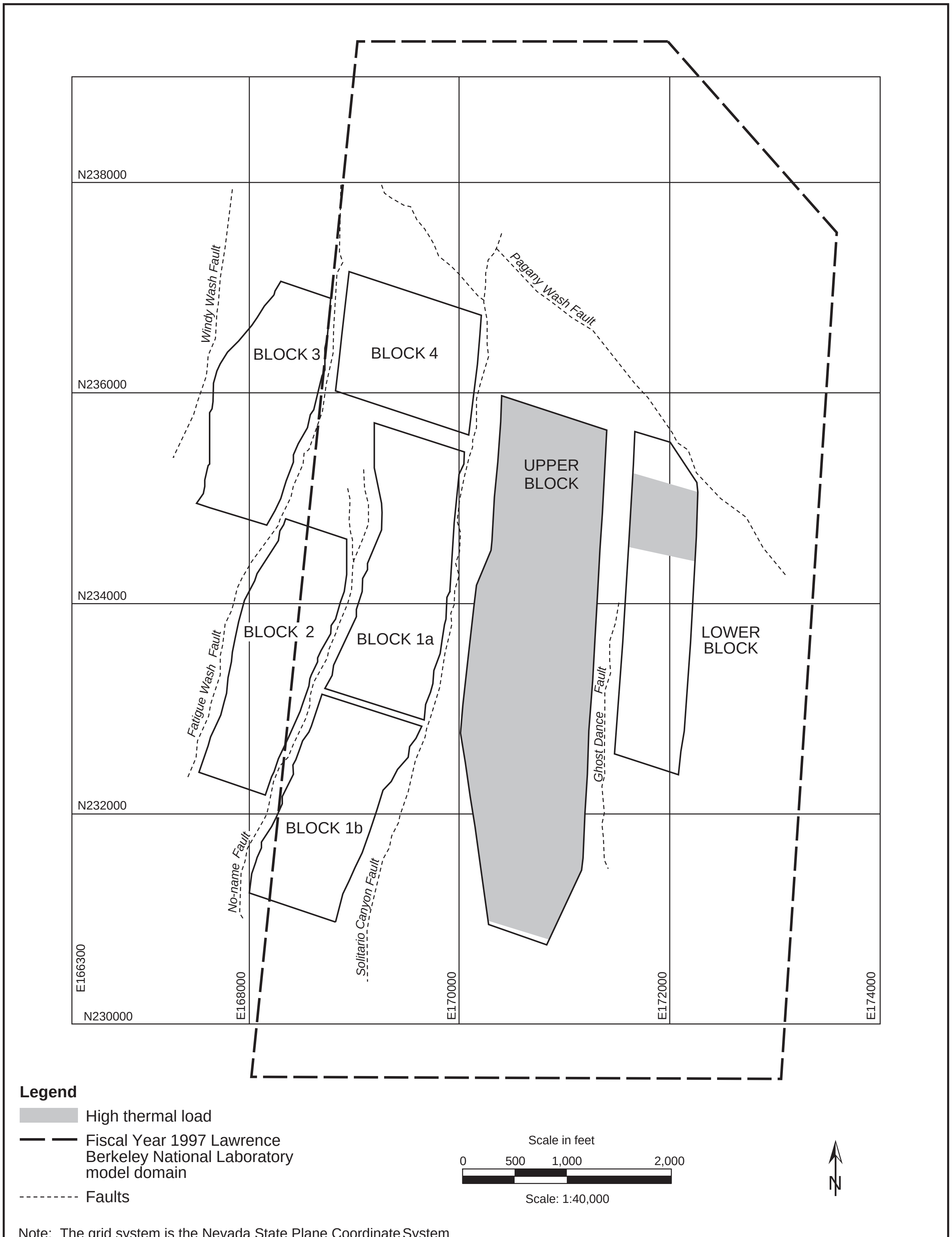
Figure I-1. Total system performance assessment model.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 2.3-1, page 2-13).

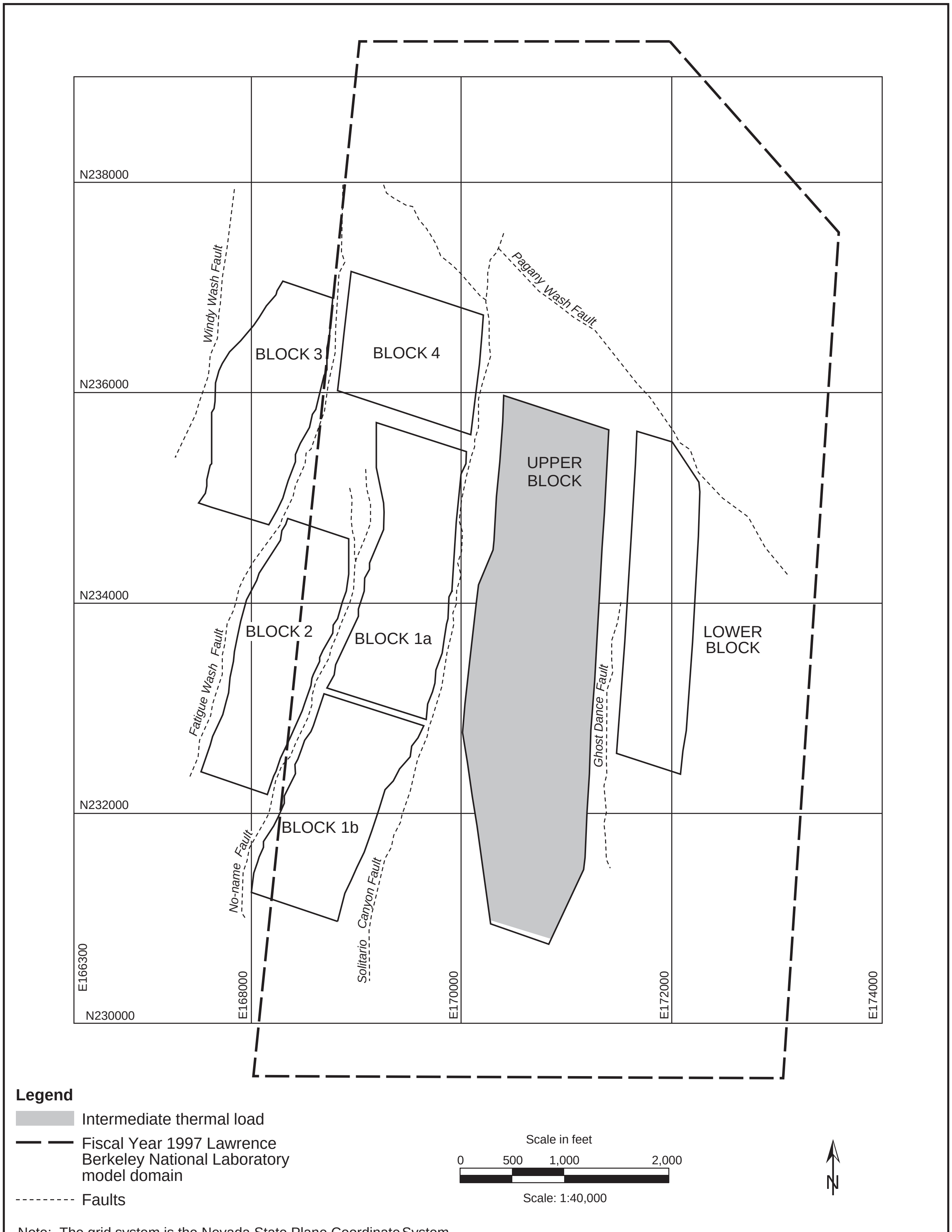
Figure I-2. Layout for Proposed Action inventory for high thermal load (85 MTHM per acre) scenario.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 2.3-2, page 2-14).

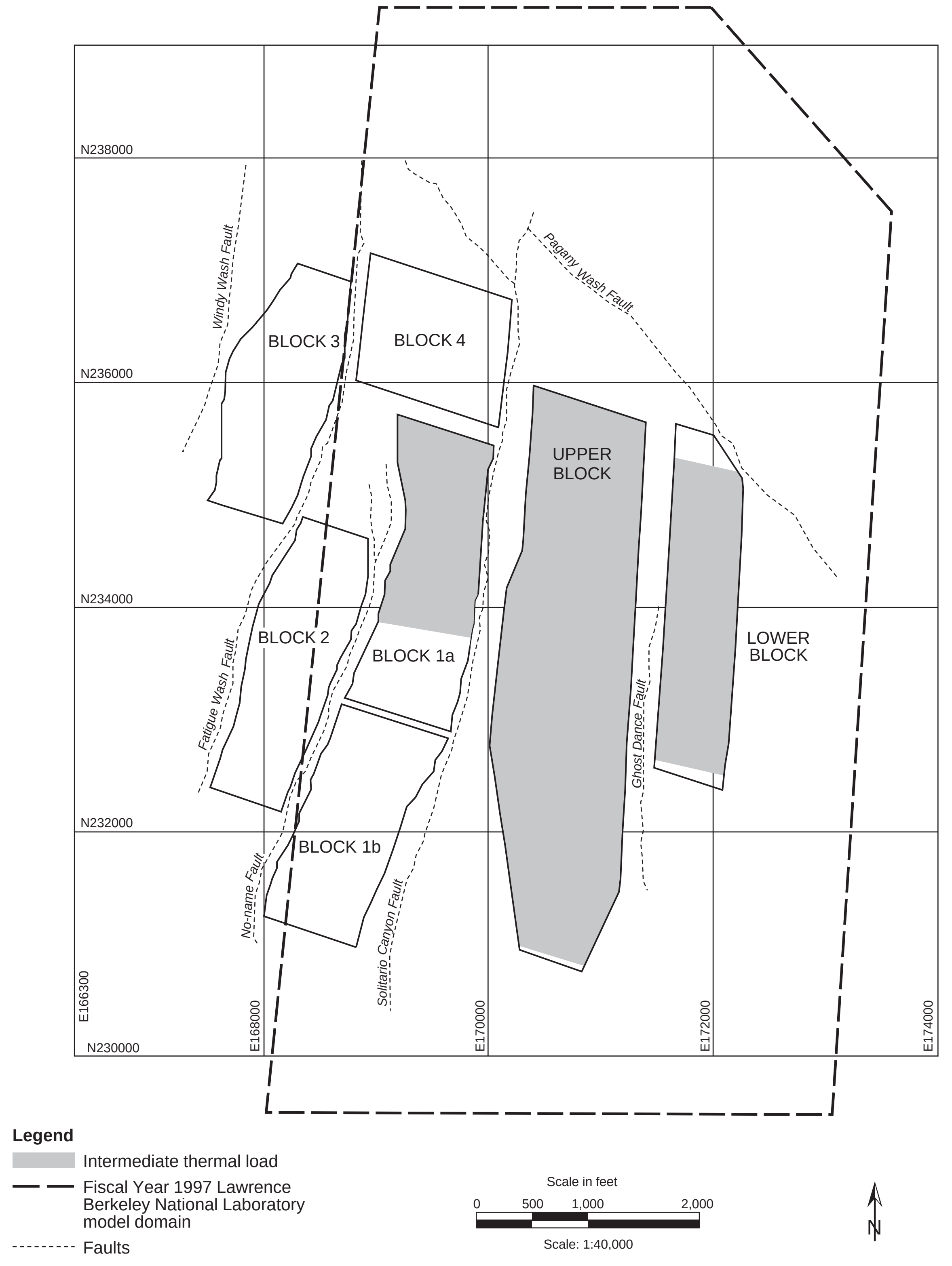
Figure I-3. Layout for Inventory Modules 1 and 2 for high thermal load (85 MTHM per acre) scenario.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 2.3-3, page 2-15).

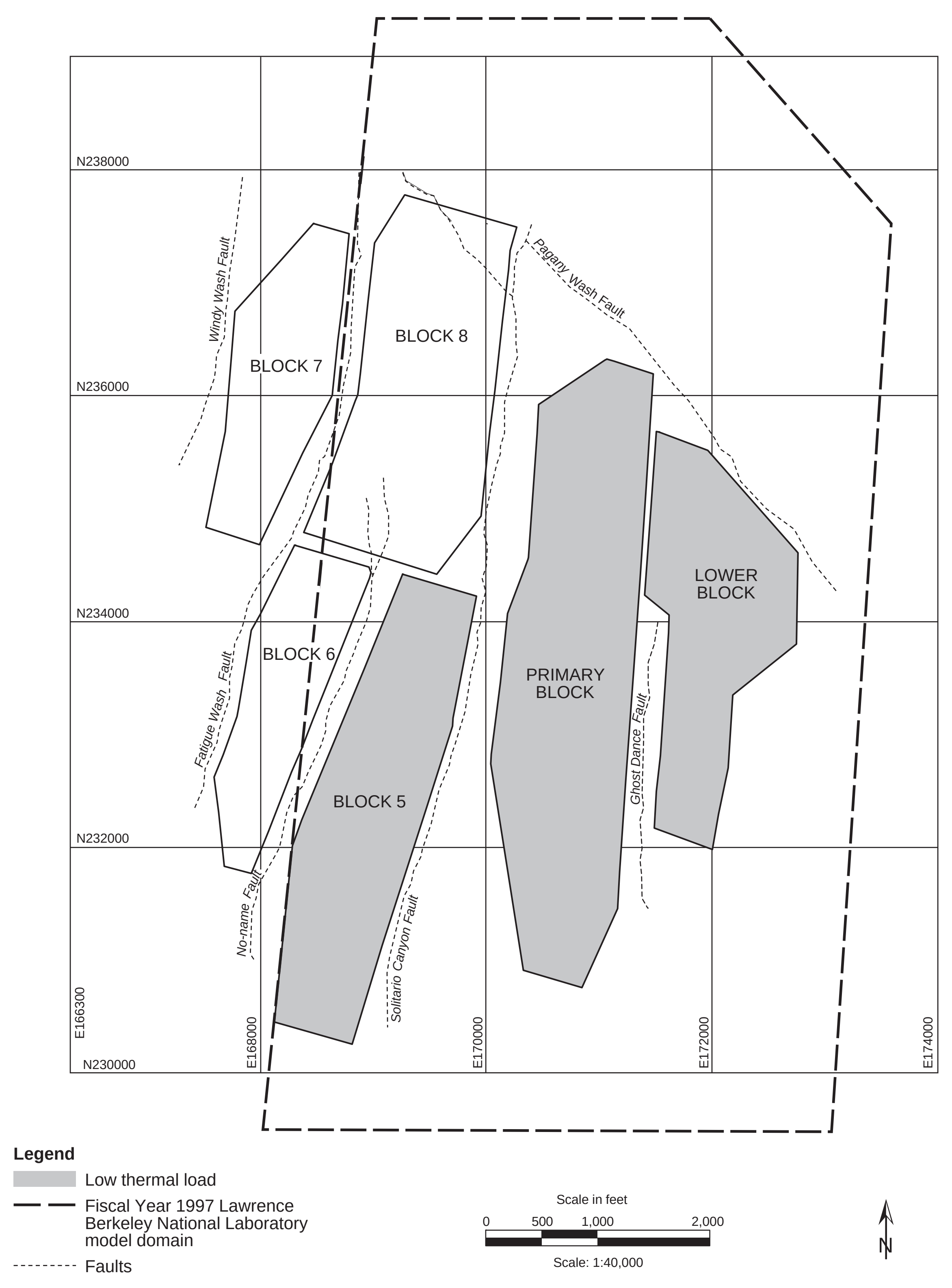
Figure I-4. Layout for Proposed Action inventory for intermediate thermal load (60 MTHM per acre) scenario.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 2.3-4, page 2-16).

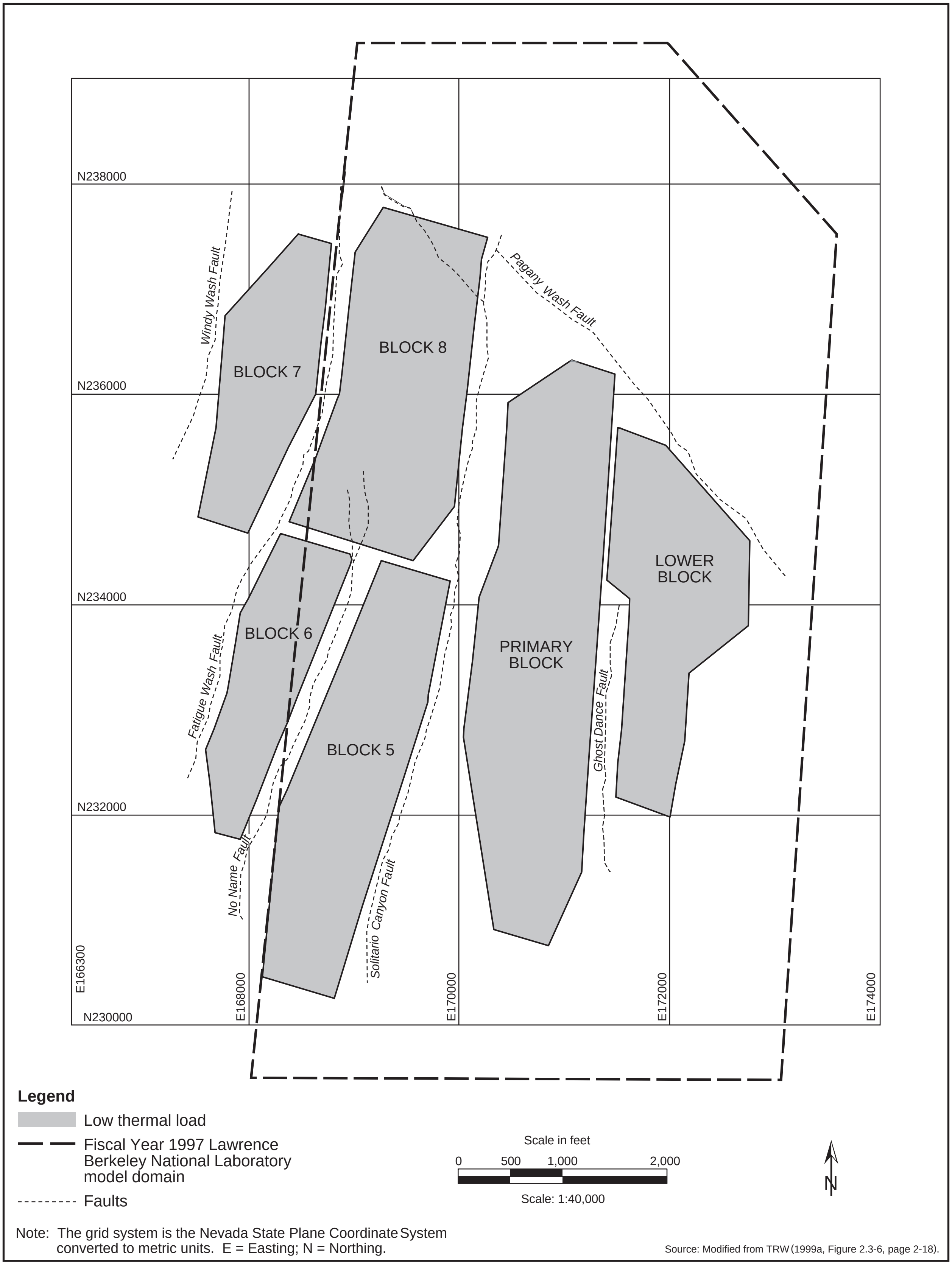
Figure I-5. Layout for Inventory Modules 1 and 2 for intermediate thermal load (60 MTHM per are) scenario.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 2.3-5, page 2-17).

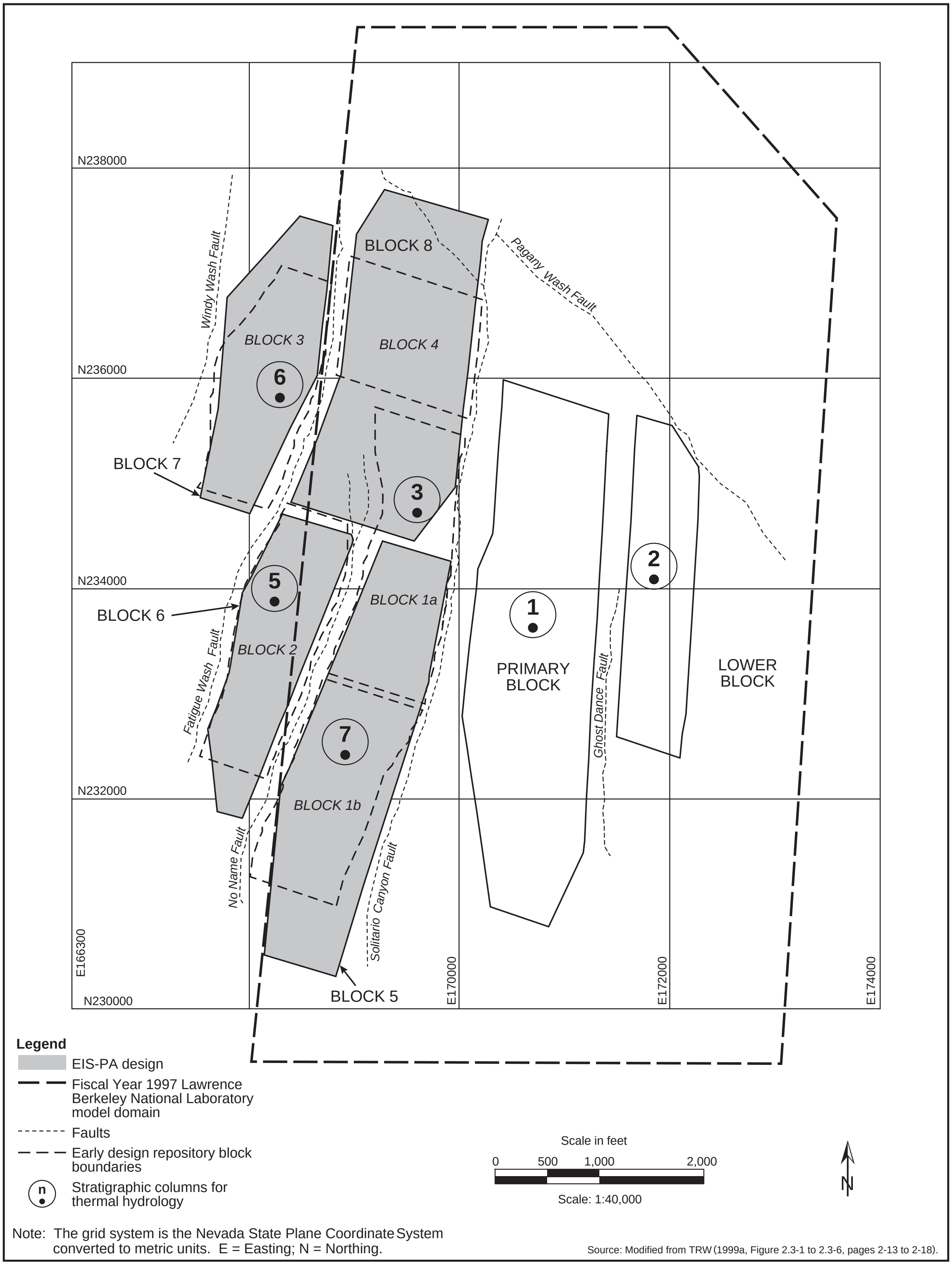
Figure I-6. Layout for Proposed Action inventory for low thermal load (25 MTHM per acre) scenario.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 2.3-6, page 2-18).

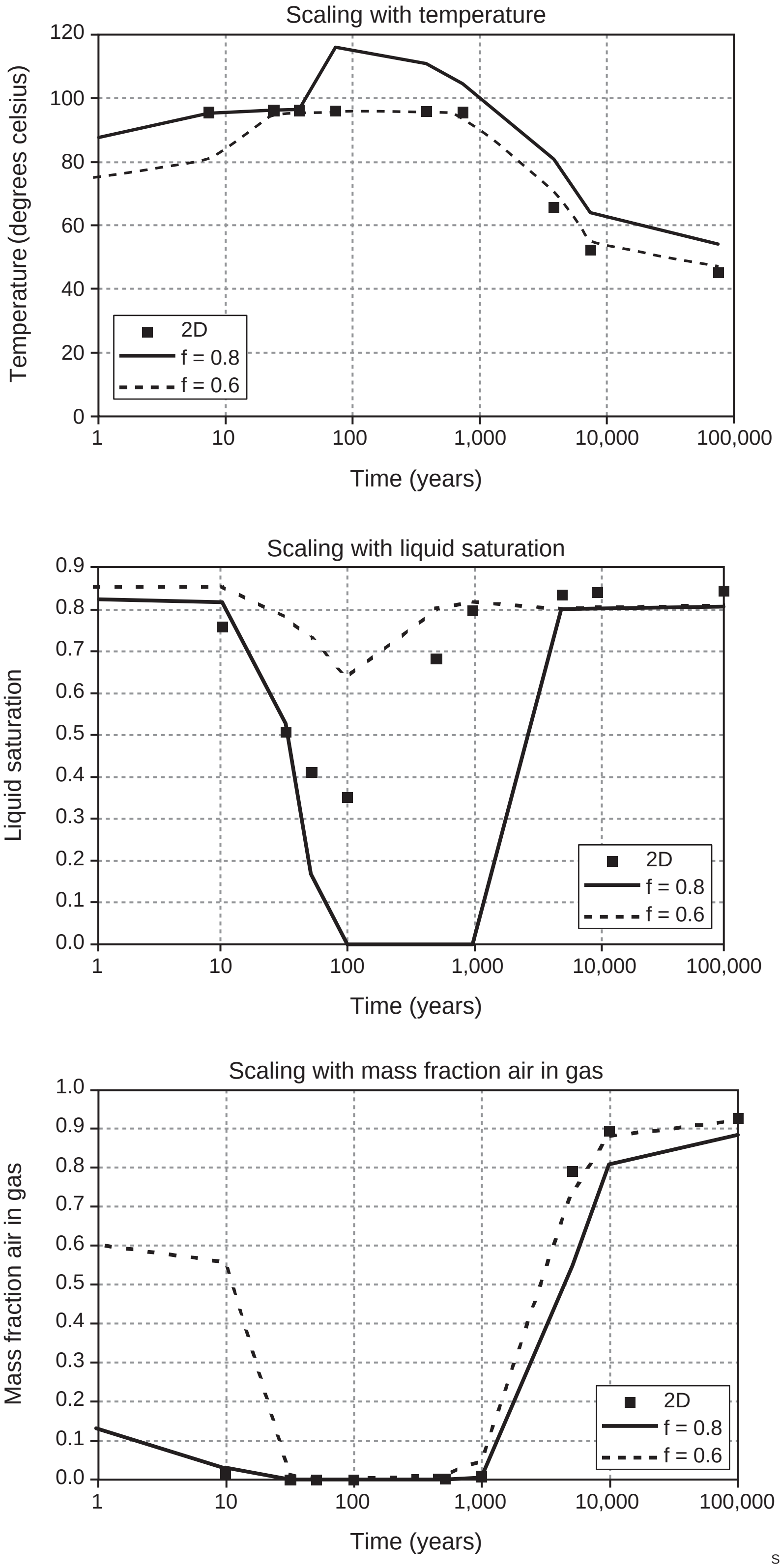
Figure I-7. Layout for Inventory Modules 1 and 2 for low thermal load (25 MTHM per acre) scenario.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

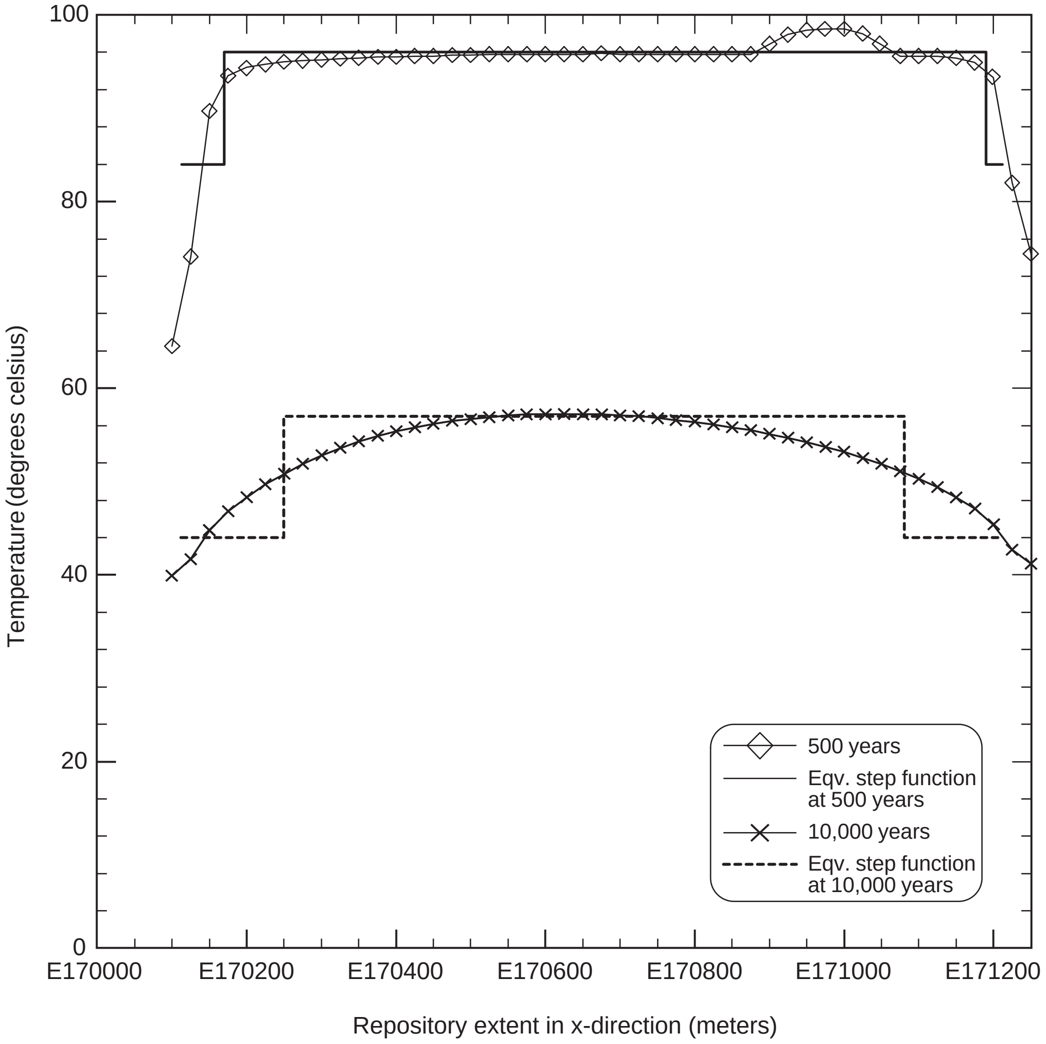
Source: Modified from TRW (1999a, Figure 2.3-1 to 2.3-6, pages 2-13 to 2-18).

Figure I-8. Relationship between the early performance assessment design and emplacement block layout considered in this EIS performance assessment analysis.



Source: Modified from TRW (1999a, Figure 3.2-1, page 3-23).

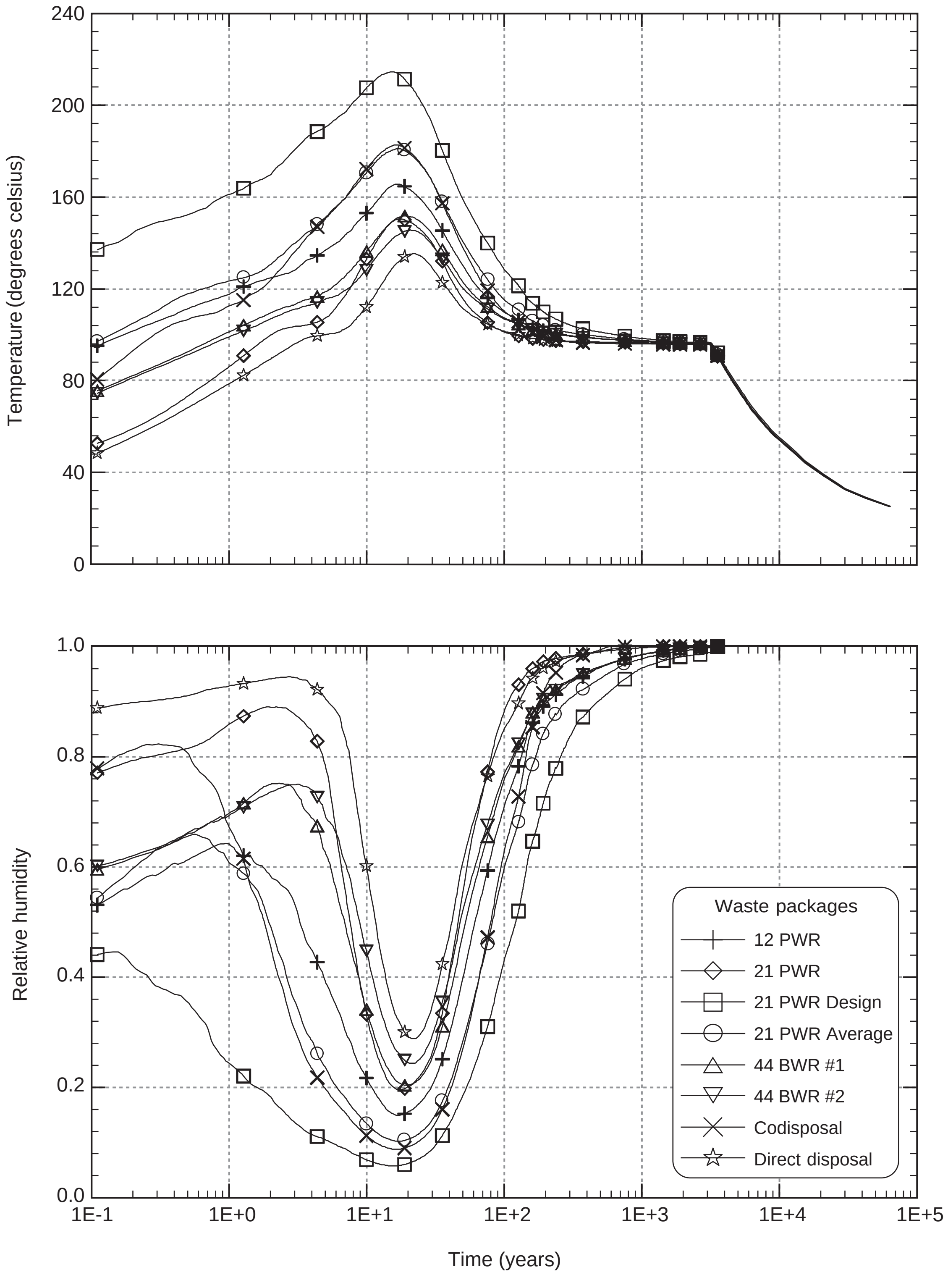
Figure I-9. Development of thermal load scale factors on the basis of two-dimensional and one-dimensional model comparisons using time history of temperature, liquid saturation, and air mass fraction.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 3.2-2, page 3-24).

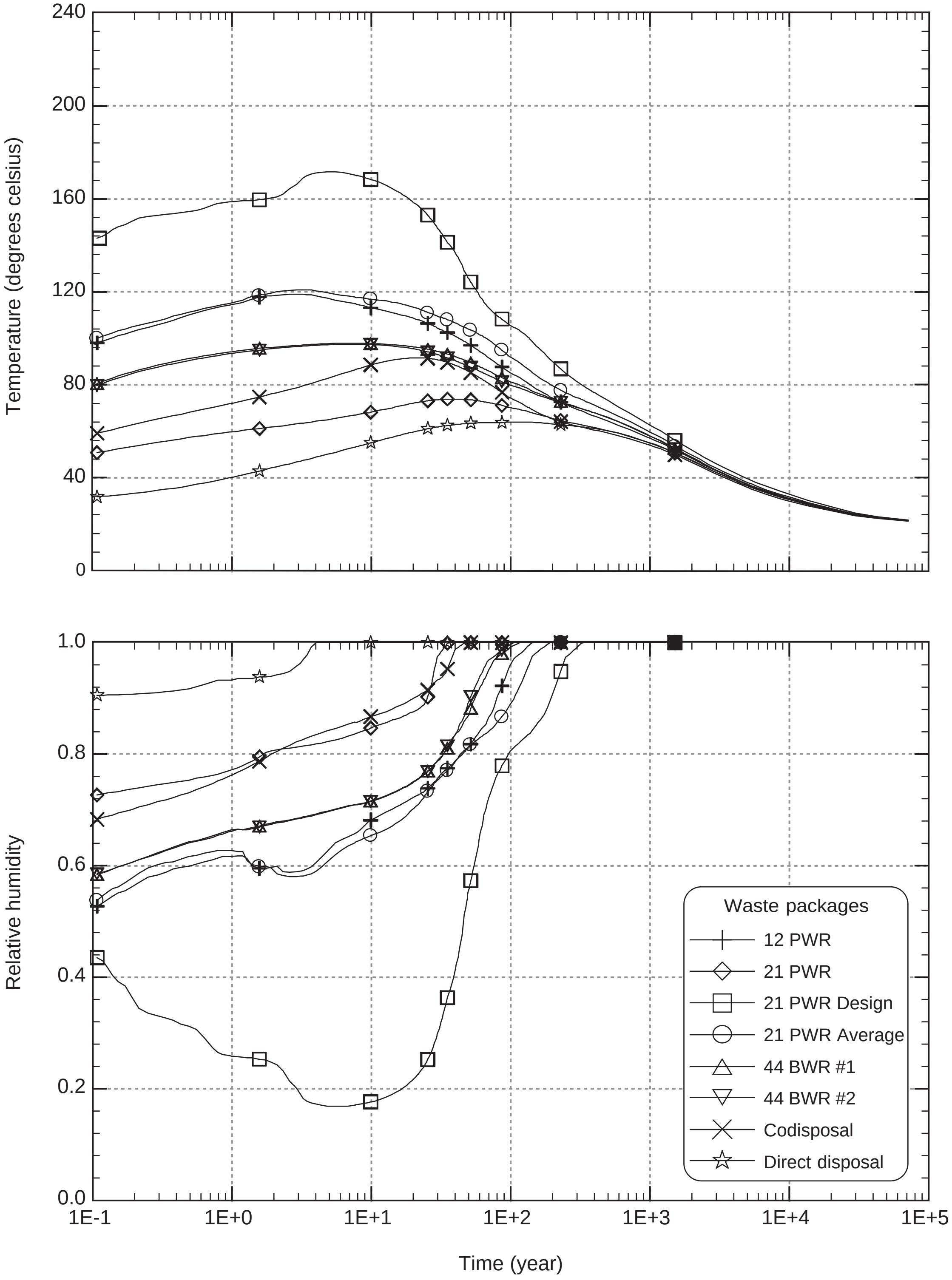
Figure I-10. Partition of repository area between center and edge regions.



BWR = boiling-water reactor; PWR = presurized-water reactor.

Source: Modified from TRW (1999a, Figure 3.2-3, page 3-25).

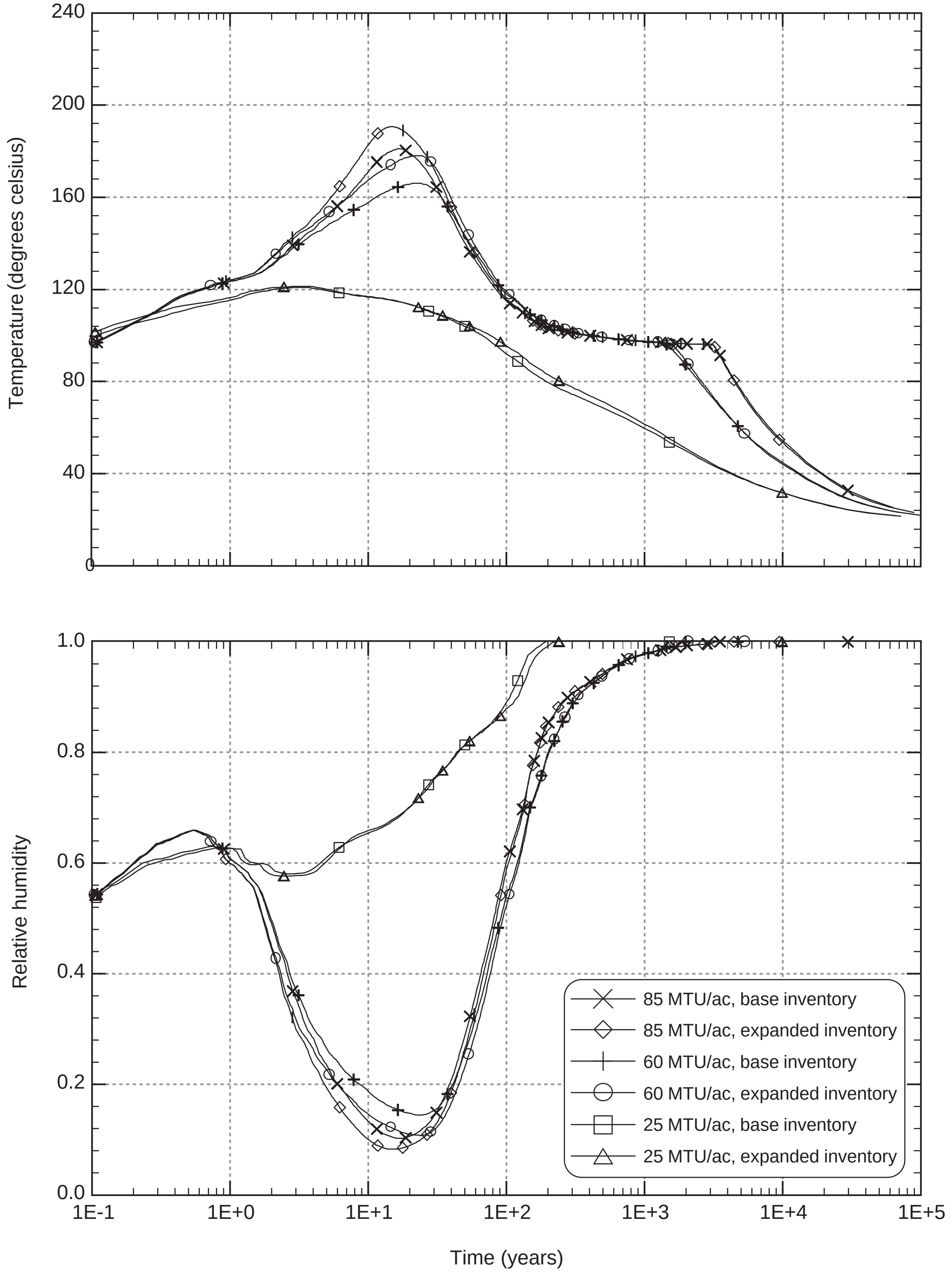
Figure I-11. Temperature and relative humidity histories for all waste packages for high thermal load scenario, Proposed Action inventory, and long-term average dimate.



BWR = boiling-water reactor; PWR = presurized-water reactor.

Source: Modified from TRW (1999a, Figure 3.2-4, page 3-26).

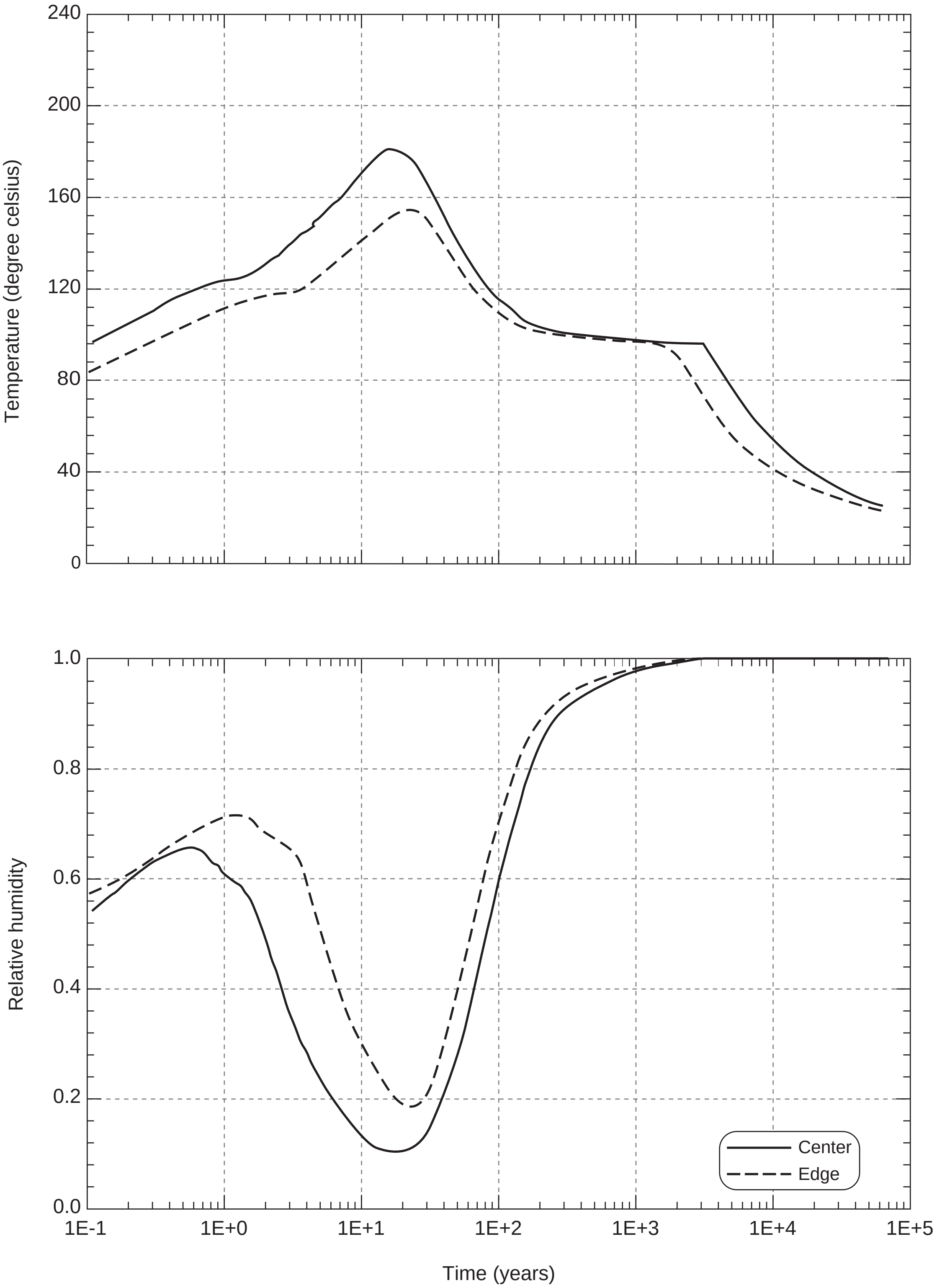
Figure I-12. Temperature and relative humidity histories for all waste packages, low thermal load scenario, Proposed Action inventory, and long-term average climate.



MTU/ac = metric tons of uranium per acre.

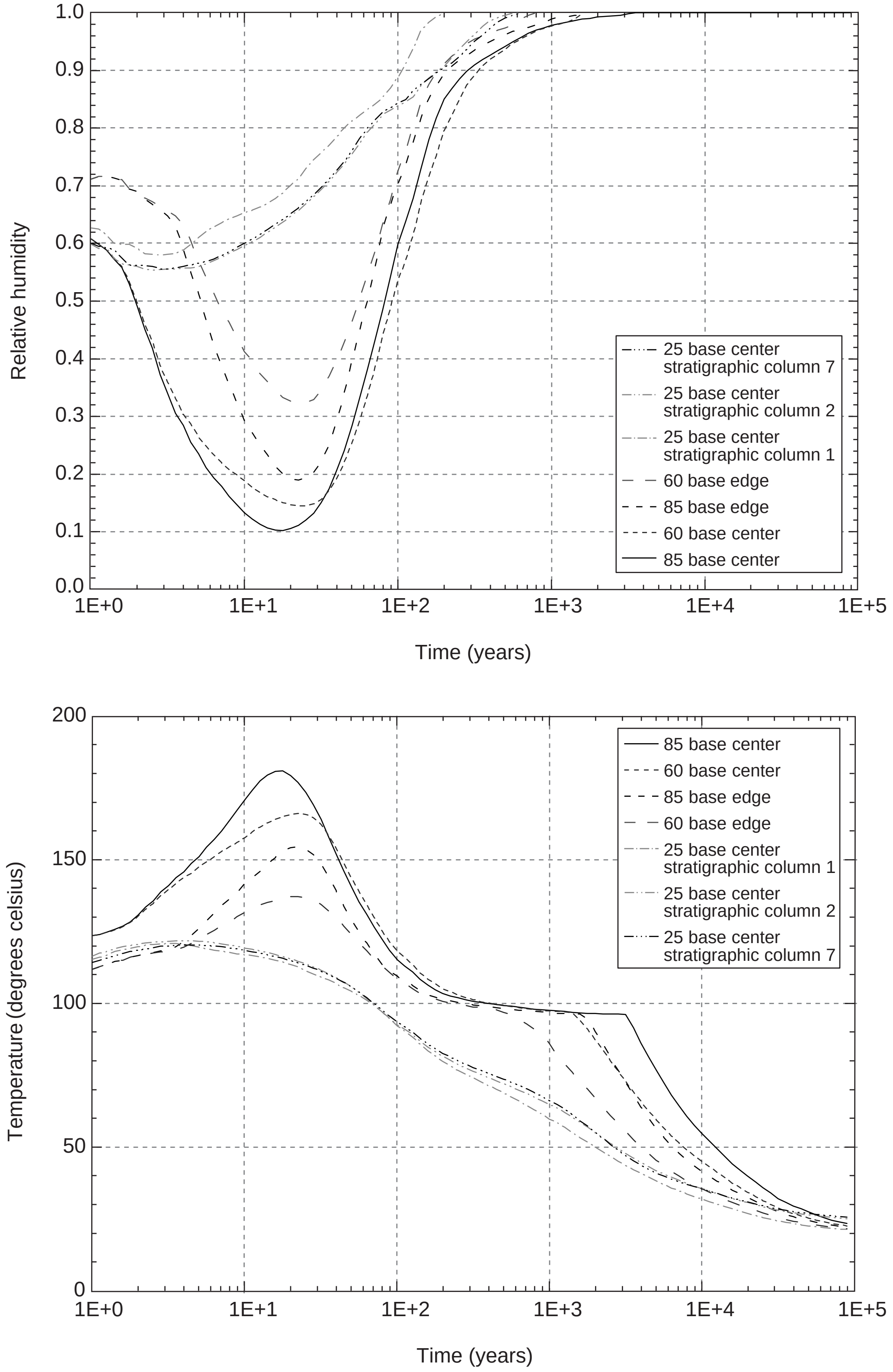
Source: Modified from TRW (1999a, Figure 3.2-5, page 3-27).

Figure I-13. Temperature and relative humidity histories for the 21 pressurized-water-reactor average waste packages, long-term average climate scenario, showing sensitivity to waste inventory.



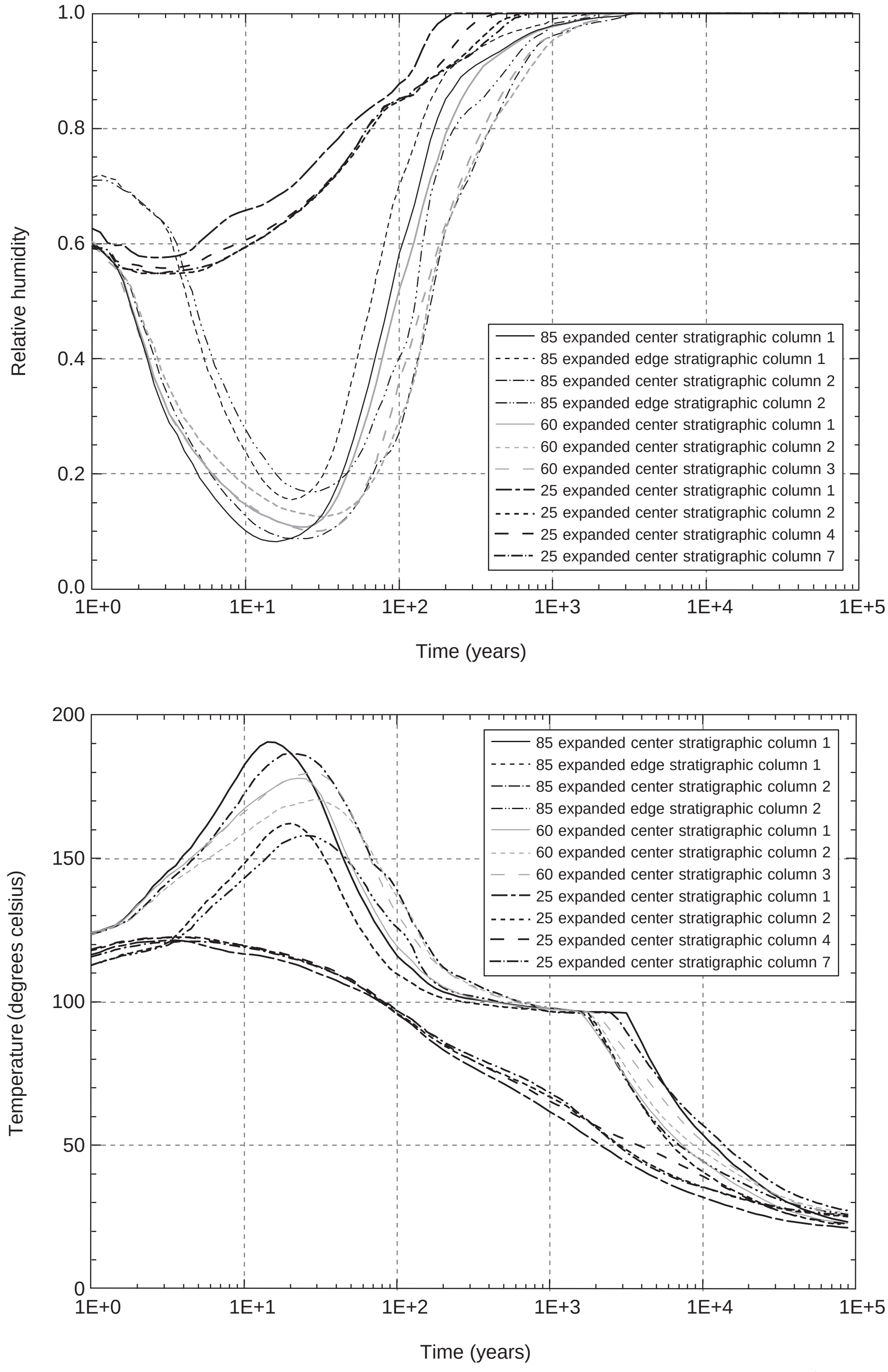
Source: Modified from TRW (1999a, Figure 3.2-6, page 3-28).

Figure I-14. Temperature and relative humidity histories for the 21 pressurized-water-reactor average waste packages, high thermal load scenario, Proposed Action inventory, long-term average climate scenario, comparing the center and edge scenarios.



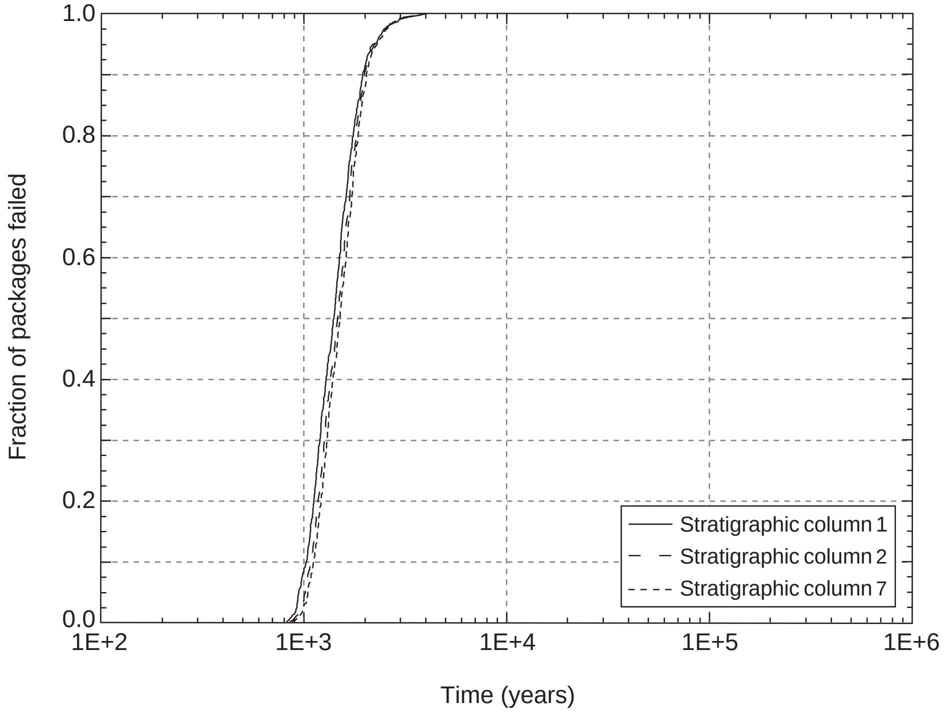
Source: Modified from TRW (1999a, Figure 3.3-1, page 3-29).

Figure I-15. WAPDEG input temperature and relative humidity histories for all thermal loads with Proposed Action inventory.



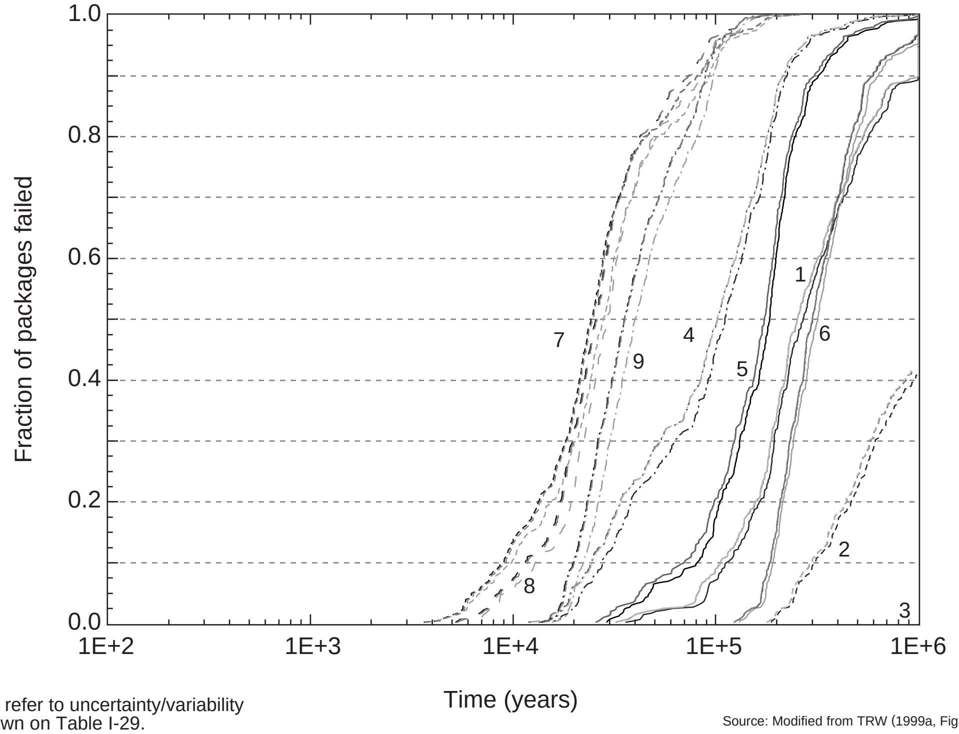
Source: Modified from TRW (1999a, Figure 3.3-2, page 3-30).

Figure I-16. WAPDEG input temperature and relative humidity histories for all thermal loads with Inventory Modules 1 and 2.



Source: Modified from TRW (1999a, Figure 3.3-3, page 3-31).

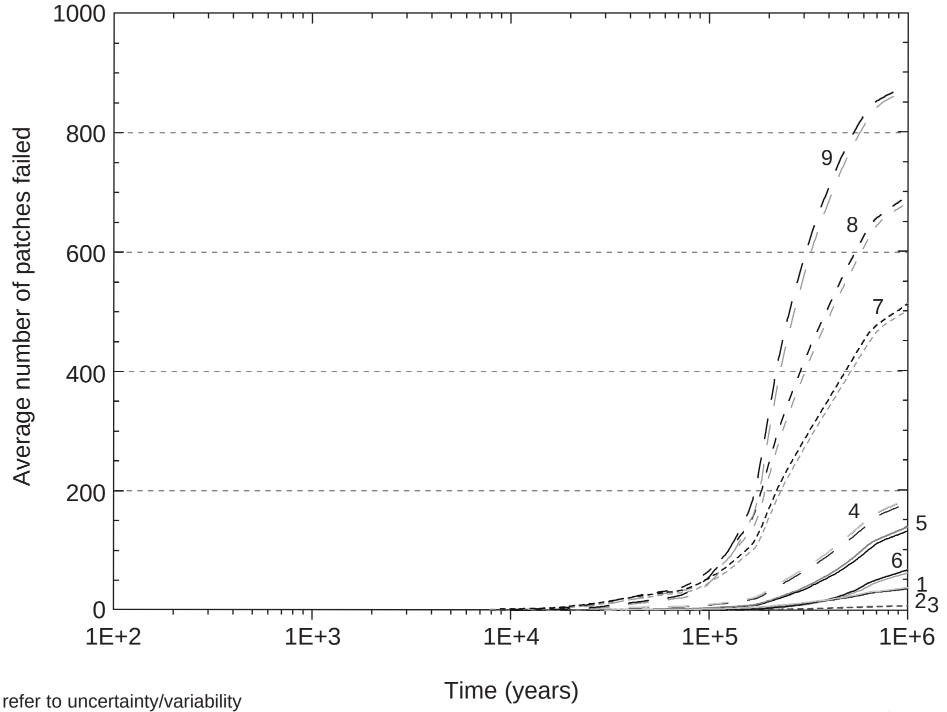
Figure I-17. Time to first breach of the corrosion-allowance material for low thermal load scenario, Proposed Action inventory, all three stratigraphic columns, always-dripping waste packages.



Numbers on plot refer to uncertainty/variability splitting sets shown on Table I-29.

Source: Modified from TRW (1999a, Figure 3.3-4, page 3-32).

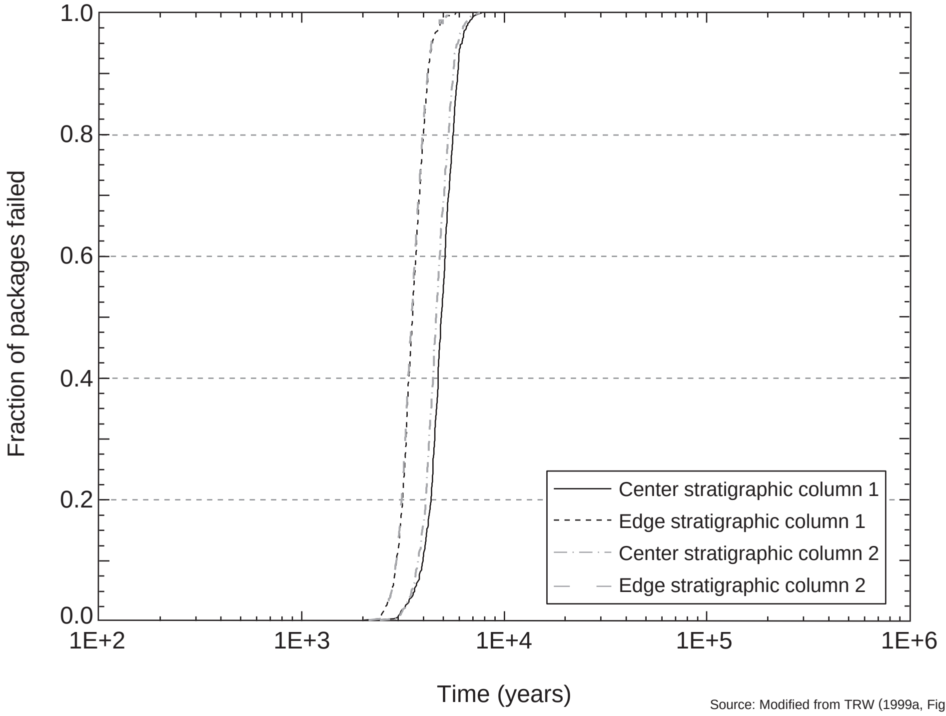
Figure I-18. Time to first breach of the corrosion-resistant material for low thermal load scenario, Proposed Action inventory, all three stratigraphic columns, always-dripping waste packages, and all nine uncertainty/variability splitting sets.



Numbers on plot refer to uncertainty/variability splitting sets shown on Table I-29.

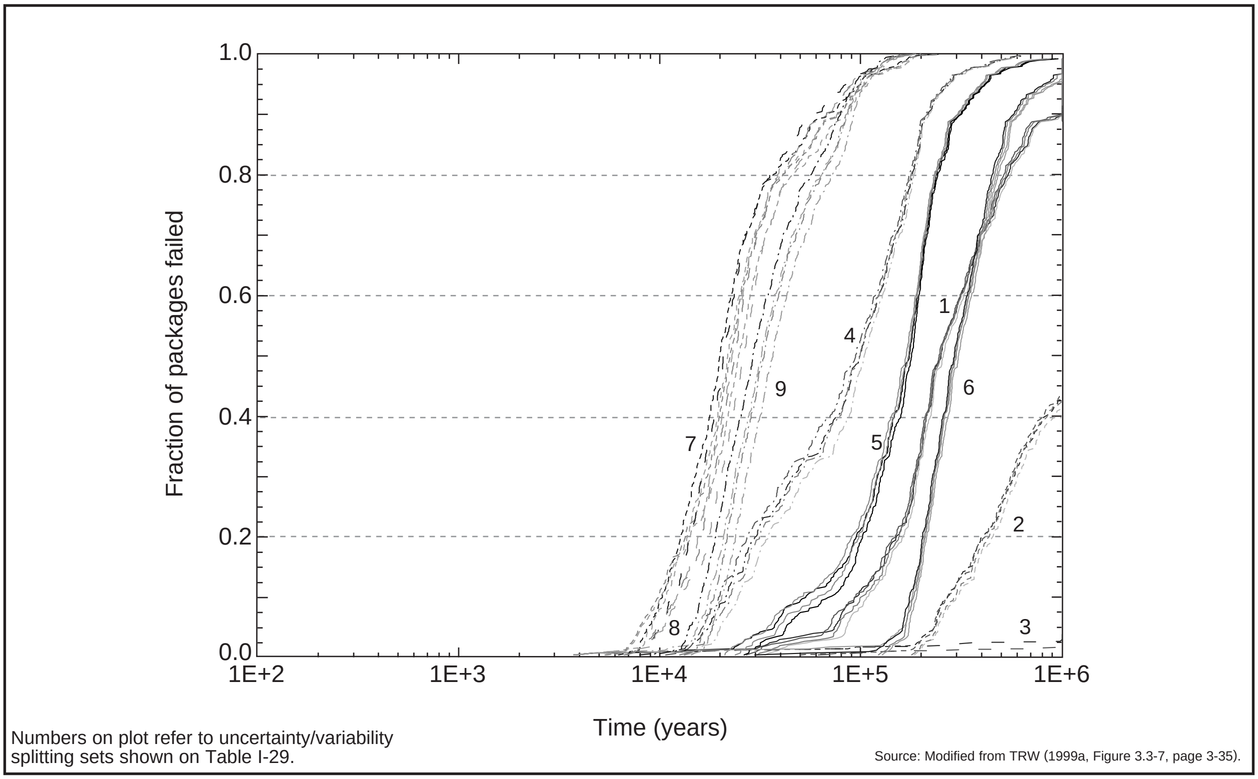
Source: Modified from TRW (1999a, Figure 3.3-5, page 3-33).

Figure I-19. Average number of patches failed per waste package as a function of time for low thermal load scenario, Proposed Action inventory, all three stratigraphic columns, always-dripping waste packages, and all nine uncertainty/variability splitting sets.



Source: Modified from TRW (1999a, Figure 3.3-6, page 3-34).

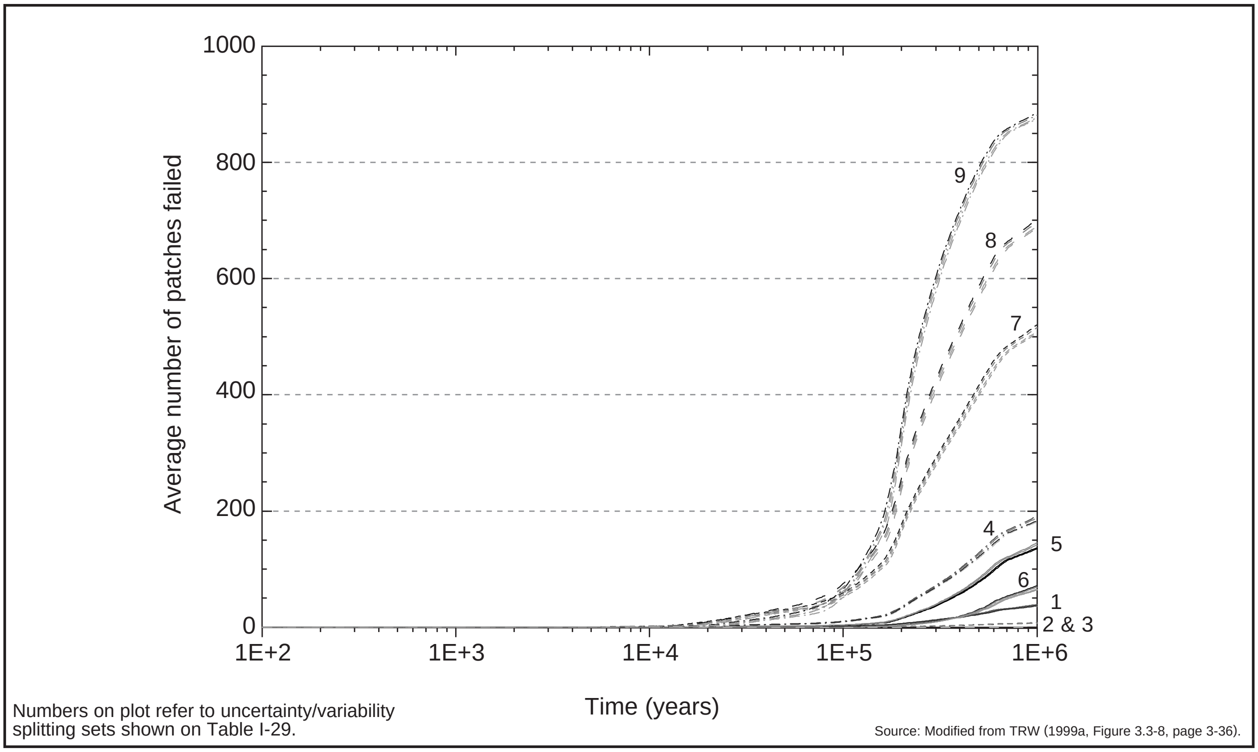
Figure I-20. Time to first breach of the corrosion-allowance material for high thermal load scenario, Inventory Modules 1 and 2, center and edge regions for both stratigraphic columns, always-dripping waste packages.



Numbers on plot refer to uncertainty/variability splitting sets shown on Table I-29.

Source: Modified from TRW (1999a, Figure 3.3-7, page 3-35).

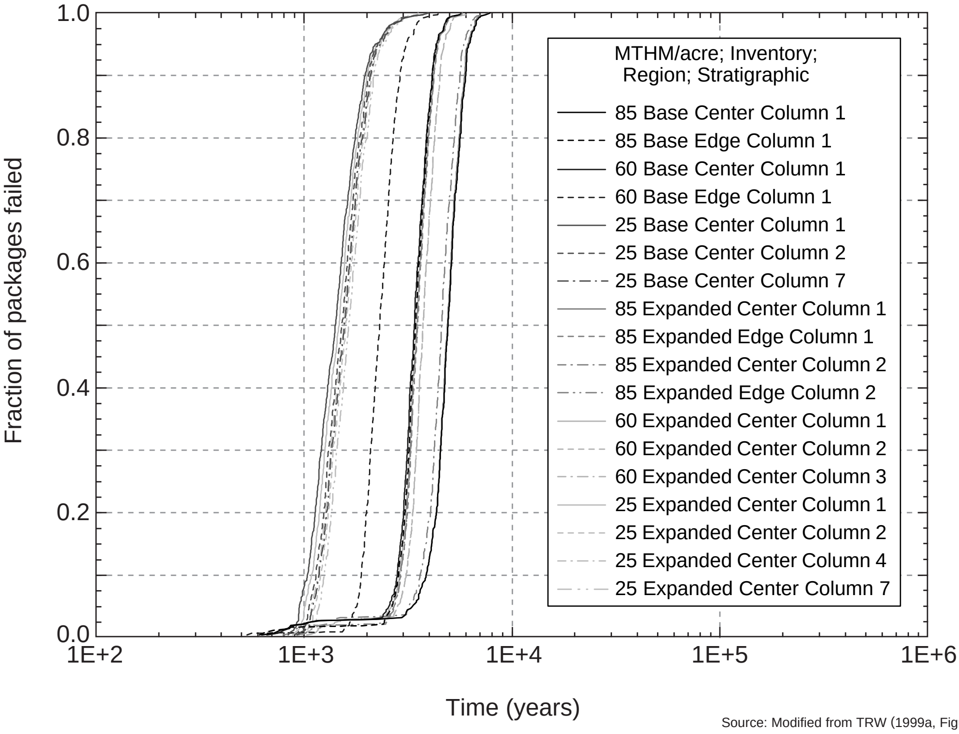
Figure I-21. Time to first breach of the corrosion-resistant material for high thermal load scenario, Inventory Modules 1 and 2, center and edge regions for both stratigraphic columns, always-dripping waste packages, and all nine uncertainty/variability splitting sets.



Numbers on plot refer to uncertainty/variability splitting sets shown on Table I-29.

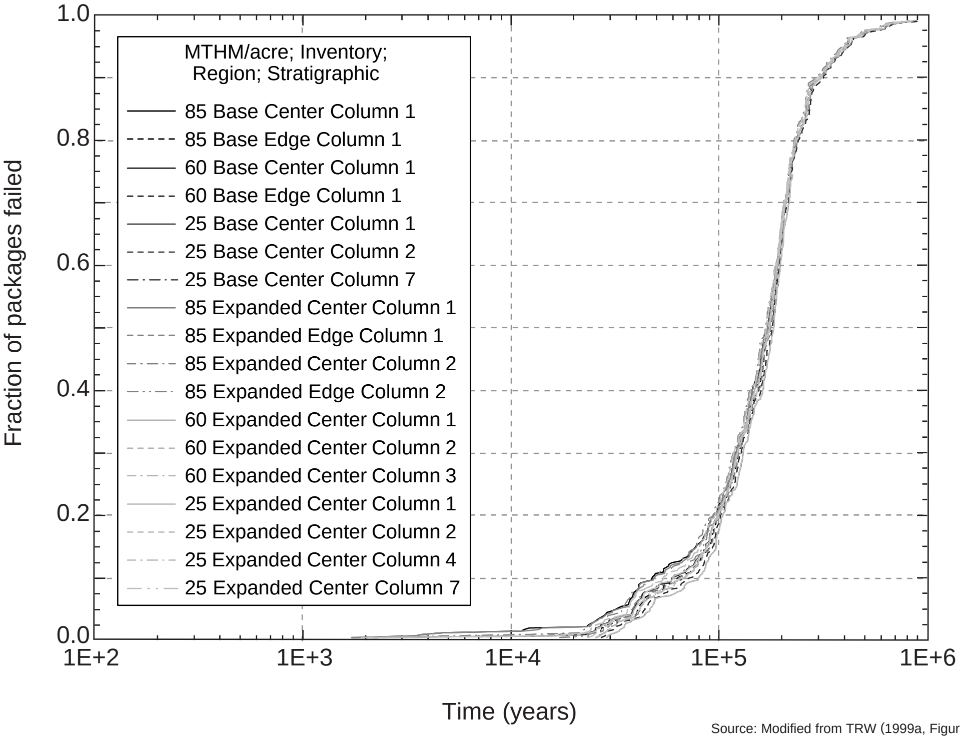
Source: Modified from TRW (1999a, Figure 3.3-8, page 3-36).

Figure I-22. Average number of patches failed per package as a function of time for high thermal load scenario, Inventory Modules 1 and 2, center and edge regions for both stratigraphic columns, always-dripping waste packages, and all nine uncertainty/variability splitting sets.



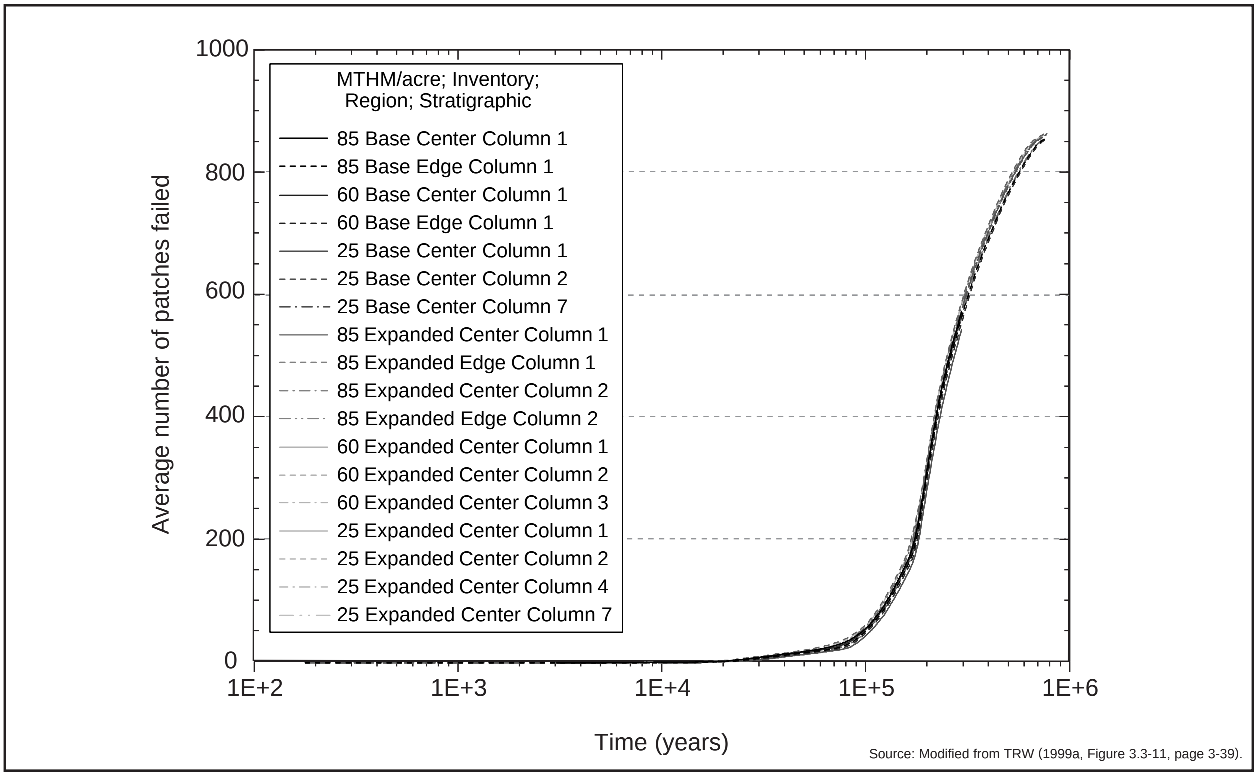
Source: Modified from TRW (1999a, Figure 3.3-9, page 3-37).

Figure I-23. Time to first breach of the corrosion-allowance material for all thermal loads and inventories, all regions, always-dripping waste packages, uncertainty/variability splitting set 5.



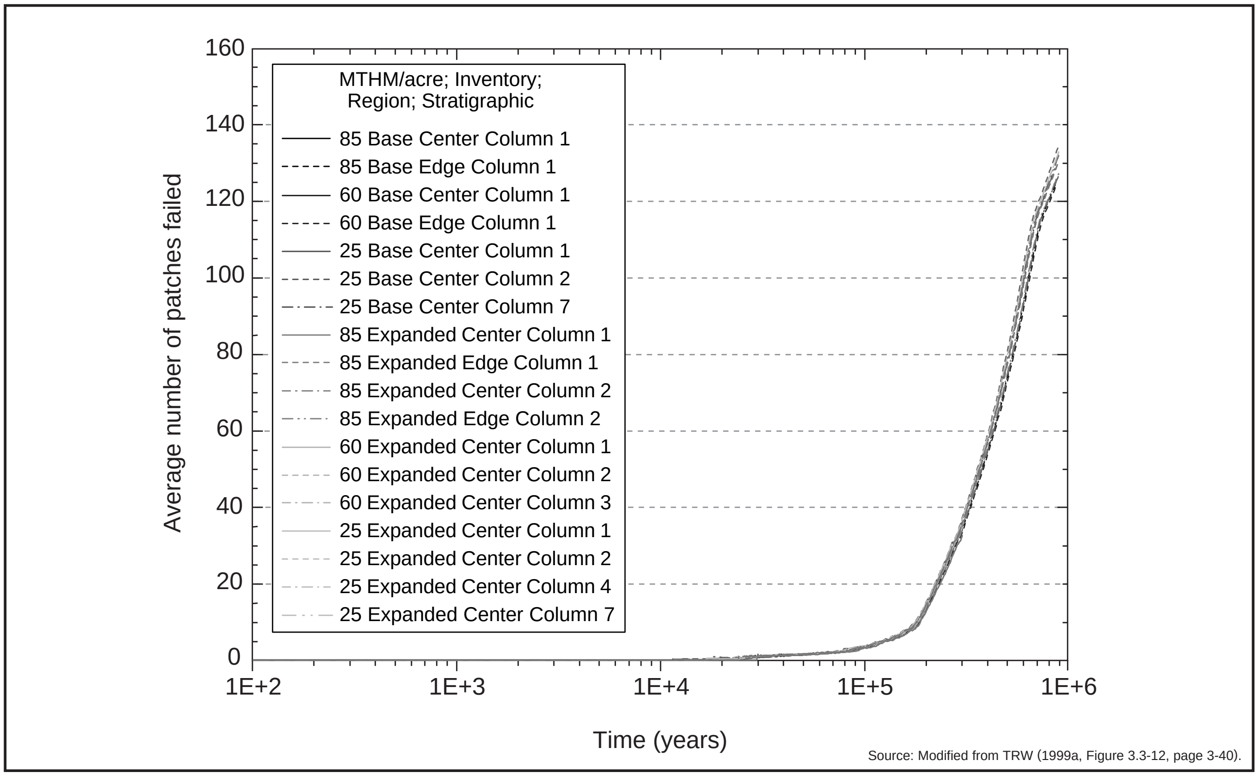
Source: Modified from TRW (1999a, Figure 3.3-10, page 3-38).

Figure I-24. Time to first breach of the corrosion-resistant material for all thermal loads and inventories, all regions, always-dripping waste packages, uncertainty/variability splitting set 5.



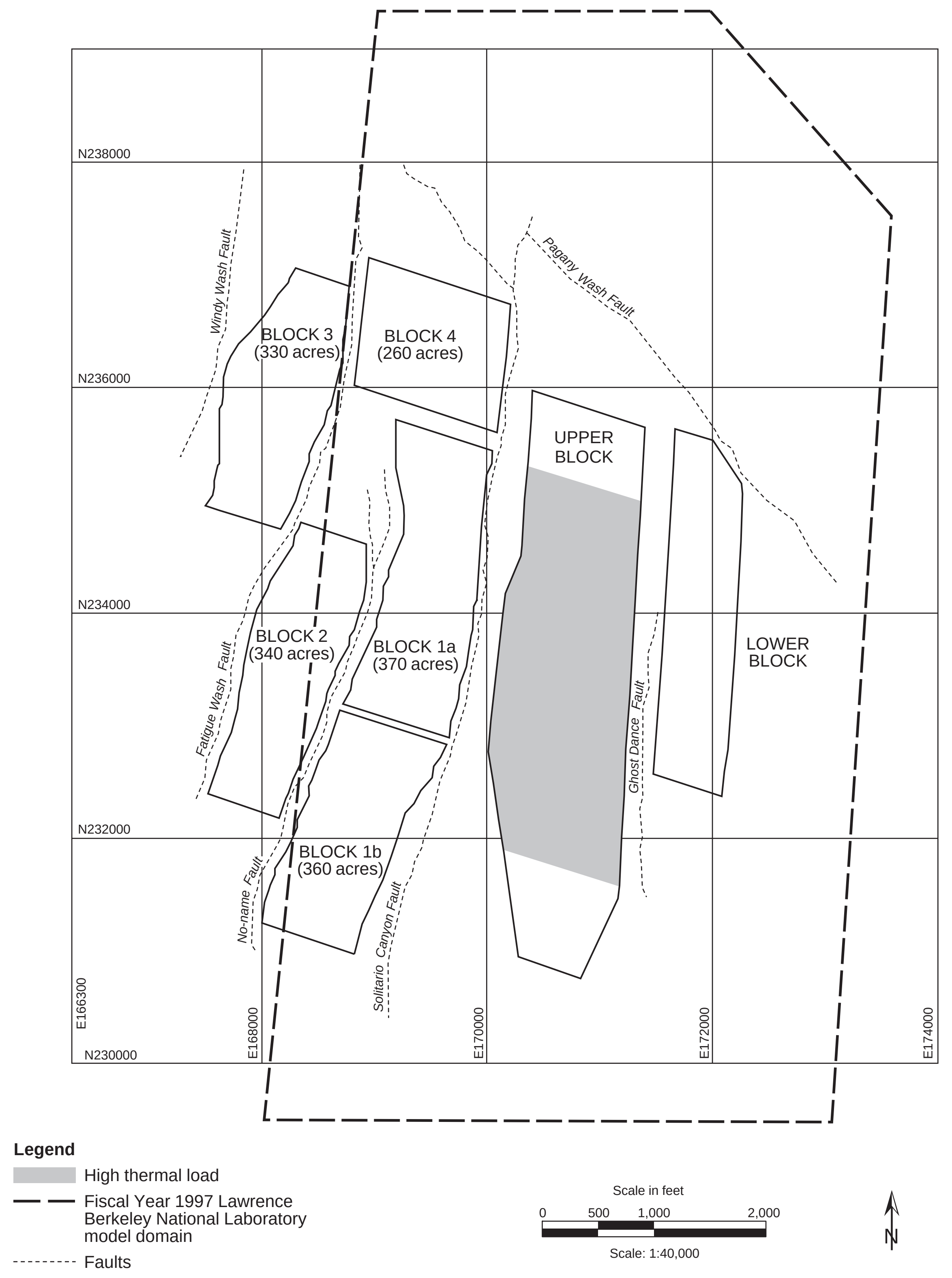
Source: Modified from TRW (1999a, Figure 3.3-11, page 3-39).

Figure I-25. Average number of patches failed per waste package as a function of time for all thermal loads and inventories, all regions, always-dripping waste packages, uncertainty/variability splitting set 9.



Source: Modified from TRW (1999a, Figure 3.3-12, page 3-40).

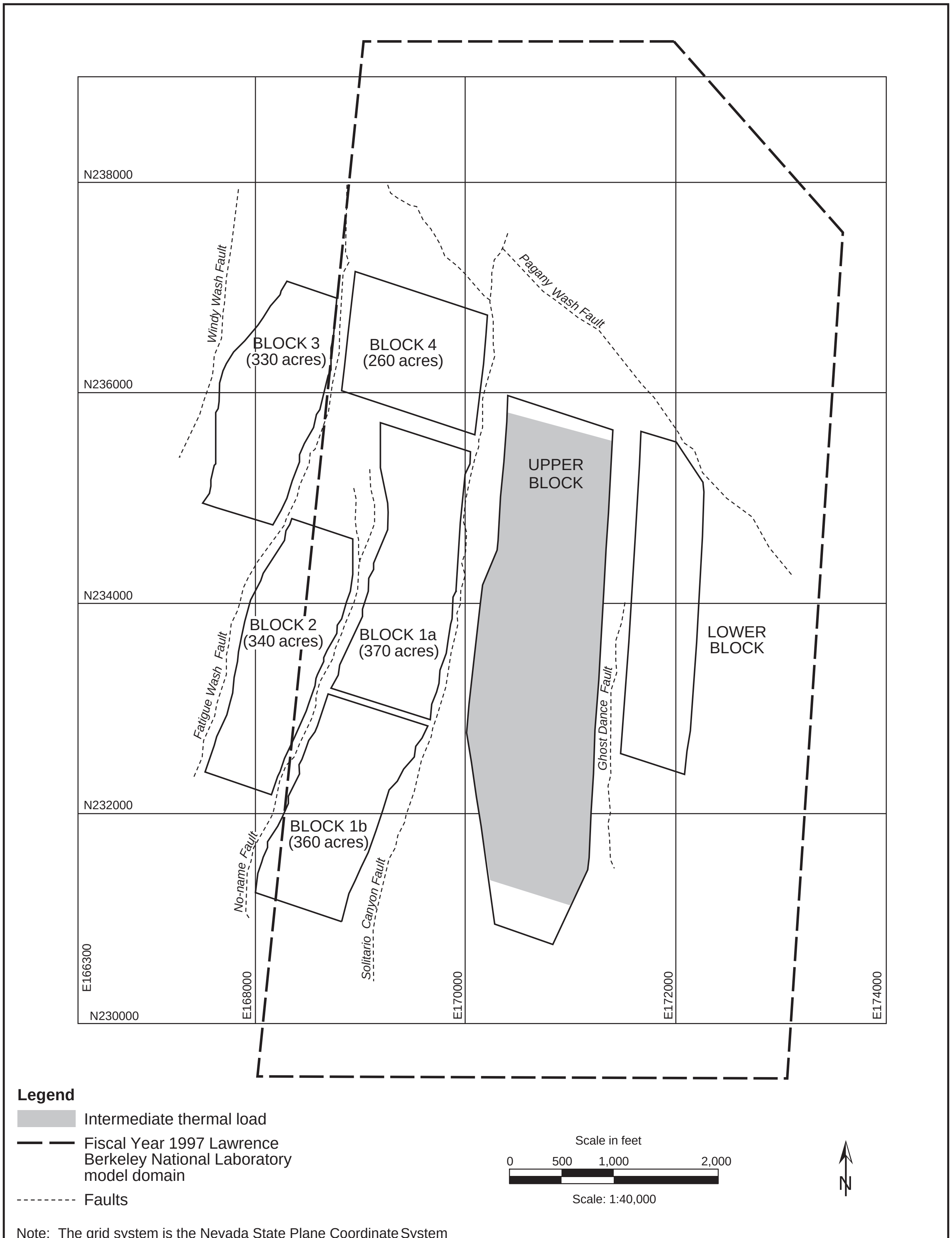
Figure I-26. Average number of patches failed per waste package as a function of time for all thermal loads and inventories, all regions, always-dripping waste packages, uncertainty/variability splitting set 5.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 3.5-1, page 3-41).

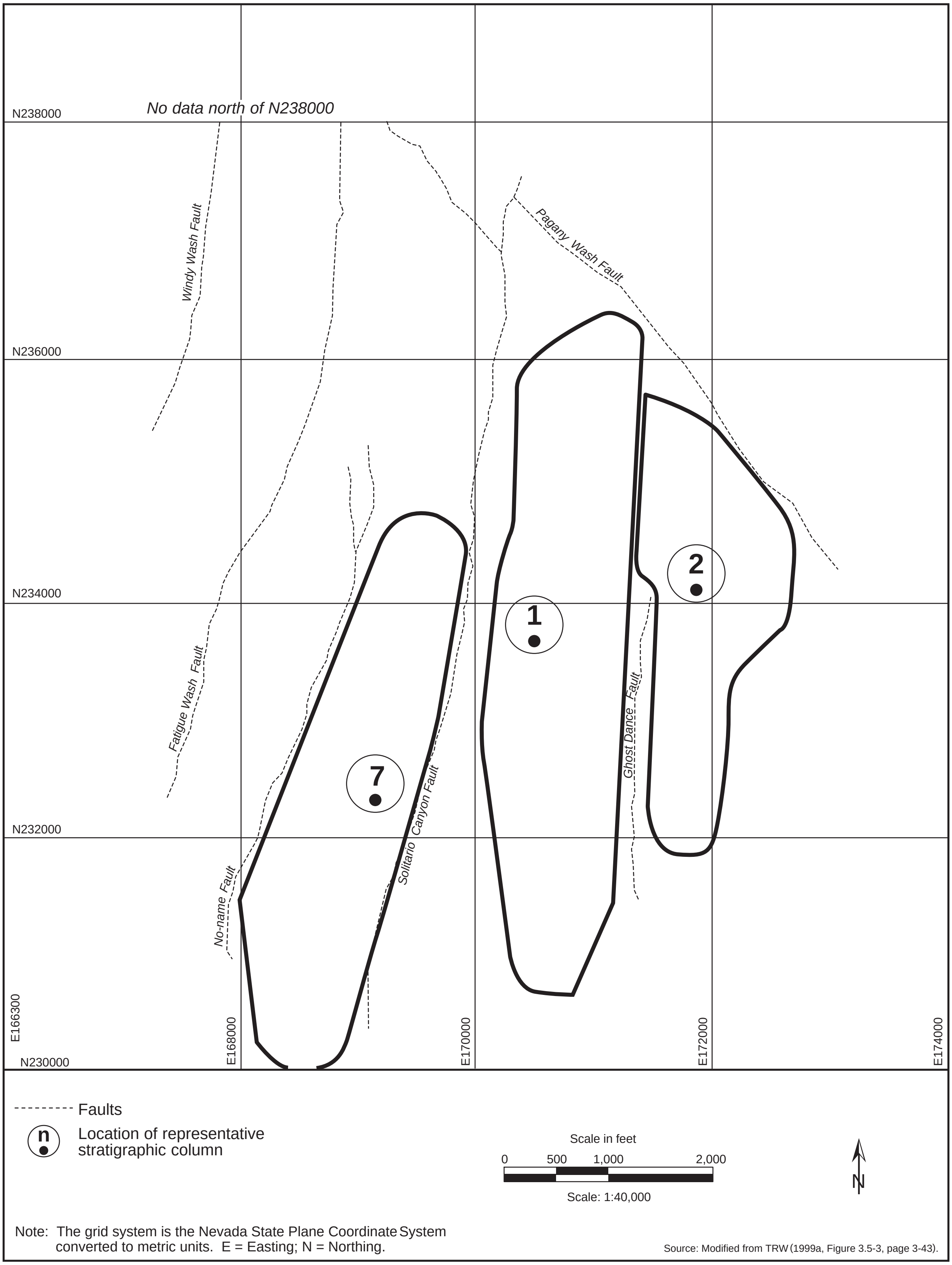
Figure I-27. Regions for performance assessment modeling, Option 1, high thermal load scenario, Proposed Action inventory.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 3.5-2, page 3-42).

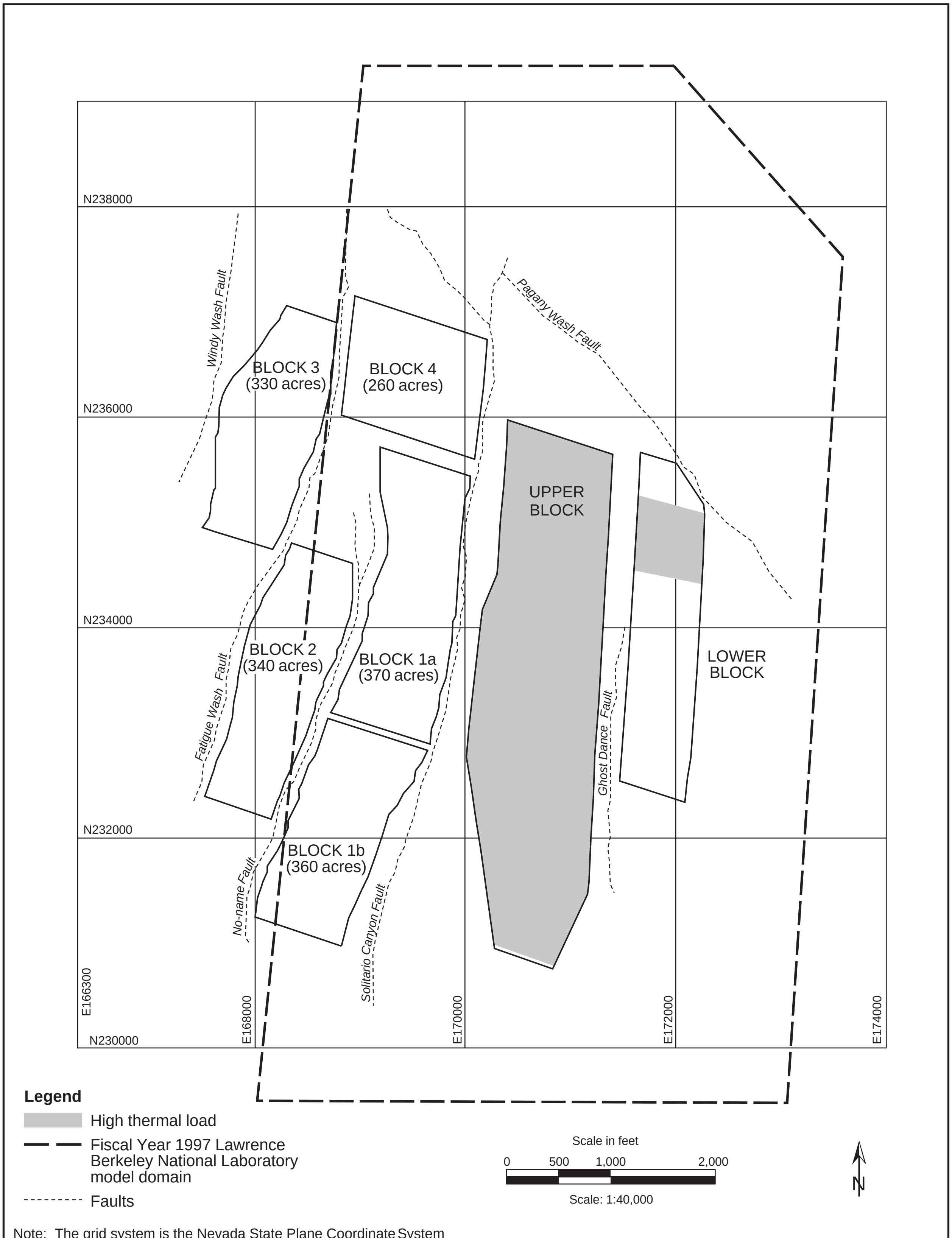
Figure I-28. Regions for performance assessment modeling, Option 2, intermediate thermal load scenario, Proposed Action inventory.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 3.5-3, page 3-43).

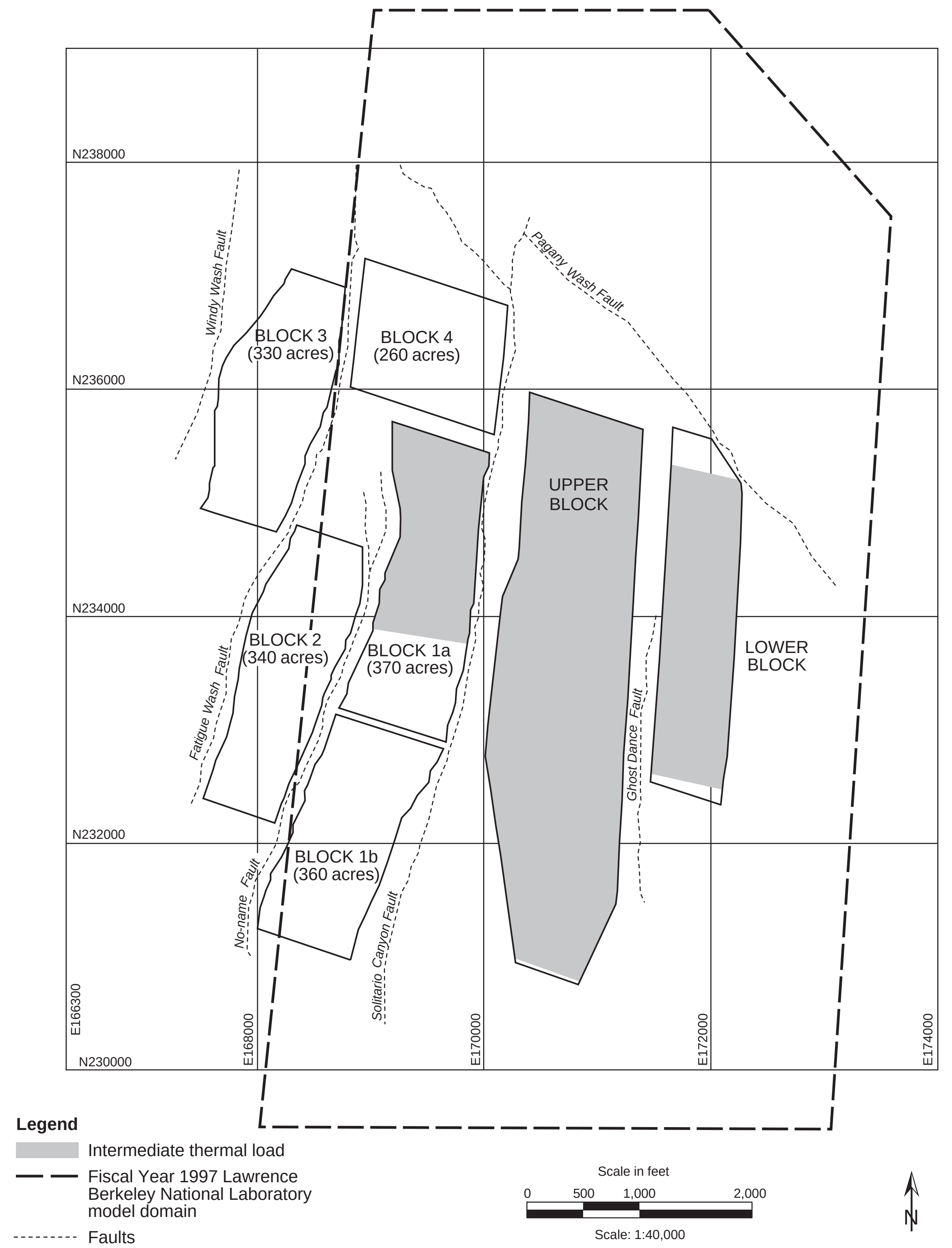
Figure I-29. Repository block areas for performance assessment modeling, Option 3, low thermal load scenario with Inventory Module 1, and intermediate thermal load scenario with Inventory Module 1 cases.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 3.5-4, page 3-44).

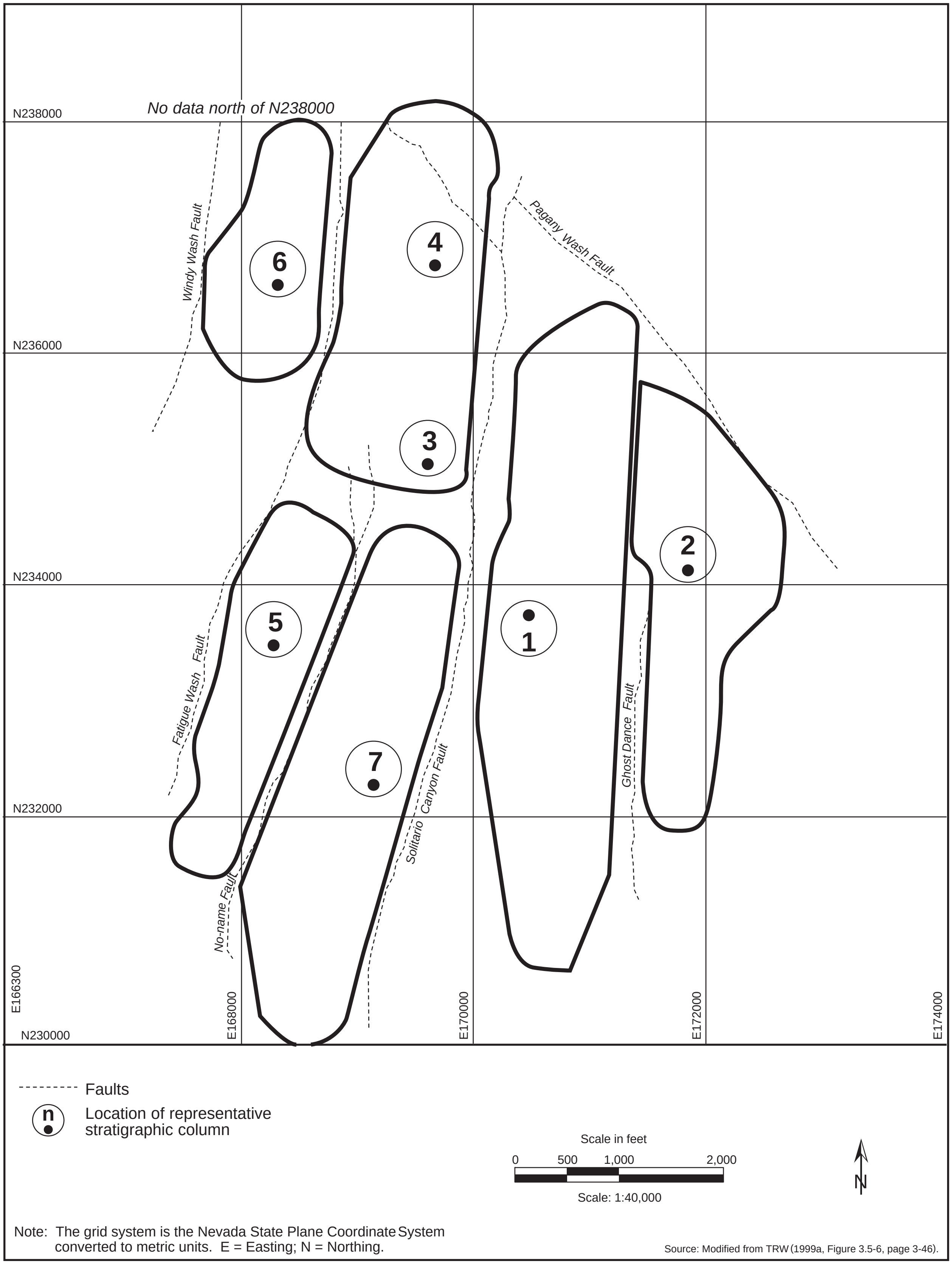
Figure I-30. Regions for performance assessment modeling, Option 4, high thermal load scenario, Proposed Action inventory.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 3.5-5, page 3-45).

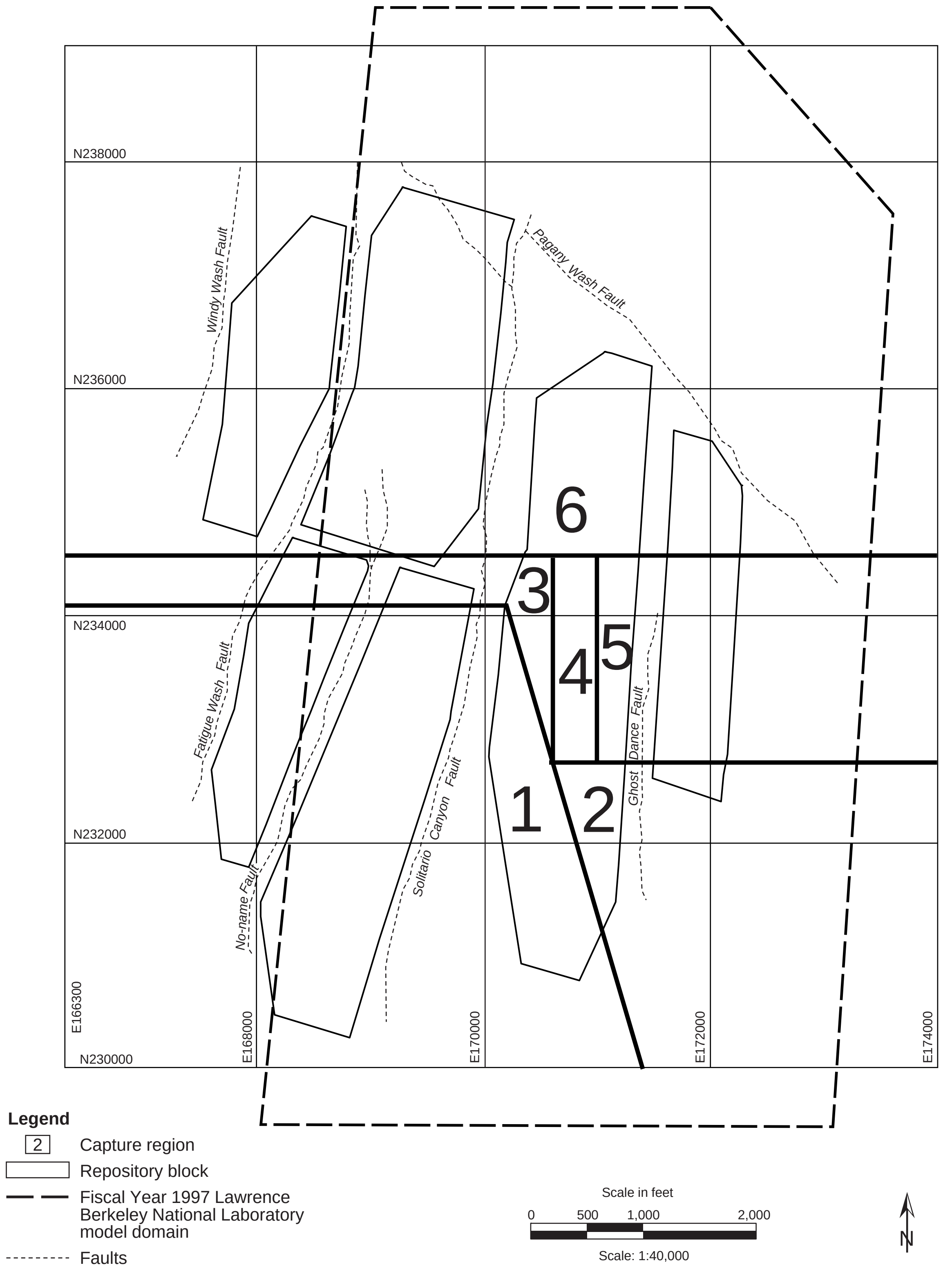
Figure I-31. Regions for performance assessment modeling, Option 5, intermediate thermal load scenario, Inventory Module 1.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 3.5-6, page 3-46).

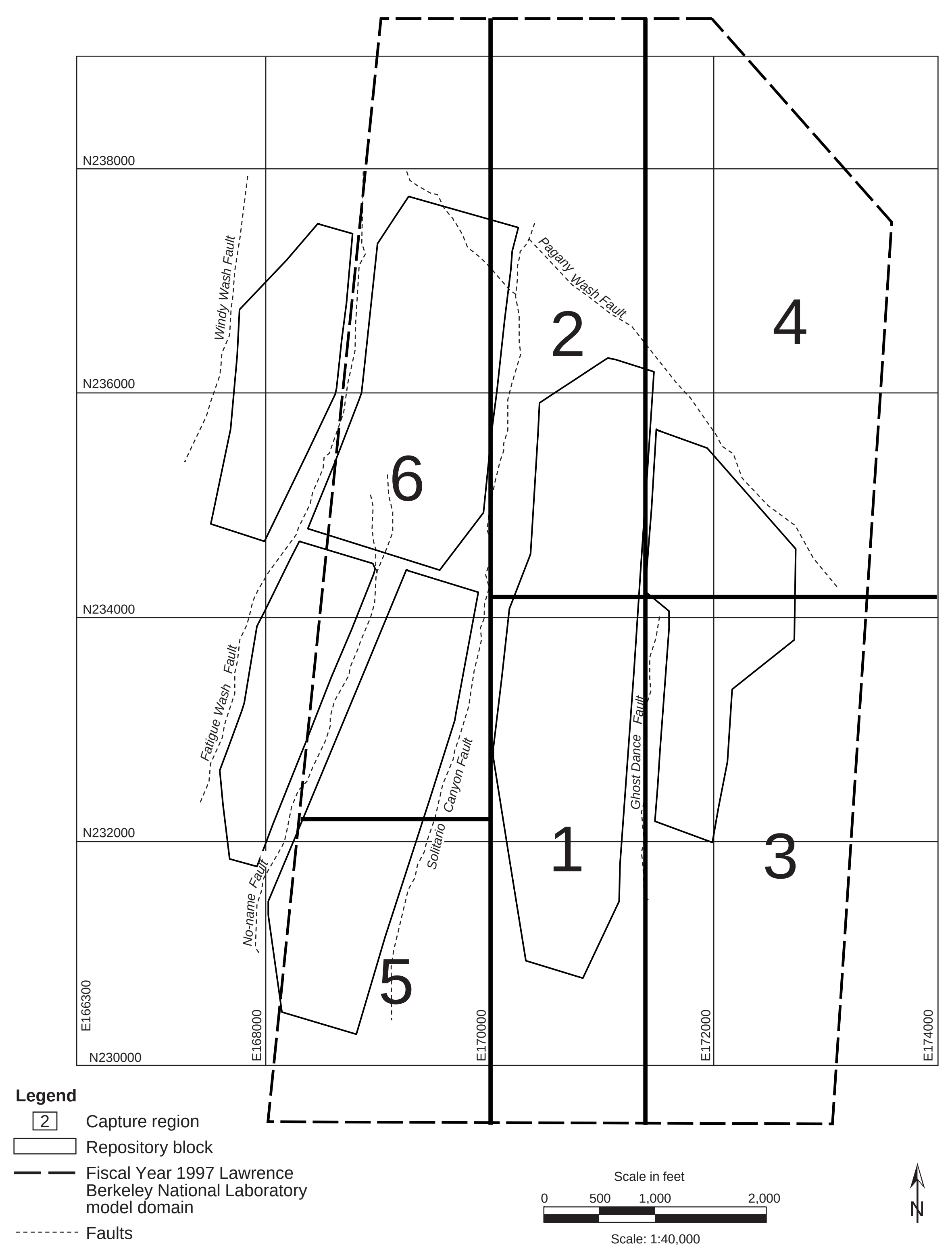
Figure I-32. Repository block areas for performance assessment modeling, Option 6, low thermal load scenario, Inventory Module 1.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 3.5-7, page 3-47).

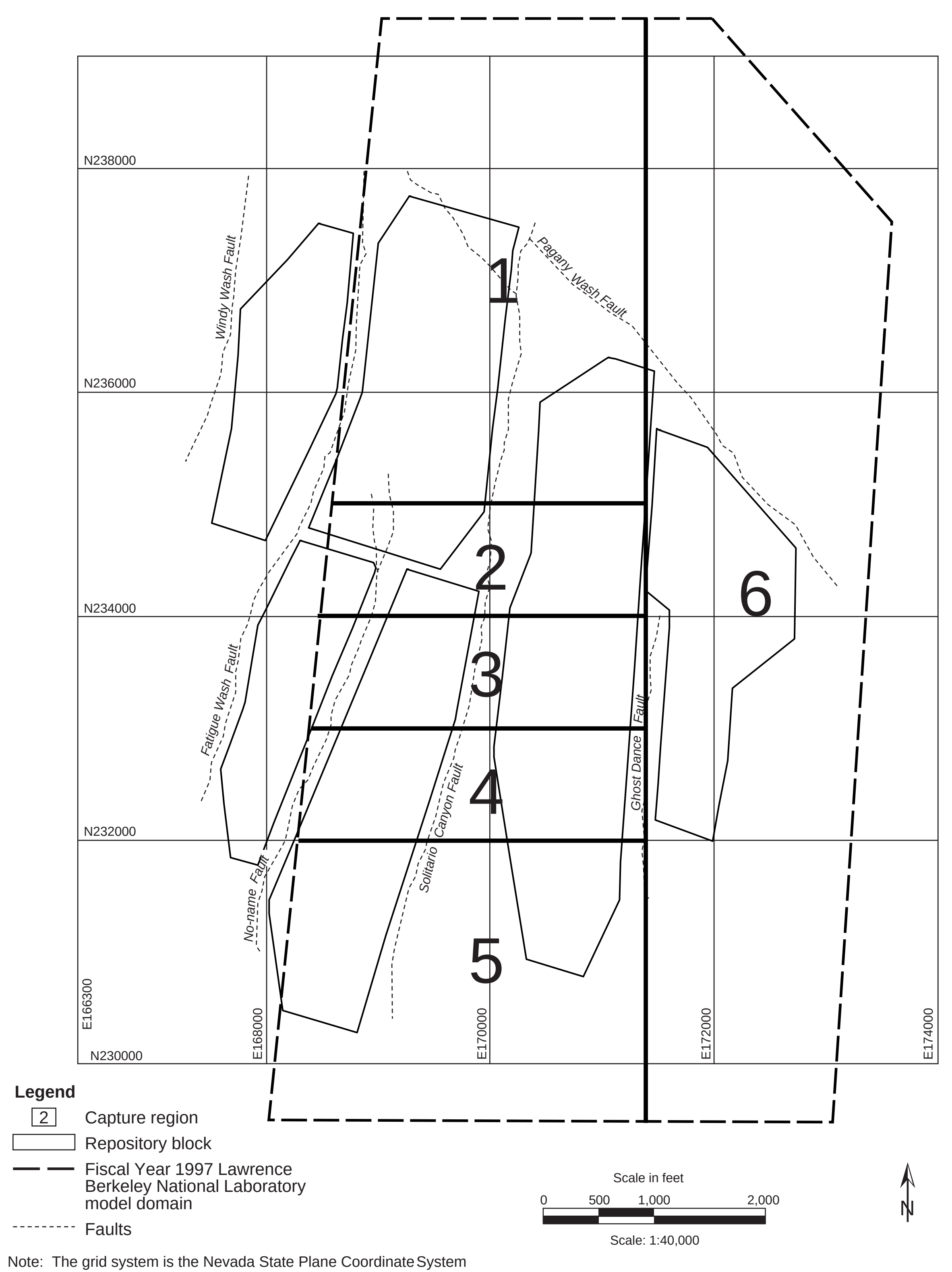
Figure I-33. Capture regions for high and intermediate thermal load scenarios with Proposed Action inventory.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 3.5-7, page 3-47).

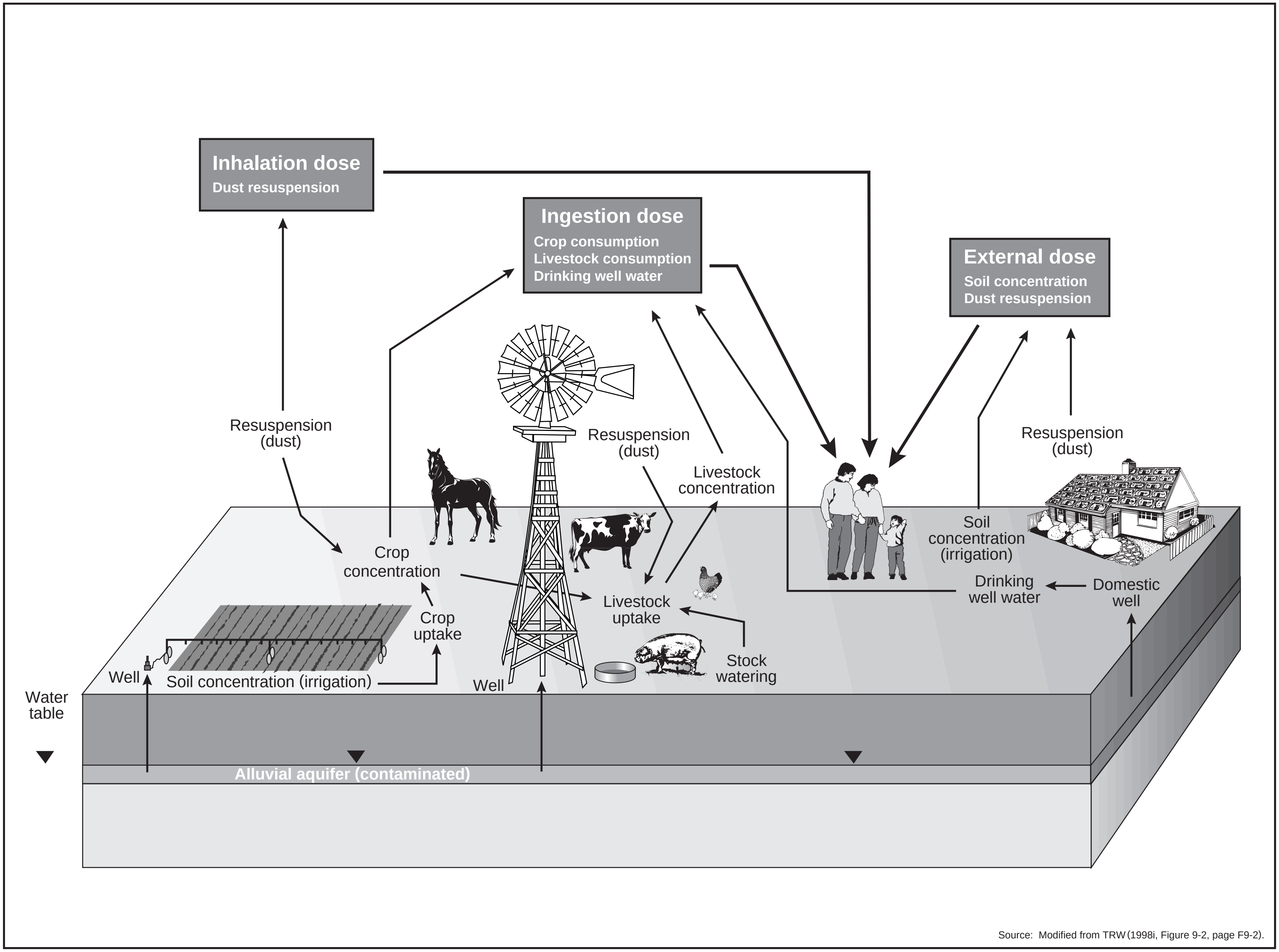
Figure I-34. Capture regions for low thermal load scenario with Proposed Action Inventory and low and intermediate thermal load scenarios with Inventory Modules 1 and 2.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

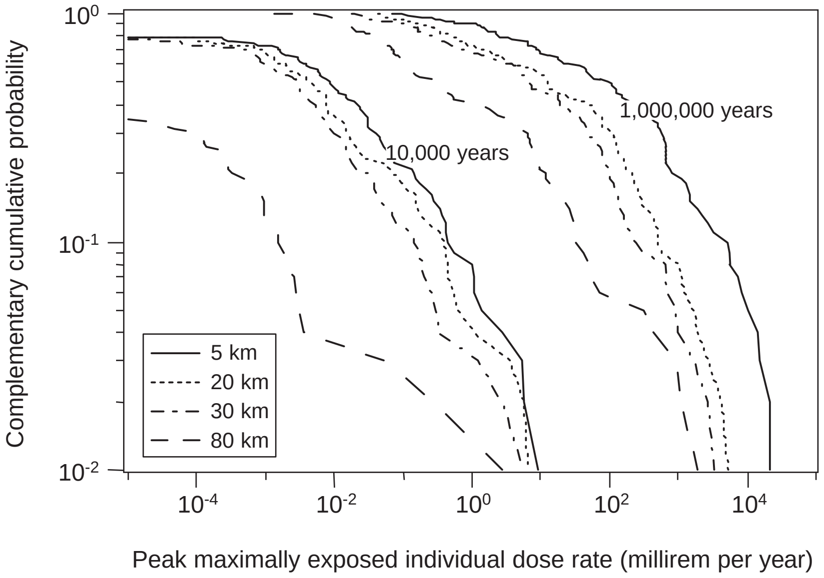
Source: Modified from TRW (1999a, Figure 3.5-8, page 3-48).

Figure I-35. Capture regions for high thermal load scenario with Inventory Modules 1 and 2.



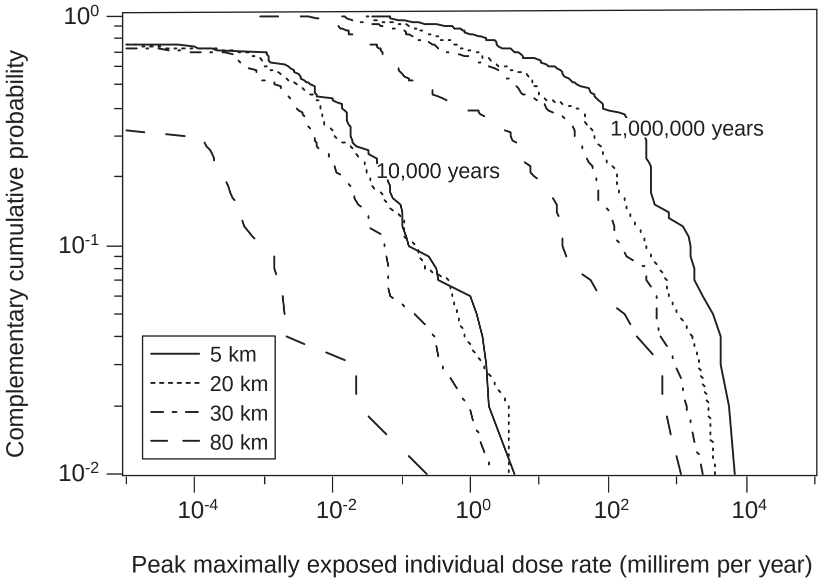
Source: Modified from TRW (1998i, Figure 9-2, page F9-2).

Figure I-36. Biosphere modeling components, including ingestion of contaminated food and water, inhalation of contaminated air, and exposure to direct external radiation.



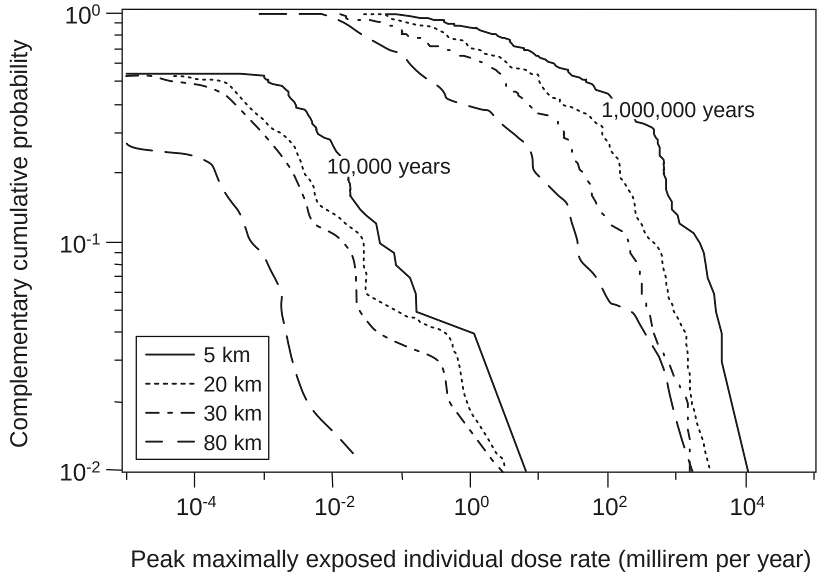
km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-37. Complementary cumulative distribution function of peak maximally exposed individual radiological dose rates during 10,000 and 1 million years following closure for high thermal load scenario with Proposed Action inventory (100 realizations, all pathways, all distances).



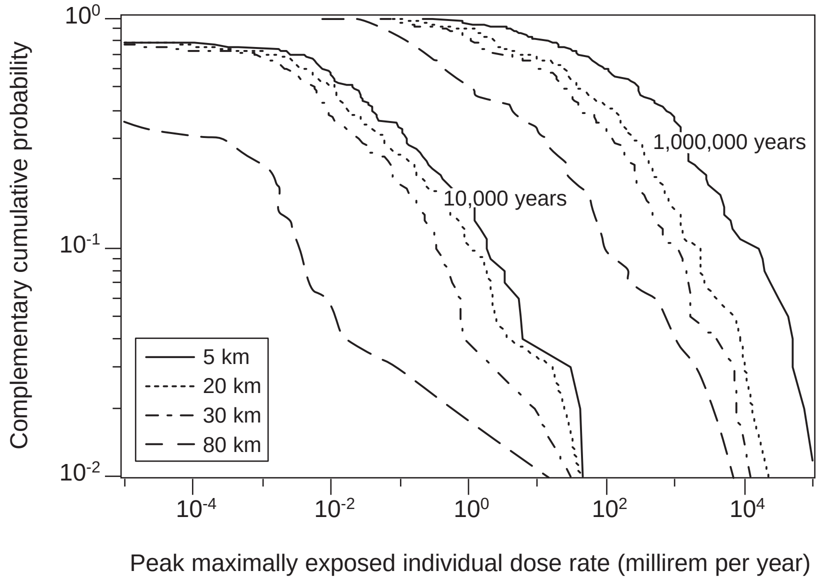
km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-38. Complementary cumulative distribution function of peak maximally exposed individual radiological dose rates during 10,000 and 1 million years following closure for intermediate thermal load scenario with Proposed Action inventory (100 realizations, all pathways, all distances).



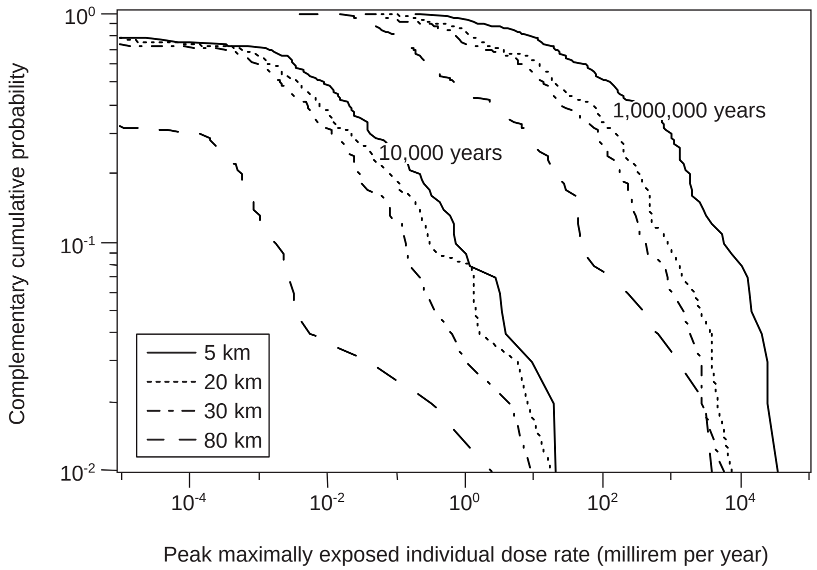
km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-39. Complementary cumulative distribution function of peak maximally exposed individual radiological dose rates during 10,000 and 1 million years following closure for low thermal load scenario with Proposed Action inventory (100 realizations, all pathways, all distances).



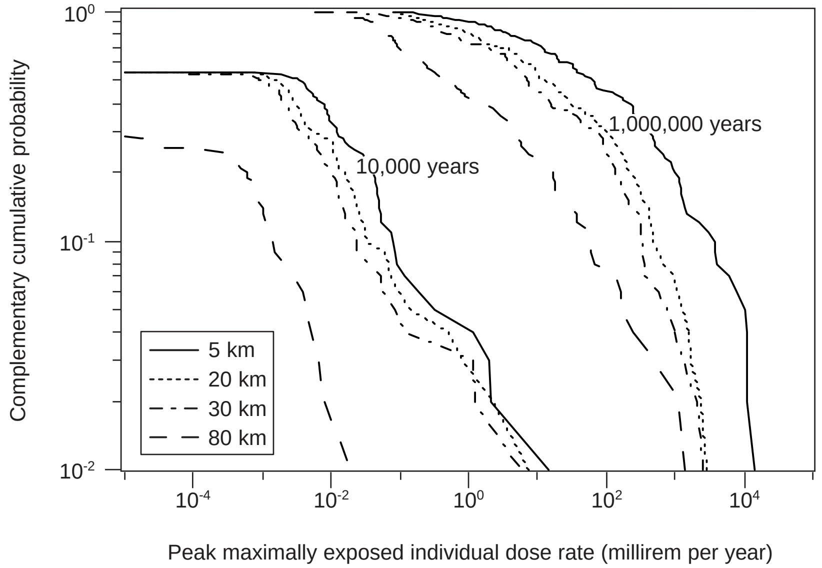
km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-40. Complementary cumulative distribution function of peak maximally exposed individual radiological dose rates during 10,000 and 1 million years following closure for high thermal load scenario with Inventory Module 1 (100 realizations, all pathways, all distances).



km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-41. Complementary cumulative distribution function of peak maximally exposed individual radiological dose rates during 10,000 and 1 million years following closure for intermediate thermal load scenario with Inventory Module 1 (100 realizations, all pathways, all distances).



km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-42. Complementary cumulative distribution function of peak maximally exposed individual radiological dose rates during 10,000 and 1 million years following closure for low thermal load scenario with Inventory Module 1 (100 realizations, all pathways, all distances).

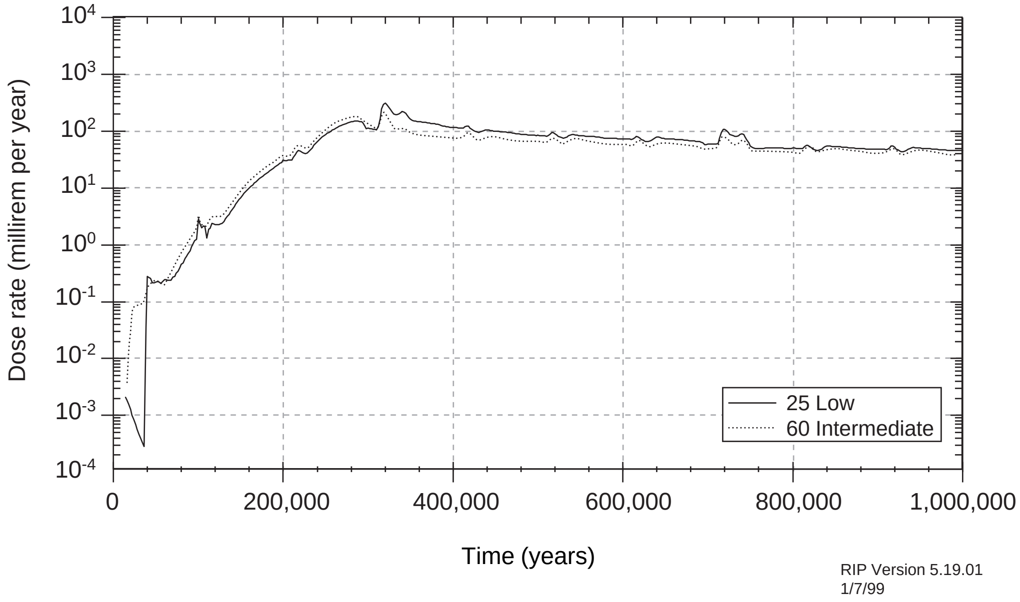


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Figure I-43. Comparison of low and intermediate thermal load scenarios total radiological dose histories for the Proposed Action inventory 20 kilometers (12 miles) from the repository.

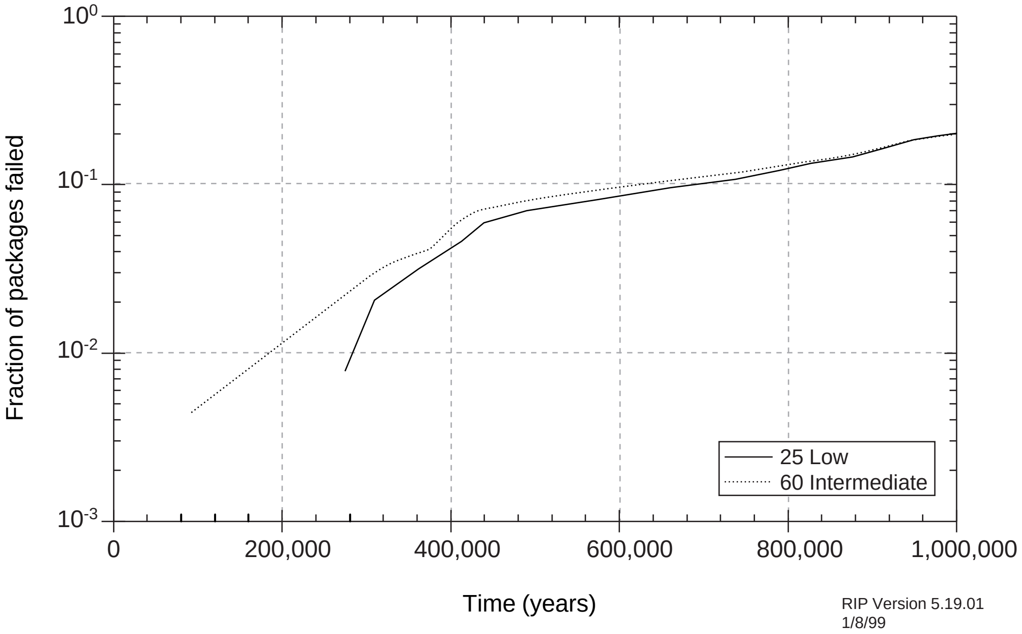

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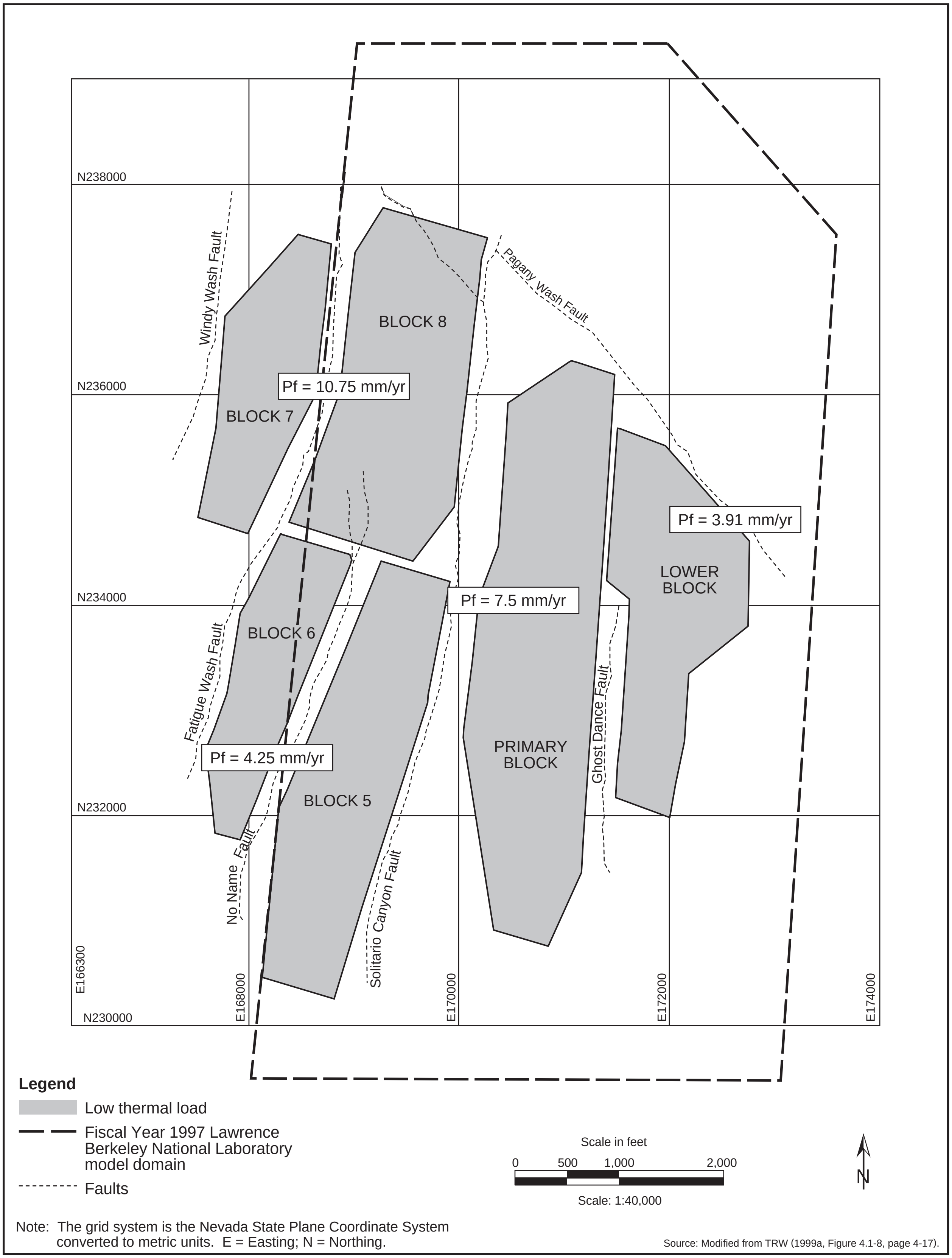
Figure I-44. Waste package failure curves for low and intermediate thermal load scenarios.



Note: The grid system is the Nevada State Plane Coordinate System converted to metric units. E = Easting; N = Northing.

Source: Modified from TRW (1999a, Figure 4.1-8, page 4-17).

Figure I-45. Average percolation flux for repository blocks.

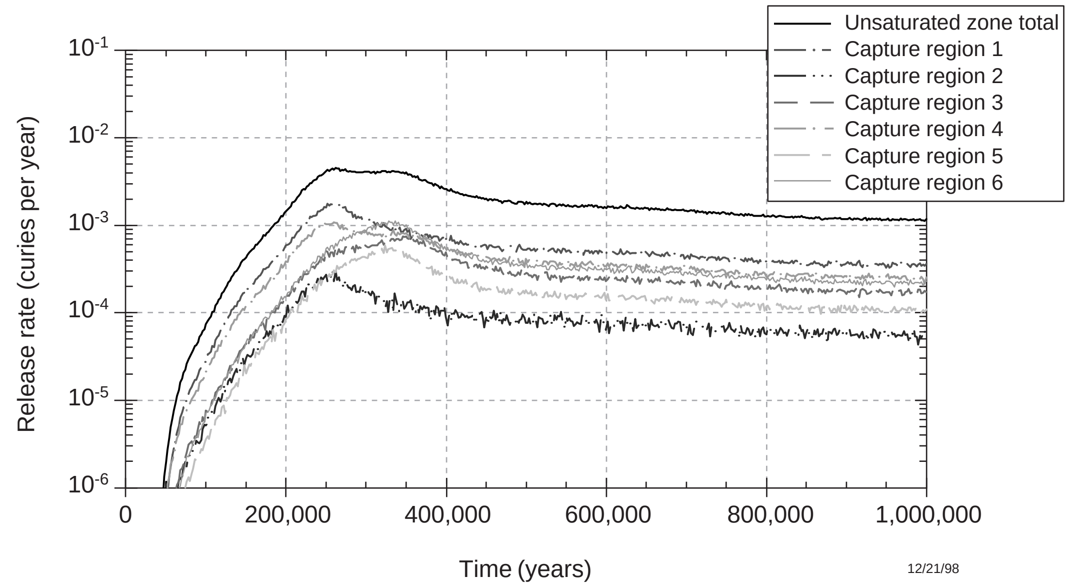


Figure I-46. Neptunium-237 release rate at the water table for fixed long-term average climate for low thermal load scenario during the first 1 million years following repository closure.

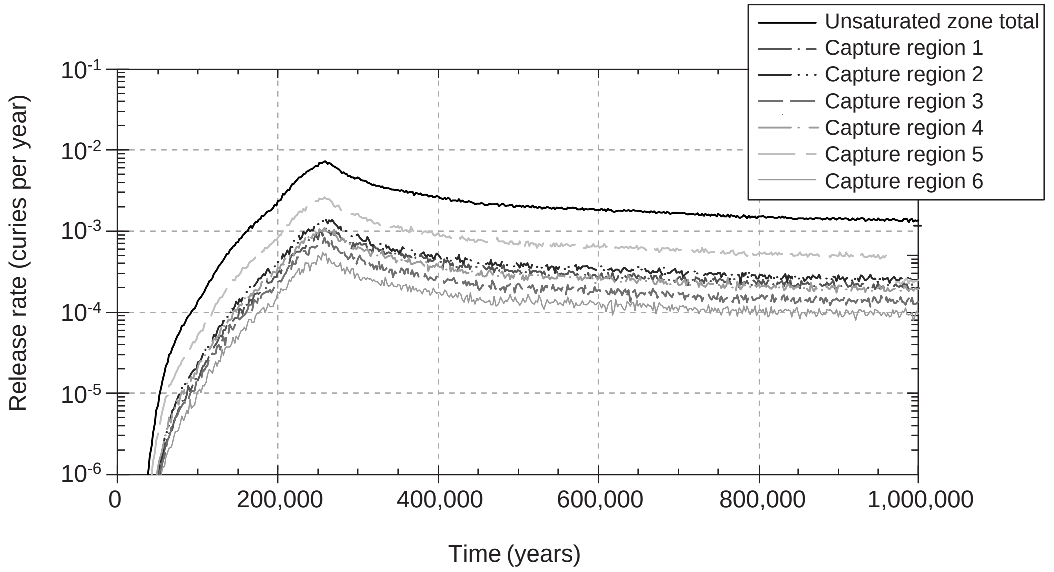


Figure I-47. Neptunium-237 release rate at the water table for fixed long-term average climate for intermediate thermal load scenario during the first 1 million years following repository closure.

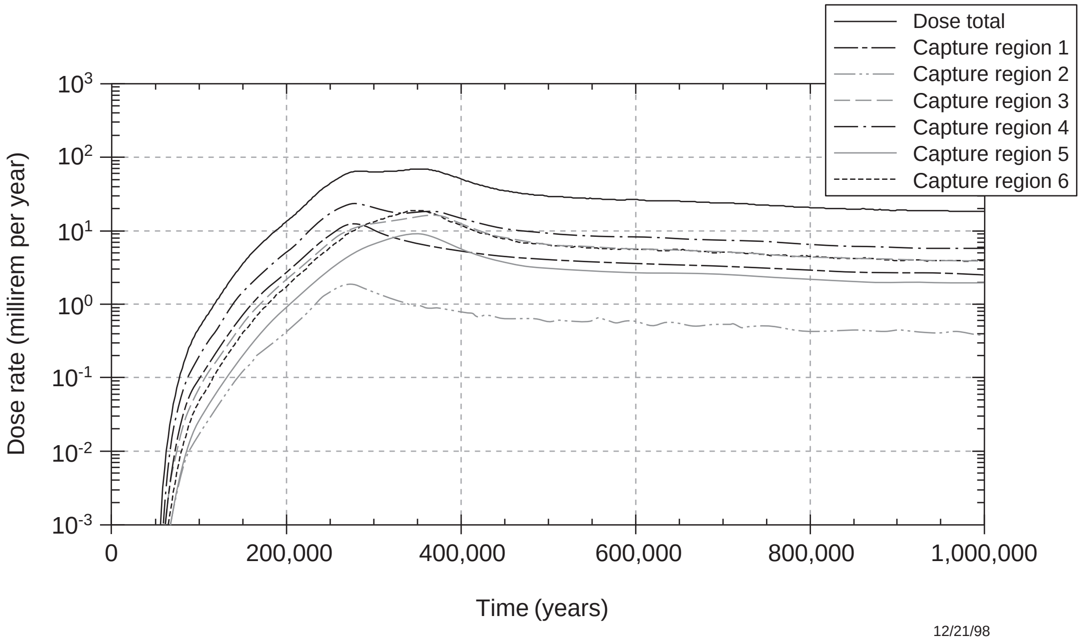


Figure I-48. Neptunium-237 release rate at the end of the saturated zone for fixed long-term average climate for low thermal load scenario during the first 1 million years following repository closure.

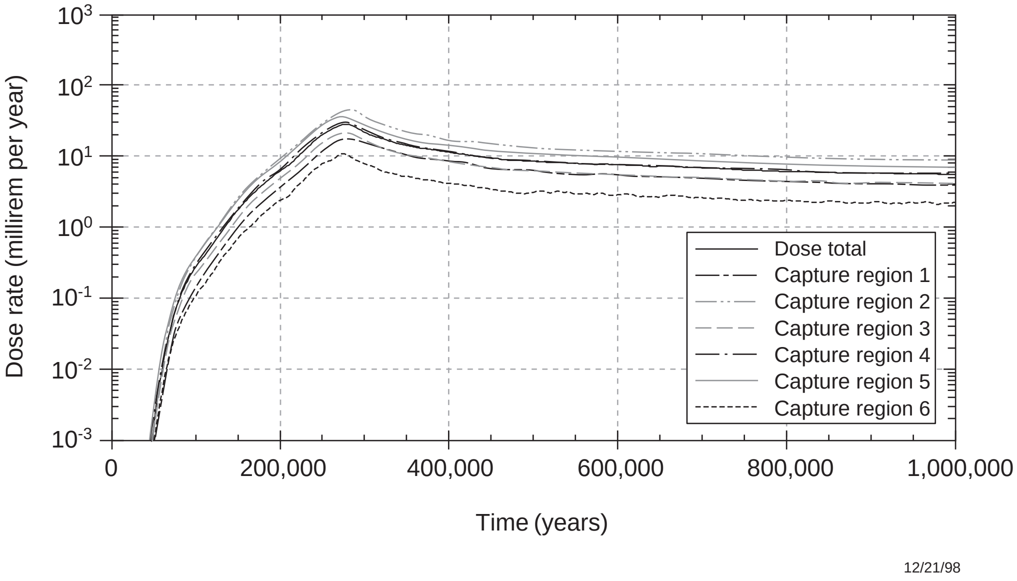


Figure I-49. Neptunium-237 release rate at the end of the saturated zone for fixed long-term average climate for intermediate thermal load scenario during the first 1 million years following repository closure.

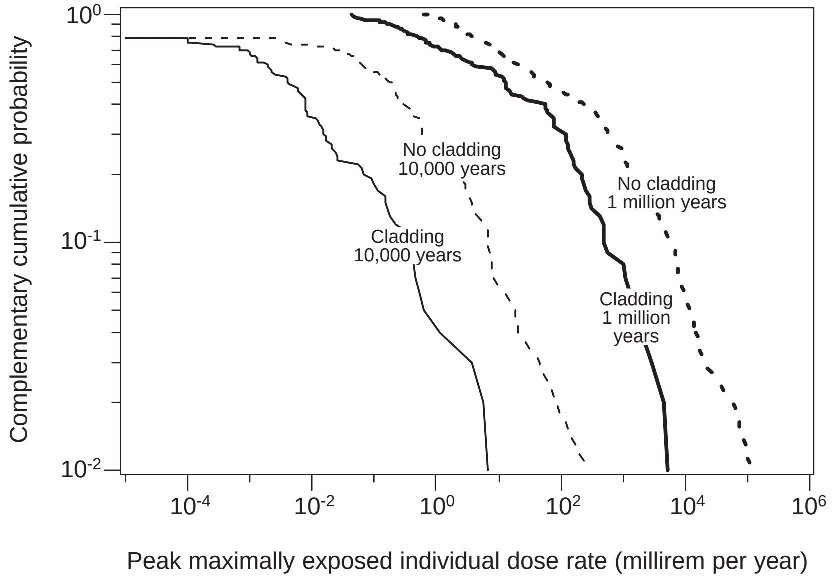
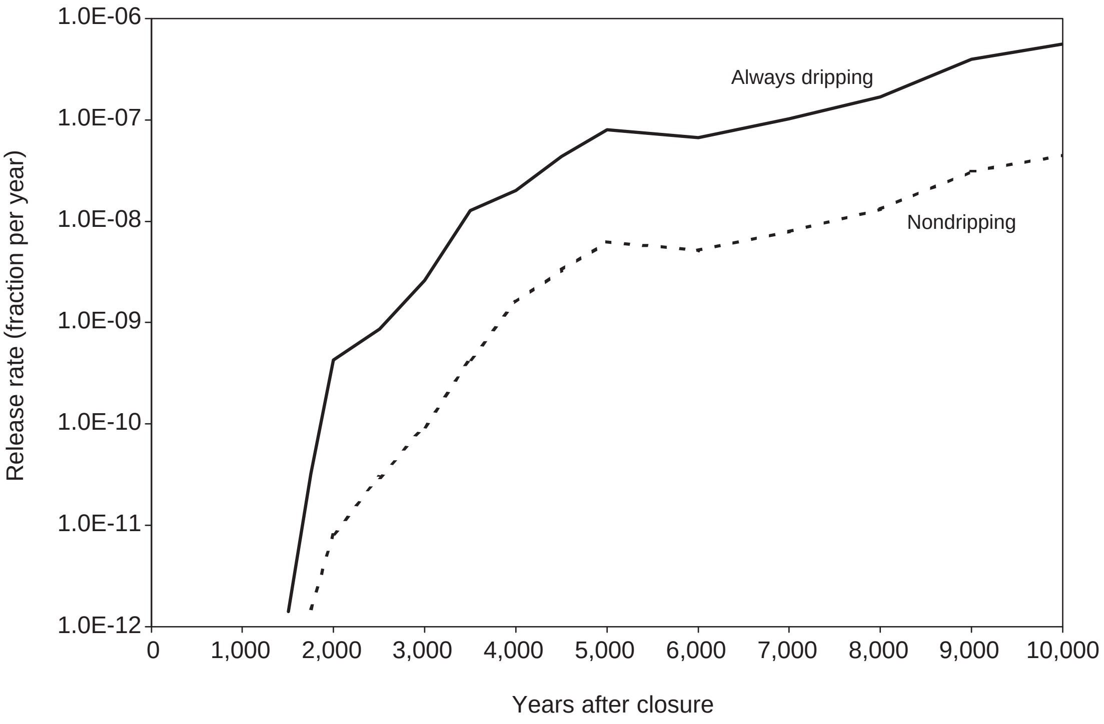
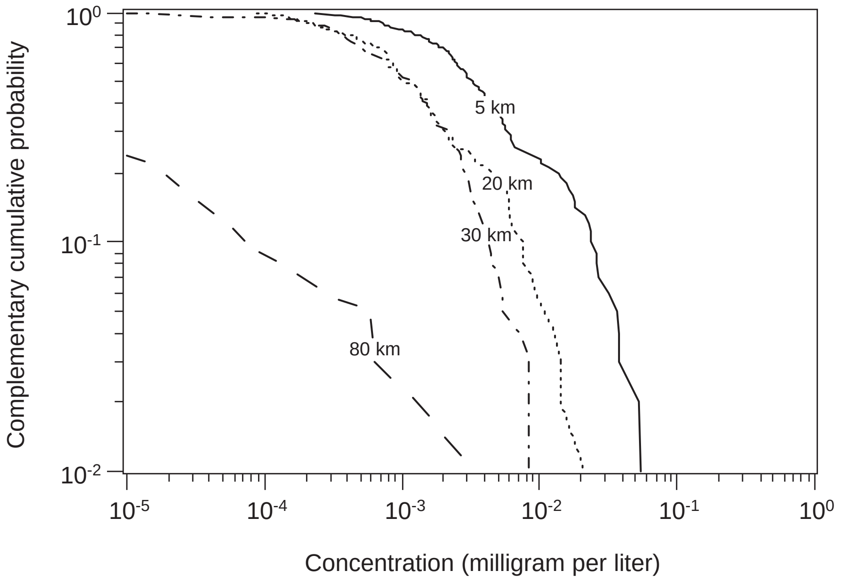


Figure I-50. Complementary cumulative distribution function of radiological doses with and without cladding for a maximally exposed individual at 20 kilometers (12 miles) under the Proposed Action 10,000 and 1 million years after repository closure.



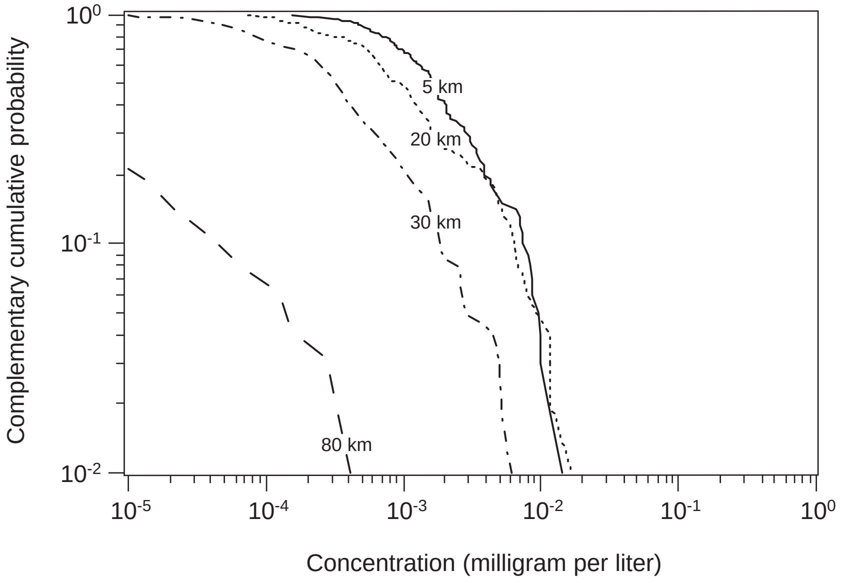
Source For WAPDEG modeling results: Mon (1999, all).

Figure I-51. Average fractional release rate of corrosion-resistant material (Alloy-22) for continually dripping and nondripping conditions computed from WAPDEG modeling results for 400 simulated waste packages.



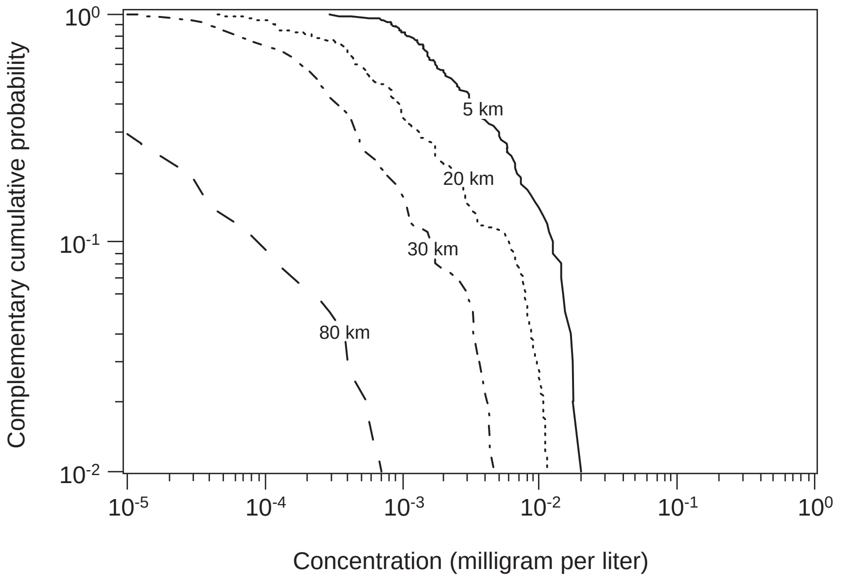
km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-52. Complementary cumulative distribution function of mean peak groundwater concentrations of chromium during 10,000 years following closure under high thermal load scenario with Proposed Action inventory.



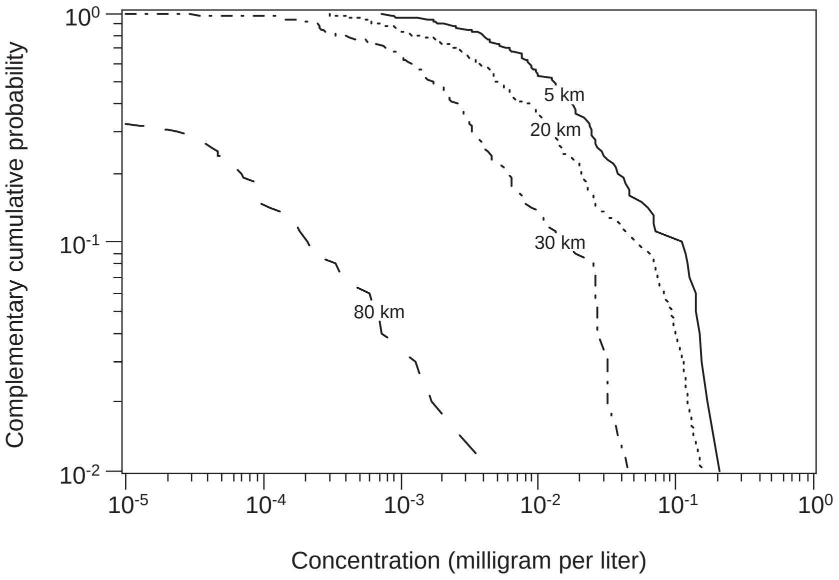
km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-53. Complementary cumulative distribution function of mean peak groundwater concentrations of chromium during 10,000 years following closure under intermediate thermal load scenario with Proposed Action inventory.



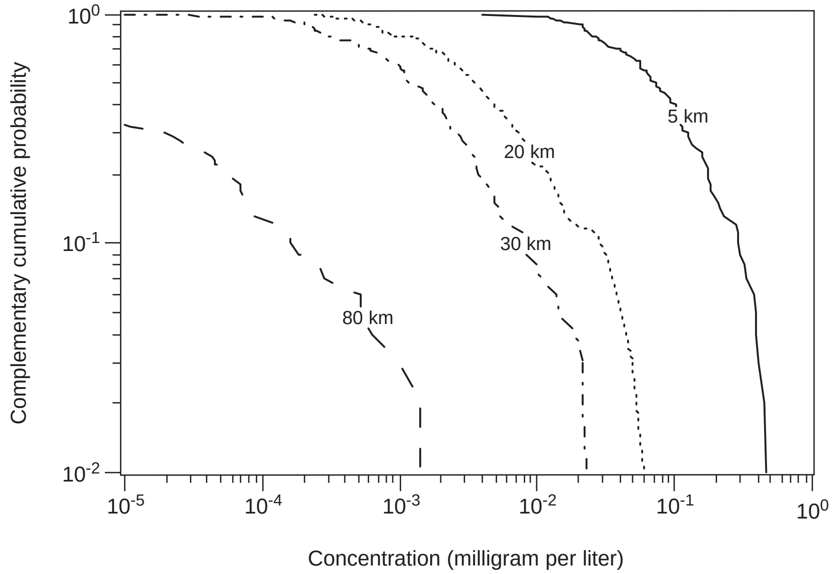
km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-54. Complementary cumulative distribution function of mean peak groundwater concentration of chromium during 10,000 years following closure under low thermal load scenario with Proposed Action inventory.



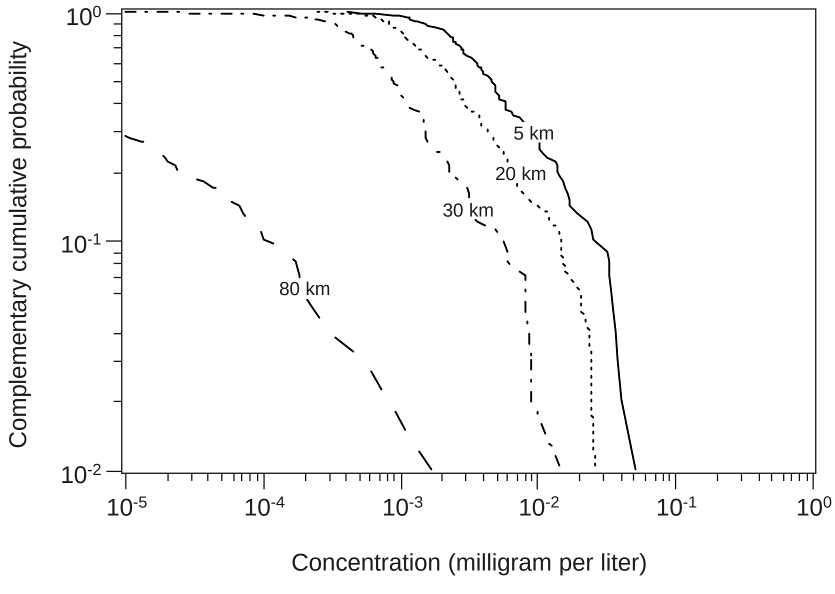
km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-55. Complementary cumulative distribution function of mean peak groundwater concentration of chromium during 10,000 years following closure under high thermal load scenario with Inventory Module 1.



km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-56. Complementary cumulative distribution function of mean peak groundwater concentration of chromium during 10,000 years following closure under intermediate thermal load scenario with Inventory Module 1.



km = kilometer. To convert kilometers to miles, multiply by0.62137.

Figure I-57. Complementary cumulative distribution function of mean peak groundwater concentration of chromium during 10,000 years following closure under low thermal load scenario with Inventory Module 1.

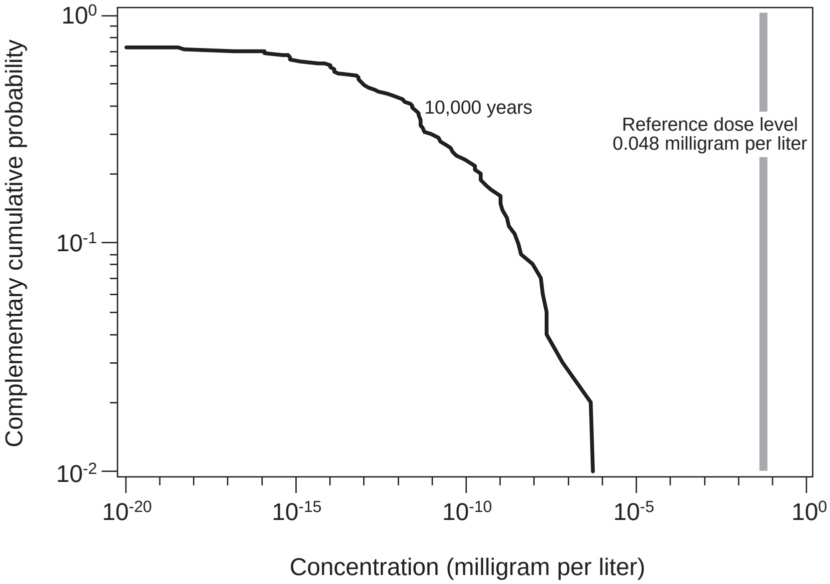


Figure I-58. Complementary cumulative distribution function of mean peak groundwater concentration of elemental uranium in water at 5 kilometers (3 miles) during 10,000 years following closure under high thermal load scenario with Proposed Action inventory.

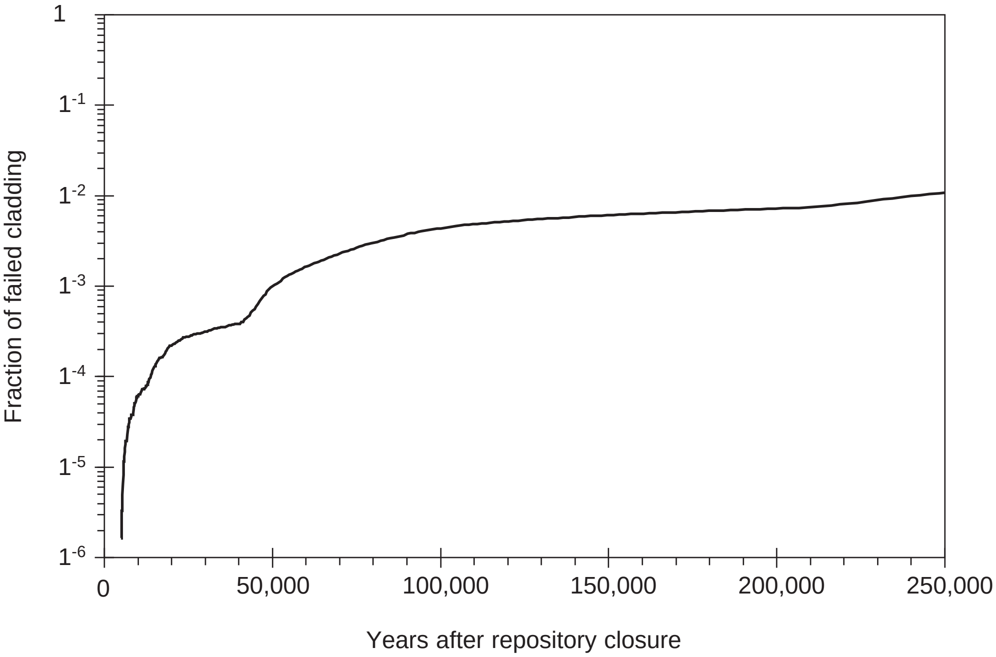


Figure I-59. Fraction (patch area) of cladding that would fail using a zirconium-alloy corrosion rate equal to 1.0 percent of that of Alloy-22.

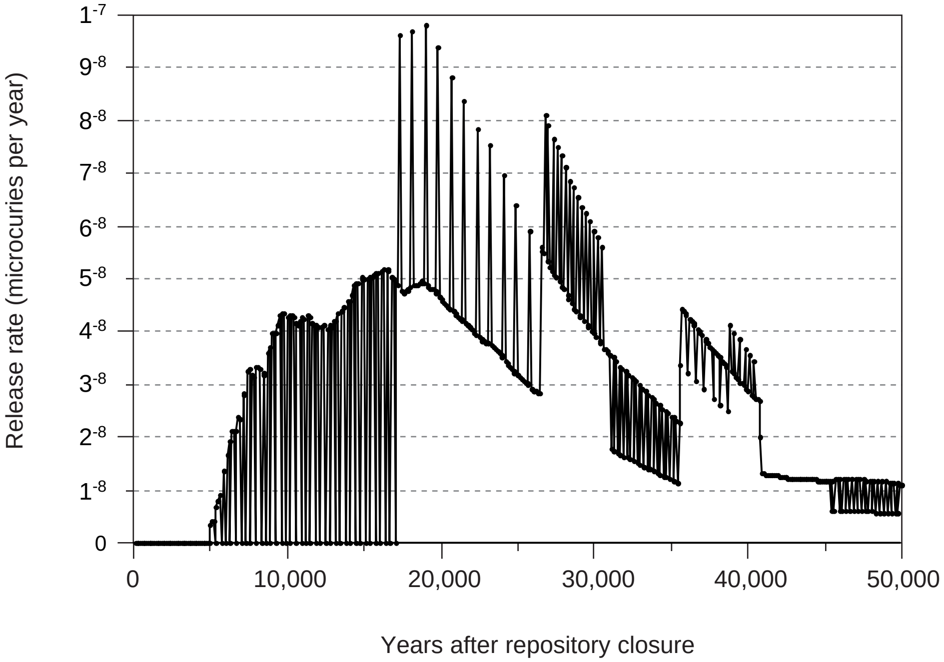


Figure I-60. Release rate of carbon-14 from the repository to the ground surface.

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Appendix J

Transportation

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APPENDIX J. TRANSPORTATION

This appendix provides additional information for readers who wish to gain a better understanding of the methods and analyses the U.S. Department of Energy (DOE) used to determine the human health impacts of transportation for the Proposed Action and Inventory Modules 1 and 2 discussed in this environmental impact statement (EIS). The materials included in Module 1 are the 70,000 metric tons of heavy metal (MTHM) for the Proposed Action and additional quantities of spent nuclear fuel and high-level radioactive waste that DOE could dispose of in the repository as part of a reasonably foreseeable future action. The materials included in Module 2 include the materials in Module 1 and other highly radioactive materials. Appendix A describes materials included in Modules 1 and 2. This appendix also provides the information DOE used to estimate traffic fatalities that would be associated with the long-term maintenance of storage facilities at 72 commercial sites and 5 DOE sites.

The appendix describes the key data and assumptions DOE used in the analyses and the analysis tools and methods the Department used to estimate impacts of loading operations at 72 commercial and 5 DOE sites; incident-free transportation by highway, rail and barge; intermodal transfer; and transportation accidents. The references listed at the end of this appendix contain additional information.

This appendix presents information on analyses of the impacts of national transportation and on analyses of the impacts that could occur in Nevada. Section J.1 presents information on the analysis of occupational and public health and safety impacts for the transportation of spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository. Section J.2 presents information on the analysis of rail and intermodal transportation options. Section J.3 presents information on the analysis of transportation in Nevada. Section J.4 presents a summary assessment of the Nevada transportation implementing alternatives.

J.1 Methods Used To Estimate Potential Impacts of National Transportation

This section provides information on the methods and data DOE used to estimate impacts from shipping spent nuclear fuel and high-level radioactive waste from 72 commercial sites and 5 DOE sites throughout the United States to the Yucca Mountain Repository.

MOSTLY LEGAL-WEIGHT TRUCK AND MOSTLY RAIL SCENARIOS

The Department does not anticipate that either the mostly legal-weight truck or the mostly rail scenario represents the actual mix of truck or rail transportation modes it would use. Nonetheless, DOE used these scenarios as a basis for the analysis of potential impacts to ensure the analysis addressed the range of possible transportation impacts. Thus, the estimated numbers of shipments for the mostly legal-weight truck and mostly rail scenarios represent only the two extremes in the possible mix of transportation modes. Therefore, the analysis provides estimates that cover the range of potential impacts to human health and safety and to the environment for the transportation modes DOE could use for the Proposed Action.

J.1.1 ANALYSIS APPROACH AND METHODS

Three types of impacts could occur to the public and workers from transportation activities associated with the Proposed Action. These would be a result of the transportation of spent nuclear fuel and high-level radioactive waste and of the personnel, equipment, materials, and supplies needed to construct, operate and monitor, and close the proposed Yucca Mountain Repository. The first type, radiological impacts, would be measured by radiological dose to populations and individuals and the resulting estimated number of latent cancer fatalities that would be caused by radiation from shipments of spent nuclear fuel and high-level radioactive waste from the 77 sites under normal and accident transport conditions. The second and third types would be nonradiological impacts—fatalities caused by vehicle emissions and fatalities caused by vehicle accidents. The analysis also estimated impacts due to the characteristics of hazardous cargoes from accidents during the transportation of nonradioactive hazardous materials to support repository construction, operation and monitoring, and closure. For perspective, about 10 fatalities resulting from hazardous material occur each year during the transportation of more than 300 million shipments of hazardous materials in the United States (DOT 1998a, Table 1). Therefore, DOE expects that the risks from exposure to hazardous materials that could be released during shipments to and from the repository sites would be very small (see Section J.1.4.2.4). The analysis evaluated the impacts of traffic accidents and vehicle emissions arising from these shipments.

The analysis used a step-wise process to estimate impacts to the public and workers. The process used the best available information from various sources and computer programs and associated data to accomplish the steps. Figures J-1 and J-2 show the steps followed in using data and computer programs. DOE has determined that the computer programs identified in the figure are suitable, and provide results in the appropriate measures, for the analysis of impacts performed for this EIS.

The CALVIN computer program (TRW 1998, all) is used to estimate the numbers of shipments of spent nuclear fuel from commercial sites. This program uses information on spent nuclear fuel stored at each site and an assumed scenario for picking up the spent fuel from each site. The program also uses information on the capacity of shipping casks that could be used.

The HIGHWAY computer program (Johnson et al. 1993a, all) is a routing tool used to select existing highway routes that would satisfy Department of Transportation route selection regulations and that DOE could use to ship spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository.

The INTERLINE computer program (Johnson et al. 1993b, all) is a routing tool used to select existing rail routes that railroads would be likely to use to ship spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository.

The RADTRAN4 computer program (Neuhauser and Kanipe 1992, all) is used to estimate the radiological dose risks to populations and transportation workers of incident-free transportation and to the general population from accident scenarios. For the analysis of incident-free transportation risks, the code uses scenarios for persons who would share transportation routes with shipments—called *onlink populations*, persons who live along the route of travel—*offlink populations*, and persons exposed at stops. For accident risks, the code evaluates the range of possible accident scenarios from high probability and low consequence to low probability and high consequence.

The RISKIND computer program (Yuan et al. 1995, all) is used to estimate radiological doses to maximally exposed individuals for incident-free transportation and to populations and maximally exposed individuals for accident scenarios. To estimate incident-free doses to maximally exposed individuals, RISKIND uses geometry to calculate the dose rate at specified locations that would arise from a source of radiation. RISKIND is also used to calculate the radiation dose to a population and hypothetical maximally exposed individuals from releases of radioactive materials that are postulated to occur in maximum reasonably foreseeable accident scenarios.

The following sections describe these programs in detail.

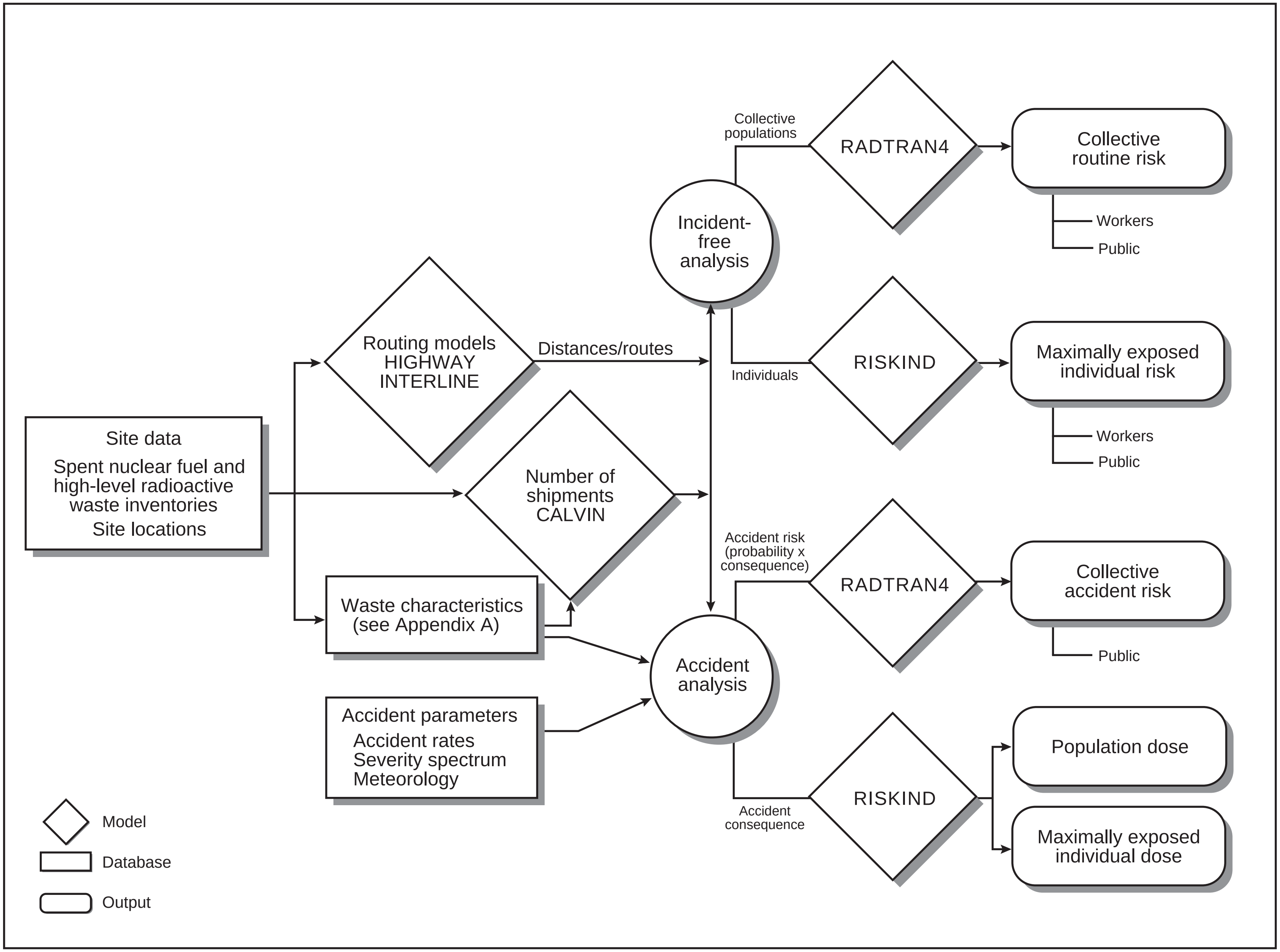


Figure J-1. Methods and approach for analyzing transportation radiological health risk.

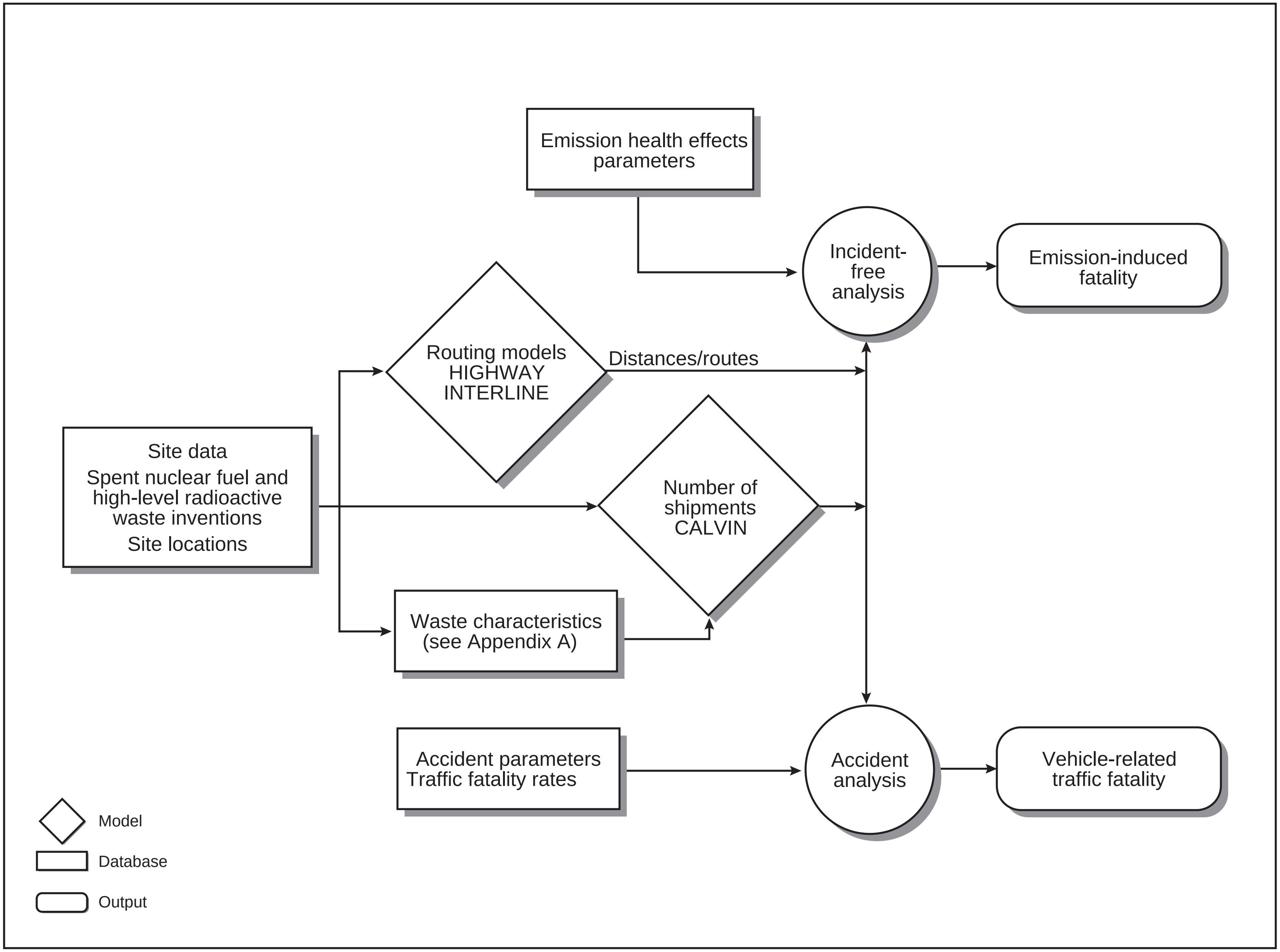


Figure J-2. Methods and approach for analyzing transportation nonradiological health risk.

DOSE RISK

Dose risk is a measure of radiological impacts to populations – public or workers – from the potential for exposure to radioactive materials. Thus, a potential of 1 chance in 1,000 of a population receiving a collective dose of 1 rem (1 person-rem) from an accident would result in a dose risk of 0.001 person-rem (0.001 is the product of 1 person-rem and the quotient of 1 over 1,000). Dose risk is often expressed in units of latent cancer fatalities.

The use of dose risk to measure radiological impacts allows a comparison of alternatives with differing characteristics in terms of radiological consequences that could result and the likelihood that the consequences would actually occur.

J.1.1.1 CALVIN

The Civilian Radioactive Waste Management System Analysis and Logistics Visually Interactive (CALVIN) model (TRW 1998, all) was developed to be a planning tool to estimate the logistic and cost impacts of various operational assumptions for accepting radioactive wastes. CALVIN is used in transportation modeling to determine the number of shipments of commercial spent nuclear fuel from each reactor site. The parameters that the CALVIN model used to determine commercial spent nuclear fuel movement include the shipping cask specifications including heat limits, $k_{infinity}$ (measure of criticality) limits for the contents of the casks, capacity (assemblies or canisters/cask), burnup/enrichment curves, and cooling time for the fuel being shipped.

The source data used by CALVIN for commercial spent nuclear fuel projections include the RW-859 historic data collected by the Energy Information Administration, and the corresponding projection produced based on current industry trends for commercial fuel (see Appendix A). This EIS used CALVIN to estimate commercial spent nuclear fuel shipment numbers based on the cask capacity (see Section J.1.2) and the shipping cask handling capabilities at each site. For the mostly rail national transportation scenario, CALVIN assumed that shipments would use the largest cask a site would be capable of handling. In some cases, CALVIN estimated that the characteristics of the spent nuclear fuel that would be picked up at a site would exceed the capabilities of the largest cask if the cask was fully loaded. In such cases, to provide a realistic estimate of the number of shipments that would be made, the program derated (reduced the capacity of) the casks. The reduction in capacity was sufficient to accommodate the characteristics of the spent nuclear fuel the program estimated for pickup at the site.

J.1.1.2 HIGHWAY

The HIGHWAY computer program (Johnson et al. 1993a, all) was used to select highway routes for the analysis of impacts presented in this EIS. HIGHWAY calculates routes by minimizing the total impedance between the origin and the destination. The impedance is determined by distance and driving time along a particular segment of highway. Using Rand McNally route data and rules that apply to carriers of Highway Route-Controlled Quantities of Radioactive Materials (49 CFR 397.101), HIGHWAY selected highway routes for legal-weight truck shipments from each commercial and DOE site to the Yucca Mountain site. In addition, DOE used this program to estimate the populations within 800 meters (0.5 mile) of the routes it selected. These population densities were used in calculating incident-free radiological risks to the public along the routes.

One of the features of the HIGHWAY model is its ability to estimate routes for the transport of Highway Route-Controlled Quantities of Radioactive Materials. The Department of Transportation has established a set of routing regulations for the transport of these materials (49 CFR 397.101). Routes following these regulations are frequently called HM-164 routes. The regulations require the transportation of these shipments on preferred highways, which include:

- Interstate highways
- An Interstate System bypass or beltway around a city
- State-designated preferred routes

State routing agencies can designate preferred routes as an alternative to, or in addition to, one or more Interstate highways. In making this determination, the state must consider the safety of the alternative preferred route in relation to the Interstate route it is replacing, and must register all such designated preferred routes with the Department of Transportation.

Frequently, the origins and destinations of Highway Route-Controlled Quantities of Radioactive Materials are not near Interstate highways. In general, the Department of Transportation routing regulations require the use of the shortest route between the pickup location to the nearest preferred route entry location and the shortest route to the destination from the nearest preferred route exit location. In general, HM-164 routes tend to be somewhat longer than other routes; however, the increased safety associated with Interstate highway travel is the primary purpose of the routing regulations.

Because many factors can influence the time in transit over a preferred route, a carrier of Highway Route-Controlled Quantities of Radioactive Materials must select a route for each shipment. Seasonal weather conditions, highway repair or construction, highways that are closed because of natural events (for example, a landslide in North Carolina closed Interstate 40 near the border with Tennessee from June until November 1997), and other events (for example, the 1996 Olympic Games in Atlanta, Georgia) are all factors that must be considered in selecting preferred route segments to reduce time in transit. For this analysis, the highway routes were selected by the HIGHWAY program using an assumption of normal travel and without consideration for factors such as seasons of the year or road construction delays. Although these shipments could use other routes, DOE considers the impacts determined in the analyses to be representative of other possible routings that would also comply with Department of Transportation regulations. Specific route mileages for truck transportation are presented in Section J.1.2.1.1.

In selecting existing routes for use in the analysis, the HIGHWAY program determined the length of travel in each type of population zone—rural, suburban, and urban. The program characterized rural, suburban, and urban population areas according to the following breakdown: rural population densities range from 0 to 54 persons per square kilometer (0 to 140 persons per square mile); the suburban range is 55 to 1,300 persons per square kilometer (140 to 3,300 persons per square mile); and urban is all population densities greater than 1,300 persons per square kilometer (3,300 persons per square mile). The population densities along a route used by the HIGHWAY program are derived from 1990 data from the Bureau of the Census.

J.1.1.3 INTERLINE

Shipments of radioactive materials by rail are not subject to route restrictions imposed by regulations. For general freight rail service, DOE anticipates that railroads would route shipments of spent nuclear fuel and high-level radioactive waste to provide expeditious travel and the minimum practical number of interchanges between railroads. The selection of a route determines the potentially exposed population along the route as well as the expected frequency of transportation-related accidents. The analysis used the INTERLINE computer program (Johnson et al. 1993b, all) to project the railroad routes that DOE would use to ship spent nuclear fuel and high-level radioactive waste from the sites to the Yucca Mountain site. Specific routes were projected for each originating generator with the exception of 9 that do not have capability to handle or load a rail transportation cask (see Section J.1.2.1.1, Table J-6).

INTERLINE computes rail routes based on rules that simulate historic routing practices of U.S. railroads. The INTERLINE data base consists of 94 separate subnetworks and represents various competing rail companies in the United States. The data base, which was originally based on data from the Federal Railroad Administration and reflected the U.S. railroad system in 1974, has been expanded and modified extensively over the past two decades. The program is updated periodically to reflect current track conditions and has been benchmarked against reported mileages and observations of commercial rail firms. The program also provides an estimate of the population within 800 meters (0.5 mile) of the routes it selected. This population estimate was used to calculate incident-free radiological risk to the public along the routes selected for analysis.

In general, rail routes are calculated by minimizing the value of a factor called *impedance* between the origin and the destination. The impedance is determined by considering trip distance along a route, the mainline classification of the rail lines that would be used, and the number of interchanges that would occur between different railroad companies involved. In general, impedance determined by the INTERLINE program:

- Decreases as the distance traveled decreases
- Is reduced by use of mainline track that has the highest traffic volume (see below)
- Is reduced for shipments that involve the fewest number of railroad companies

Thus, routes that are the most direct, that use high-traffic volume mainline track, and that involve only one railroad company would have the lowest impedance. The most important of these characteristics from a routing standpoint is the *mainline classification*, which is the measure of traffic volume on a particular link. The mainline classifications used in the INTERLINE routing model are as follows:

- A – mainline – more than 20 million gross ton miles per year
- B – mainline – between 5 and 20 million gross ton miles per year
- A – branch line – between 1 and 5 million gross ton miles per year
- B – branch line – less than 1 million gross ton miles per year

The INTERLINE routing algorithm is designed to route a shipment preferentially on the rail lines having the highest traffic volume. Frequently traveled routes are preferred because they are generally well maintained because the railroad depends on these lines for a major portion of its revenue. In addition, routing along the high-traffic lines usually replicates railroad operational practices.

The population densities along a route were derived from 1990 data from the Bureau of the Census, as described above for the HIGHWAY computer program.

DOE anticipates that routing of rail shipments in dedicated (special) train service, if used, would be similar to routing of general freight shipments for the same origin and destination pairs. However, because cask cars would not be switched between trains at classification yards, dedicated train service would be likely to result in less time in transit.

J.1.1.4 RADTRAN4

The RADTRAN4 computer program (Neuhauser and Kanipe 1992, all) was used for the routine and accident cargo-related risk assessment to estimate the radiological impacts to collective populations. RADTRAN4 was developed by Sandia National Laboratories to calculate population risks associated with the transportation of radioactive materials by a variety of modes, including truck, rail, air, ship, and barge. The code has been used extensively for transportation risk assessment since it was issued in the late 1970s and has been reviewed and updated periodically. In 1995, a validation of the RADTRAN4 code demonstrated that it yielded acceptable results (Maheras and Pippen 1995, page iii). In the context of the validation analysis, *acceptable results* means that the difference between the estimates generated by the RADTRAN4 code and hand calculations were small, that is, less than 5 percent (Maheras and Pippen 1995, page 3-1).

The RADTRAN4 calculations for routine (or incident-free) dose are based on expressing the dose rate as a function of distance from a point source. Associated with the calculation of routine doses for each exposed population group are parameters such as the radiation field strength, the source-receptor distance, the duration of the exposure, vehicular speed, stopping time, traffic density, and route characteristics such as population density. In calculating population doses from incident-free transportation, the RADTRAN4 program used population density data provided by the HIGHWAY and INTERLINE computer programs. These data are based on the 1990 Census.

In addition to routine doses, RADTRAN4 was used to estimate dose risk from a spectrum of accident scenarios. The spectrum of accident scenarios encompass the range of possible accidents, including low-probability accident scenarios that have high consequences, and high-probability accident scenarios that have low consequences (fender benders). The RADTRAN4 calculation of collective accident risk for populations along routes employed models that quantified the range of potential accident severities and the responses of the shipping casks to the accident scenarios. The spectrum of accident severity was divided into categories. Each category of severity received a conditional probability of occurrence; that is, the probability that an accident will be of a particular severity if an accident occurs — the more severe the accident, the more remote the chance of such an accident. A release fraction, which is the fraction of the material in a shipping cask that could be released in an accident, is assigned to each accident scenario severity category on the basis of the physical and chemical form of the material being transported. The model also takes into account the mode of transportation, the state-specific accident rates, and population densities for rural suburban, and urban population zones through which shipments would pass to estimate accident risks for this analysis. The RADTRAN4 program used actual population densities within 800 meters (0.5 mile) of transportation routes based on 1990 census data as the basis for estimating populations within 80 kilometers (50 miles).

For accident scenarios involving the release of radioactive material, RADTRAN4 assumes that the material is dispersed in the environment as described by a Gaussian dispersion model. The dispersion analysis assumes that meteorological conditions are national averages for wind speed and atmospheric stability. For the risk assessment, the analysis used these meteorological conditions and assumed an instantaneous ground-level release and a small diameter source cloud (Neuhauser and Kanipe 1993, page 5-6). The calculation of the collective population dose following the release and the dispersal of radioactive material includes the following exposure pathways:

- External exposure to the passing radioactive cloud
- External exposure to contaminated ground
- Internal exposure from inhalation of airborne contaminants
- Internal exposure from ingestion of contaminated food

For the ingestion pathway, the analysis used state-specific food transfer factors (TRW 1999a, page 35), which relate the amount of radioactive material ingested to the amount deposited on the ground, as input to the RADTRAN4 code. Radiation doses from the ingestion or inhalation of radionuclides were calculated by using standard dose conversion factors from Federal Guidance Reports No. 11 and 12 (TRW 1999a, page 36).

J.1.1.5 RISKIND

The RISKIND computer program (Yuan et al. 1995, all) was used as a complement to the RADTRAN4 calculations to estimate scenario-specific doses to maximally exposed individuals for both routine operations and accident conditions and to estimate population impacts for the assessment of accident scenario consequences. The RISKIND code was originally developed for the DOE Office of Civilian Radioactive Waste Management specifically to analyze radiological consequences to individuals and population subgroups from the transportation of spent nuclear fuel and is used now to analyze the transport of other radioactive materials, as well as spent nuclear fuel.

The RISKIND external dose model considers direct external exposure and exposure from radiation scattered from the ground and air. RISKIND was used to calculate the dose as a function of distance from a shipment on the basis of the dimensions of the shipment (millirem per hour for stationary exposures and millirem per event for moving shipments). The code approximates the shipment as a cylindrical volume source, and the calculated dose includes contributions from secondary radiation scatter from buildup (scattering by material contents), cloudshine (scattering by air), and groundshine (scattering by the ground). Credit for potential shielding between the shipment and the receptor was not considered.

The RISKIND code was also used to provide a scenario-specific assessment of radiological consequences of severe transportation-related accidents. Whereas the RADTRAN4 risk assessment considers the entire range of accident severities and their related probabilities, the RISKIND consequence assessment focuses on accident scenarios that result in the largest releases of radioactive material to the environment. The consequence assessment was intended to provide an estimate of the potential impacts posed by a severe, but highly unlikely, transportation-related accident scenario.

The dose to each maximally exposed individual considered was calculated with RISKIND for an exposure scenario defined by a given distance, duration, and frequency of exposure specific to that receptor. The distances and durations were similar to those given in previous transportation risk assessments. The scenarios were not meant to be exhaustive but were selected to provide a range of potential exposure situations.

J.1.2 NUMBER AND ROUTING OF SHIPMENTS

This section discusses the number of shipments and routing information used to analyze potential impacts that would result from preparation for and conduct of transportation operations to ship spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site. Table J-1 summarizes the estimated numbers of shipments for the various inventory and national shipment scenario combinations.

J.1.2.1 Number of Shipments

DOE used two analysis scenarios—mostly legal-weight truck and mostly train (rail)—as bases for estimating the number of shipments of spent nuclear fuel and high-level radioactive waste from 72 commercial and 5 DOE sites. The number of shipments for the scenarios was used in analyzing transportation impacts for the Proposed Action and Inventory Modules 1 and 2. DOE selected the scenarios because, more than 10 years before the projected start of operations at the repository, it cannot accurately predict the actual mix of rail and legal-weight truck transportation that would occur from the 77 sites to the repository. Therefore, the selected scenarios enable the analysis to bound (or bracket) the ranges of legal-weight truck and rail shipments that could occur.

Table J-1. Summary of estimated numbers of shipments for the various inventory and national transportation analysis scenario combinations.

	Mostly truck		Mostly rail	
	Truck	Rail	Truck	Rail
Proposed Action				
Commercial spent nuclear fuel	37,738	0	2,601	8,386
High-level radioactive waste	8,315	0	0	1,663
Spent nuclear fuel	3,470	300	0	766
Greater-Than-Class-C waste	0	0	0	0
Special-Performance-Assessment-Required waste	0	0	0	0
Proposed Action totals	**49,523**	**300**	**2,601**	**10,815**
Module 1[a]				
Commercial spent nuclear fuel	66,850	0	3,701	13,906
High-level radioactive waste	22,280	0	0	4,456
Spent nuclear fuel	3,721	300	0	797
Greater-Than-Class-C waste	0	0	0	0
Special-Performance-Assessment-Required waste	0	0	0	0
Module 1 totals	**92,851**	**300**	**3,701**	**19,159**
Module 2[a]				
Commercial spent nuclear fuel	66,850	0	3,701	13,906
High-level radioactive waste	22,280	0	0	4,456
Spent nuclear fuel	3,721	300	0	797
Greater-Than-Class-C waste	1,096	0	0	282
Special-Performance-Assessment-Required waste	2,010	0	0	404
Module 2 totals	**95,957**	**300**	**3,701**	**19,845**

a. The number of shipments for Module 1 includes all shipments of spent nuclear fuel and high-level radioactive waste included in the Proposed Action and shipments of additional spent nuclear fuel and high-level radioactive waste as described in Appendix A. The number of shipments for Module 2 includes all the shipments in Module 1 and additional shipments of highly radioactive materials described in Appendix A.

The analysis estimated the number of shipments from commercial sites where spent nuclear fuel would be loaded and shipped and from DOE sites where spent nuclear fuel, naval spent nuclear fuel, and high-level radioactive waste would be loaded and shipped.

For the mostly legal-weight truck scenario, with one exception, shipments were assumed to use legal-weight trucks. Overweight, overdimensional trucks weighing between about 36,300 and 52,300 kilograms (80,000 and 115,000 pounds) but otherwise similar to legal-weight trucks could be used for some spent nuclear fuel and high-level radioactive waste (for example, spent nuclear fuel from the South Texas reactors). The exception that gives the scenario its name—mostly legal-weight truck—was for shipments of naval spent nuclear fuel. Under this scenario, naval spent nuclear fuel would have to be shipped by rail because of the size and weight of the shipping container (cask) that would be used.

For the mostly rail scenario, the analysis assumed that all sites would ship by rail, with the exception of those with physical limitations that would make rail shipment impractical. The exception would be for shipments by legal-weight trucks from 9 commercial sites that do not have the capability to load rail casks. The analysis assumed that 19 commercial sites that do not have direct rail service but that could handle large casks would ship by barge or heavy-haul truck to nearby railheads with intermodal capability.

For commercial spent nuclear fuel, the CALVIN code was used to compute the number of shipments. The number of shipments of DOE spent nuclear fuel and high-level radioactive waste was estimated based on the data in Appendix A and information provided by the DOE sites. The numbers of shipments were estimated based on the characteristics of the materials shipped, mode interface capability (for example, the lift capacity of the cask-handling crane) of each shipping facility, and the modal-mix case analyzed. Table J-2 summarizes the basis for the national and Nevada transportation impact analysis.

Table J-2. Analysis basis—national and Nevada transportation scenarios.[a,b]

Material	Mostly legal-weight truck scenario national and Nevada	National mostly rail scenario	
		Nevada rail scenario	Nevada heavy-haul truck scenario
Casks			
Commercial SNF	Truck casks – about 1.8 MTHM per cask	Rail casks – 6 to 12 MTHM per cask for shipments from 63 sites	Rail casks – 6 to 12 MTHM per cask for shipments from 63 sites
		Truck casks – about 1.8 MTHM per cask for shipments from 9 sites	Truck casks – about 1.8 MTHM per cask for shipments from 9 sites
DOE HLW and DOE SNF, except naval SNF	Truck casks – 1 SNF or HLW canister per cask	Rail casks – four to nine SNF or HLW canisters per cask	Rail casks – four to nine SNF or HLW canisters per cask
Naval SNF	Disposal canisters in large rail casks for shipment from INEEL	Disposable canisters in large rail casks for shipments from INEEL	Disposable canisters in large rail casks for shipments from INEEL
Transportation modes			
Commercial SNF	Legal-weight trucks	Direct rail from 44 sites served by railroads to repository	Rail from 44 sites served by railroads to intermodal transfer station in Nevada, then heavy-haul trucks to repository
		Heavy-haul trucks from 5 sites to railhead, then rail to repository	Heavy-haul trucks from 5 sites to railheads, then rail to intermodal transfer station in Nevada, then heavy-haul trucks to repository
		Heavy-haul trucks or barges[c] from 14 sites to railhead, then rail to repository	Heavy-haul trucks or barges from 14 sites to railheads, then rail to intermodal transfer station in Nevada, then heavy-haul trucks to repository[e]
		Legal-weight trucks from 9 sites to repository	Legal-weight trucks from 9 sites to repository
DOE HLW and DOE SNF, except naval SNF	Legal-weight trucks	Rail from DOE sites[d] to repository	Rail from DOE sites to intermodal transfer station in Nevada, then heavy-haul trucks to repository
Naval SNF	Rail from INEEL to intermodal transfer station in Nevada, then heavy-haul trucks to repository	Rail from INEEL to repository	Rail from INEEL to intermodal transfer station in Nevada, then heavy-haul trucks to repository

a. Abbreviations: SNF = spent nuclear fuel; MTHM = metric tons of heavy metal; HLW = high-level radioactive waste; INEEL = Idaho National Engineering and Environmental Laboratory.

b. G. E. Morris facility is included with the Dresden reactor facilities in the 72 commercial sites.

c. Fourteen of 19 commercial sites not served by a railroad are on or near a navigable waterway. Some of these 14 sites could ship by barge rather than by heavy-haul truck to a nearby railhead.

d. Hanford Site, Savannah River Site, Idaho National Engineering and Environmental Laboratory, West Valley Demonstration Project, and Ft. St. Vrain.

Detailed descriptions of spent nuclear fuel and high-level radioactive waste that would be shipped to the Yucca Mountain site are presented in Appendix A.

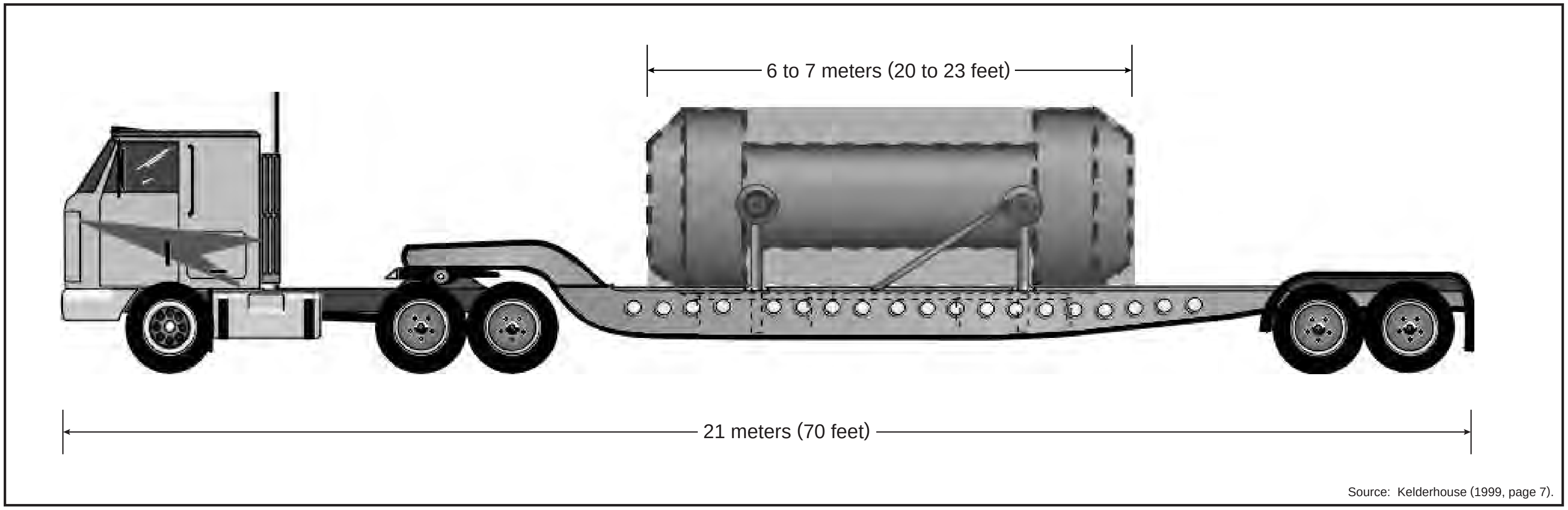
J.1.2.1.1 *Commercial Spent Nuclear Fuel*

For the analysis, the CALVIN model used 32 shipping cask configurations: 15 for legal-weight truck casks (Figure J-3) and 17 for rail casks (Figure J-4). Table J-3 lists the legal-weight truck and rail cask configurations used in the analysis and their capacities. The analysis assumed that all shipments would use one of the 32 configurations. If the characteristics of the spent nuclear fuel projected for shipment exceeded the capabilities of one of the casks, the model reduced the cask's capacity for the affected shipments. The reduction, which is sometimes referred to as cask derating, was needed to satisfy nuclear criticality, shielding, and thermal constraints. For shipments that DOE would make using specific casks, derating would be accomplished by partially filling the assigned casks in compliance with provisions of applicable Nuclear Regulatory Commission certificates of compliance. An example of derating is discussed in Section 5 of the GA-4 legal-weight truck shipping cask design report (General Atomics 1993, page 5.5-1). The analysis addresses transport of two high-burnup or short cooling time pressurized-water reactor assemblies rather than four design basis assemblies.

RAIL SHIPMENTS

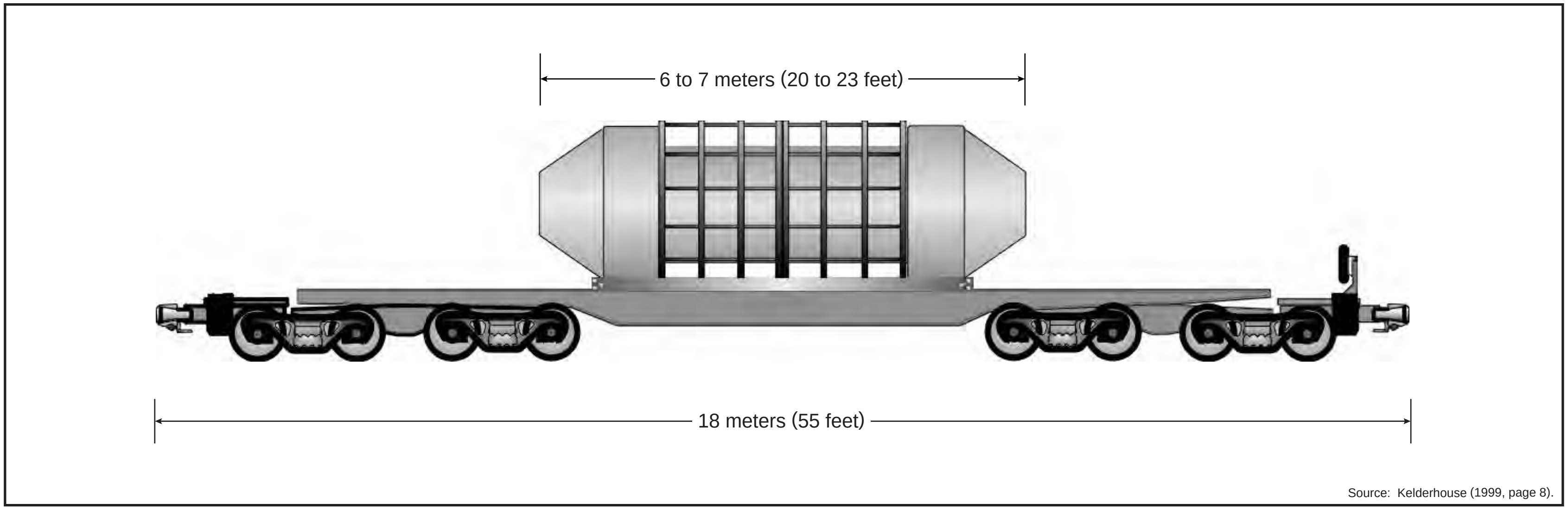
This appendix assumes that rail shipments of spent nuclear fuel would use large rail shipping casks, one per railcar. DOE anticipates that as many as five railcars with casks containing spent nuclear fuel or high-level radioactive waste would move together in individual trains with buffer cars and escort cars. For general freight service, a train would include other railcars with other materials. In dedicated (or special) service, trains would move only railcars containing spent nuclear fuel or high-level radioactive waste and the buffer and escort cars.

For the mostly rail scenario, 9 sites without sufficient crane capacity to lift a rail cask or without other factors such as sufficient floor loading capacity or ceiling height were assumed to ship by legal-weight truck. The 19 sites with sufficient crane capacity but without direct rail access were assumed to ship by heavy-haul truck to the nearest railhead. Of these 19 sites, 14 with access to navigable waterways were analyzed for shipping by barge to a railhead (see Section J.2.1). The number of rail shipments (direct or indirect) was estimated based on each site using the largest cask size feasible based on the load capacity of its cask handling crane. In calculating the number of shipments from the sites, the model used the DOE allocation of delivery rights (10 CFR Part 961) to the sites and the anticipated receipt rate at the repository listed in Table J-4. Using CALVIN, the number of shipments of legal-weight truck casks (Figure J-3) of commercial spent nuclear fuel estimated for the Proposed Action (63,000 MTU of commercial spent nuclear fuel) for the mostly legal-weight truck scenario, would be about 14,000 containing boiling-water reactor assemblies and 24,000 containing pressurized-water reactor assemblies. Under Inventory Modules 1 and 2, for which approximately 105,000 MTU of commercial spent nuclear fuel would be shipped to the repository (see Appendix A), the estimated number of shipments for the mostly legal-weight truck scenario would be 24,000 for boiling-water reactor spent nuclear fuel and 43,000 for pressurized-water reactor spent nuclear fuel. Table J-5 lists the number of shipments of commercial spent nuclear fuel for the mostly legal-weight truck scenario. Specifically, it lists the site, plant, and state where shipments would originate, the total number of shipments from each site, and the type of spent nuclear fuel that would be shipped. A total of 72 commercial sites with 104 plants (or facilities) are listed in the table.



Source: Kelderhouse (1999, page 7).

Figure J-3. Artist's conception of a truck cask on a legal-weight tractor-trailer truck.



Source: Kelderhouse (1999, page 8).

Figure J-4. Artist's conception of a large rail cask on a railcar.

Table J-3. Shipping cask configurations.

Shipping casks	Capacity (number of spent nuclear fuel assemblies)	Description[a,b]
Rail		
B-RAIL-LGSP	61	Large BWR single-purpose shipping container
B-RAIL-SMSP	24	Small BWR single-purpose shipping container
BP-TRAN-OVLG74	74	Big Rock Point dual-purpose shipping container
B-TRAN-OVLG	61	Large BWR dual-purpose shipping container
B-TRAN-OVMED	44	Medium BWR dual-purpose shipping container
B-TRAN OVSM	24	Small BWR dual-purpose shipping container
B-High Heat Rail	17	BWR high heat shipping container
P-RAIL-LGSP	26	Large PWR single-purpose shipping container
P-RAIL-SMSP	12	Small PWR single-purpose shipping container
P-RAIL-MOX	9	Mixed-oxide SNF shipping container
P-RL-LGSP-ST	12	South Texas single-purpose shipping container
P-TRAN-OVLG-YR	36	Yankee Rowe dual-purpose shipping container
P-TRAN-OVLG	24	Large PWR dual-purpose shipping container
P-TRAN-OVMED	21	Medium PWR dual-purpose shipping container
P-TRAN-OVSM	12	Small PWR dual-purpose shipping container
P-TRNST-OVLG	12	South Texas dual-purpose shipping container
P-High Heat-Rail	7	PWR high heat shipping container
Truck		
B-LWT-GA9I	9	Primary BWR shipping container
B-LWT-GA9II	7	Derated BWR shipping container
B-LWT-GA9III	5	Derated BWR shipping container
B-LWT-GA9IV	4	Derated BWR shipping container
B-LWT-GAV	2	Derated BWR shipping container
BP-LWT-GA4I	4	Big Rock Point shipping container
B-NLI-1/2	2	Secondary BWR shipping container
P-LWT-GA4I	4	Primary PWR shipping container
P-LWT-GA4II	3	Derated PWR shipping container
P-LWT-GA4III	2	Derated PWR shipping container
P-LWT-GA4I-ST	4	South Texas shipping container
P-LWT-GA4II-ST	3	Derated South Texas shipping container
P-LWT-GA4III-ST	2	Derated South Texas shipping container
P-NLI-1/2	1	Secondary PWR shipping container
P-LWT-MOX	4	Mixed-oxide SNF shipping container

a. Source: TRW (1999a, page 3).

b. BWR = boiling-water reactor; PWR = pressurized-water reactor; SNF = spent nuclear fuel.

The number of shipments of truck and rail casks (Figure J-4) of commercial spent nuclear fuel estimated for the Proposed Action for the mostly rail scenario would be 4,200 for boiling-water reactor spent nuclear fuel and 6,800 for pressurized-water reactor spent nuclear fuel. Under Modules 1 and 2, the estimated number of shipments for the mostly rail scenario would be 6,500 containing boiling-water reactor spent nuclear fuel and 11,100 containing pressurized-water reactor spent nuclear fuel. Table J-6 lists the number of shipments for the mostly rail scenario. It also lists the site and state where shipments would originate, the total number of shipments from each site, the size of rail cask assumed for each site, and the type of spent nuclear fuel that would be shipped. In addition, it lists the 19 sites not served by a railroad that would ship rail casks by barge or heavy-haul trucks to a nearby railhead and the 9 commercial sites without capability to load a rail cask.

Table J-4. Anticipated receipt rate for spent nuclear fuel and high-level radioactive waste at the Yucca Mountain Repository[a].

	Commercial spent nuclear fuel annual receipt[b]			High-level radioactive waste and DOE spent nuclear fuel[c] annual receipts		
		Shipments			Shipments	
Year	MTHM[d]	Mostly LWT[e]	Mostly rail	MTHM	Mostly LWT	Mostly rail
2010	300	267	100	0	0	0
2011	600	413	184	0	0	0
2012	1,200	757	294	0	0	0
2013	2,000	1,246	478	0	0	0
2014	3,000	1,805	663	0	0	0
2015	3,000	1,792	638	400	650	140
2016	3,000	1,797	600	400	650	140
2017	3,000	1,803	555	400	650	140
2018	3,000	1,787	497	400	650	140
2019	3,000	1,782	508	400	650	140
2020	3,000	1,773	501	400	650	140
2021	3,000	1,780	514	400	650	140
2022	3,000	1,771	513	400	650	140
2023	3,000	1,772	484	400	650	140
2024	3,000	1,796	496	400	650	140
2025	3,000	1,779	472	400	650	140
2026	3,000	1,777	437	400	650	140
2027	3,000	1,793	488	400	650	140
2028	3,000	1,772	469	400	650	140
2029	3,000	1,794	460	400	650	140
2030	3,000	1,768	419	400	675	140
2031	3,000	1,808	451	400	685	140
2032	3,000	1,781	458	200	675	49
2033	1,900	1,125	308	0	0	0
Totals	**63,000**	**37,738**	**10,987**	**7,000**	**12,085**	**2,429**

a. Receipt rates based on assumptions presented in the *Analysis of the Total System Life-Cycle Cost of the Civilian Radioactive Waste Management Program* (DOE 1998a, all) and the results of the CALVIN analysis.

b. Projected spent nuclear fuel acceptance rates (until agreements are reached with purchasers/producers/custodians).

c. DOE spent nuclear fuel at the Idaho National Engineering and Environmental Laboratory to be removed by 2035. Three hundred rail shipments of Navy fuel will be among the early shipments to a DOE receiving facility.

d. MTHM = metric tons of heavy metal.

e. LWT = legal-weight truck.

J.1.2.1.2 *DOE Spent Nuclear Fuel and High-Level Radioactive Waste*

To estimate the number of DOE spent nuclear fuel and high-level radioactive waste shipments, the analysis used the number of handling units or number of canisters and the number of canisters per shipment reported by the DOE sites in 1998 (see Appendix A, page A-34; Jensen 1998, all). To determine the number of shipments of DOE spent nuclear fuel and high-level radioactive waste, the analysis assumed one canister would be shipped in a legal-weight truck cask. For rail shipments, the analysis assumed that five 61-centimeter (24-inch)-diameter high-level radioactive waste canisters would be shipped in a rail cask. For rail shipments of DOE spent nuclear fuel, the analysis assumed that rail casks would contain nine approximately 46-centimeter (18-inch) canisters or four approximately 61-centimeter canisters. The number of DOE spent nuclear fuel canisters of each size is presented in Appendix A.

Table J-5. Shipments of commercial spent nuclear fuel, mostly legal-weight truck scenario[a] (page 1 of 2).

Site	Reactor	State	Fuel type	Proposed Action (2010-2033)	Modules 1 and 2 (2010-2048)
Browns Ferry	Browns Ferry 1	AL	B[b]	856	1,465
	Browns Ferry 3	AL	B	319	602
Joseph M. Farley	Joseph M. Farley 1	AL	P[c]	336	544
	Joseph M. Farley 2	AL	P	297	582
Arkansas Nuclear One	Arkansas Nuclear One, Unit 1	AR	P	302	438
	Arkansas Nuclear One, Unit 2	AR	P	332	525
Palo Verde	Palo Verde 1	AZ	P	345	797
	Palo Verde 2	AZ	P	364	840
	Palo Verde 3	AZ	P	309	861
Diablo Canyon	Diablo Canyon 1	CA	P	327	617
	Diablo Canyon 2	CA	P	305	691
Humboldt Bay	Humboldt Bay	CA	B	44	44
Rancho Seco	Rancho Seco 1	CA	P	124	124
San Onofre	San Onofre 1	CA	P	52	52
	San Onofre 2	CA	P	402	600
	San Onofre 3	CA	P	413	632
Haddam Neck	Haddam Neck	CT	P	255	255
Millstone	Millstone 1	CT	B	463	543
	Millstone 2	CT	P	358	551
	Millstone 3	CT	P	245	575
Crystal River	Crystal River 3	FL	P	283	442
St. Lucie	St. Lucie 1	FL	P	389	571
	St. Lucie 2	FL	P	292	515
Turkey Point	Turkey Point 3	FL	P	295	413
	Turkey Point 4	FL	P	287	458
Edwin I. Hatch	Edwin I. Hatch 1	GA	B	871	1,334
Vogtle	Vogtle 1	GA	P	593	1,462
Duane Arnold	Duane Arnold	IA	B	279	420
Braidwood	Braidwood 1	IL	P	615	1,494
Byron	Byron 1	IL	P	617	1,444
Clinton	Clinton 1	IL	B	296	690
Dresden/Morris	Dresden 1	IL	B	76	76
	Dresden 2	IL	B	430	521
	Dresden 3	IL	B	473	565
	Morris[d]	IL	B	319	319
	Morris[d]	IL	P	88	88
LaSalle	LaSalle 1	IL	B	596	1,261
Quad Cities	Quad Cities 1	IL	B	798	1,123
Zion	Zion 1	IL	P	771	1,028
Wolf Creek	Wolf Creek 1	KS	P	349	708
River Bend	River Bend 1	LA	B	324	823
Waterford	Waterford 3	LA	P	313	675
Pilgrim	Pilgrim 1	MA	B	316	476
Yankee-Rowe	Yankee-Rowe 1	MA	P	134	134
Calvert Cliffs	Calvert Cliffs 1	MD	P	757	1,140
Maine Yankee	Maine Yankee	ME	P	356	356
Big Rock Point	Big Rock Point	MI	B	131	131
D. C. Cook	D. C. Cook 1	MI	P	824	1,235
Fermi	Fermi 2	MI	B	312	764
Palisades	Palisades	MI	P	367	454
Monticello	Monticello	MN	B	267	342
Prairie Island	Prairie Island 1	MN	P	572	805
Callaway	Callaway 1	MO	P	392	735
Grand Gulf	Grand Gulf 1	MS	B	516	1,016
Brunswick	Brunswick 1	NC	P	40	40
	Brunswick 2	NC	P	36	36

Table J-5. Shipments of commercial spent nuclear fuel, mostly legal-weight truck scenario[a] (page 2 of 2).

Site	Reactor	State	Fuel type	Proposed Action (2010-2033)	Modules 1 and 2 (2010-2048)
Brunswick (continued)					
	Brunswick 1	NC	B[b]	232	426
	Brunswick 2	NC	B	232	401
Shearon Harris	Shearon Harris 1	NC	P[c]	298	769
	Shearon Harris	NC	B	152	152
McGuire	McGuire 1	NC	P	387	690
	McGuire 2	NC	P	436	774
Cooper Station	Cooper Station	NE	B	274	454
Fort Calhoun	Fort Calhoun	NE	P	258	362
Seabrook	Seabrook 1	NH	P	235	630
Oyster Creek	Oyster Creek 1	NJ	B	424	519
Salem/Hope Creek	Salem 1	NJ	P	330	545
	Salem 2	NJ	P	298	571
	Hope Creek	NJ	B	399	876
James A. FitzPatrick/ Nine Mile Point	James A. FitzPatrick	NY	B	364	554
	Nine Mile Point 1	NY	B	401	499
	Nine Mile Point 2	NY	B	329	918
Ginna	Ginna	NY	P	309	379
Indian Point	Indian Point 1	NY	P	40	40
	Indian Point 2	NY	P	364	590
	Indian Point 3	NY	P	297	525
Davis-Besse	Davis-Besse 1	OH	P	286	535
Perry	Perry 1	OH	B	288	631
Trojan	Trojan	OR	P	195	195
Beaver Valley	Beaver Valley 1	PA	P	330	534
	Beaver Valley 2	PA	P	221	622
Limerick	Limerick 1	PA	B	693	1,722
Peach Bottom	Peach Bottom 2	PA	B	480	696
	Peach Bottom 3	PA	B	444	712
Susquehanna	Susquehanna 1	PA	B	808	1,582
Three Mile Island	Three Mile Island 1	PA	P	287	435
Catawba	Catawba 1	SC	P	325	663
	Catawba 2	SC	P	318	667
Oconee	Oconee 1	SC	P	727	1,043
	Oconee 3	SC	P	280	457
H. B. Robinson	H. B. Robinson 2	SC	P	231	306
Summer	Summer 1	SC	P	291	538
Sequoyah	Sequoyah	TN	P	560	1,179
Watts Bar	Watts Bar 1	TN	P	146	840
Comanche Peak	Comanche Peak 1	TX	P	559	1,558
South Texas	South Texas 1	TX	P	256	738
	South Texas 2	TX	P	229	710
North Anna	North Anna 1	VA	P	634	1,079
Surry	Surry 1	VA	P	647	902
Vermont Yankee	Vermont Yankee 1	VT	B	369	484
WPPSS[e] 2	WPPSS 2	WA	B	353	736
Kewaunee	Kewaunee	WI	P	288	401
LaCrosse	LaCrosse	WI	B	37	37
Point Beach	Point Beach	WI	P	575	742
Total BWR[b]				**13,965**	**23,914**
Total PWR[c]				**23,773**	**42,936**

a. Source: TRW (1999a, Section 2).
b. B = boiling-water reactor (BWR).
c. P = pressurized-water reactor (PWR).
d. Morris is a storage facility located close to the three Dresden reactors.
e. WPPSS = Washington Public Power Supply System.

Table J-6. Shipments of commercial spent nuclear fuel, mostly rail scenario[a] (page 1 of 2).

Site	Reactor	State	Fuel type	Cask	Proposed Action 2010 - 2033	Modules 1 and 2 2010 - 2048
Browns Ferry	Browns Ferry 1	AL	B[b]	Medium	239	422
	Browns Ferry 3	AL	B	Medium	88	168
Joseph M. Farley	Joseph M. Farley 1	AL	P[c]	Large	54	78
	Joseph M. Farley 2	AL	P	Large	49	79
Arkansas Nuclear One	Arkansas Nuclear One, Unit 1	AR	P	Medium	81	115
	Arkansas Nuclear One, Unit 2	AR	P	Medium	89	137
Palo Verde	Palo Verde 1	AZ	P	Large	53	120
	Palo Verde 2	AZ	P	Large	56	124
	Palo Verde 3	AZ	P	Large	47	106
Diablo Canyon	Diablo Canyon 1	CA	P	Medium	103	169
	Diablo Canyon 2	CA	P	Medium	97	174
Humboldt Bay	Humboldt Bay	CA	B	Truck	44	44
Rancho Seco	Rancho Seco 1	CA	P	Large	21	21
San Onofre	San Onofre 1	CA	P	Large	9	8
	San Onofre 2	CA	P	Large	66	97
	San Onofre 3	CA	P	Large	68	102
Haddam Neck	Haddam Neck	CT	P	Truck	255	255
Millstone	Millstone 1	CT	B	Small	174	204
	Millstone 2	CT	P	Small	120	183
	Millstone 3	CT	P	Medium	73	137
Crystal River	Crystal River 3	FL	P	Truck	283	442
St. Lucie	St. Lucie 1	FL	P	Truck	389	571
	St. Lucie 2	FL	P	Medium	88	140
Turkey Point	Turkey Point 3	FL	P	Medium	73	111
	Turkey Point 4	FL	P	Medium	72	117
Edwin I. Hatch	Edwin I. Hatch 1	GA	B	Large	128	197
Vogtle	Vogtle 1	GA	P	Small	195	431
Duane Arnold	Duane Arnold	IA	B	Small	105	158
Braidwood	Braidwood 1	IL	P	Large	95	215
Byron	Byron 1	IL	P	Large	136	244
Clinton	Clinton 1	IL	B	Medium	103	200
Dresden/Morris	Dresden 1	IL	B	Small	29	29
	Dresden 2	IL	B	Small	162	193
	Dresden 3	IL	B	Small	177	208
	Morris[d]	IL	B	Large	47	47
	Morris[d]	IL	P	Large	14	14
LaSalle	LaSalle 1	IL	B	Large	89	172
Quad Cities	Quad Cities 1	IL	B	Small	299	419
Zion	Zion 1	IL	P	Medium	147	250
Wolf Creek	Wolf Creek 1	KS	P	Large	52	106
River Bend	River Bend 1	LA	B	Large	48	101
Waterford	Waterford 3	LA	P	Large	49	91
Pilgrim	Pilgrim 1	MA	B	Truck	316	476
Yankee-Rowe	Yankee-Rowe 1	MA	P	Large	15	15
Calvert Cliffs	Calvert Cliffs 1	MD	P	Medium	198	303
Maine Yankee	Maine Yankee	ME	P	Large	60	60
Big Rock Point	Big Rock Point	MI	B	Large	8	8
D. C. Cook	D. C. Cook 1	MI	P	Medium	214	346
Fermi	Fermi 2	MI	B	Medium	100	199
Palisades	Palisades	MI	P	Medium	78	117
Monticello	Monticello	MN	B	Truck	267	342
Prairie Island	Prairie Island 1	MN	P	Medium	151	221
Callaway	Callaway 1	MO	P	Large	62	114
Grand Gulf	Grand Gulf 1	MS	B	Large	76	143

Table J-6. Shipments of commercial spent nuclear fuel, mostly rail scenario[a] (page 2 of 2).

Site	Reactor	State	Fuel type	Cask	Proposed Action 2010 - 2033	Modules 1 and 2 2010 - 2048
Brunswick	Brunswick 1	NC	P[c]	Small	14	14
	Brunswick 2	NC	P	Small	12	12
	Brunswick 1	NC	B[b]	Small	88	150
	Brunswick 2	NC	B	Small	87	145
Shearon Harris	Shearon Harris 1	NC	P	Small	93	201
	Shearon Harris	NC	B	Small	57	57
McGuire	McGuire 1	NC	P	Medium	115	199
	McGuire 2	NC	P	Medium	138	228
Cooper Station	Cooper Station	NE	B	Small	103	166
Fort Calhoun	Fort Calhoun	NE	P	Small	87	121
Seabrook	Seabrook 1	NH	P	Large	37	83
Oyster Creek	Oyster Creek 1	NJ	B	Medium	108	151
Salem/Hope Creek	Salem 1	NJ	P	Medium	97	153
	Salem 2	NJ	P	Medium	83	143
	Hope Creek	NJ	B	Large	59	125
James A. FitzPatrick/ Nine Mile Point	FitzPatrick	NY	B	Large	54	79
	Nine Mile Point 1	NY	B	Medium	135	167
	Nine Mile Point 2	NY	B	Medium	101	206
Ginna	Ginna	NY	P	Truck	309	379
Indian Point	Indian Point 1	NY	P	Truck	40	40
	Indian Point 2	NY	P	Truck	364	590
	Indian Point 3	NY	P	Truck	297	525
Davis-Besse	Davis-Besse 1	OH	P	Large	44	71
Perry	Perry 1	OH	B	Large	42	82
Trojan	Trojan	OR	P	Large	33	33
Beaver Valley	Beaver Valley 1	PA	P	Large	52	81
	Beaver Valley 2	PA	P	Large	34	79
Limerick	Limerick 1	PA	B	Medium	262	497
Peach Bottom	Peach Bottom 2	PA	B	Medium	138	206
	Peach Bottom 3	PA	B	Medium	127	197
Susquehanna	Susquehanna 1	PA	B	Large	119	219
Three Mile Island	Three Mile Island 1	PA	P	Medium	71	113
Catawba	Catawba 1	SC	P	Large	72	123
	Catawba 2	SC	P	Large	76	130
Oconee	Oconee 1	SC	P	Medium	187	266
	Oconee 3	SC	P	Medium	67	107
H. B. Robinson	H. B. Robinson 2	SC	P	Small	75	97
Summer	Summer 1	SC	P	Large	46	82
Sequoyah	Sequoyah	TN	P	Large	90	161
Watts Bar	Watts Bar 1	TN	P	Large	21	121
Comanche Peak	Comanche Peak 1	TX	P	Large	90	246
South Texas	South Texas 1	TX	P	Large	79	180
	South Texas 2	TX	P	Large	72	178
North Anna	North Anna 1	VA	P	Large	101	167
Surry	Surry 1	VA	P	Large	105	144
Vermont Yankee	Vermont Yankee 1	VT	B	Small	139	182
WPPSS[e] 2	WPPSS 2	WA	B	Large	53	107
Kewaunee	Kewaunee	WI	P	Medium	73	106
La Crosse	La Crosse	WI	B	Truck	37	37
Point Beach	Point Beach	WI	P	Large	93	118
Total BWR[b]					**4,208**	**6,503**
Total PWR[c]					**6,779**	**11,104**

a. Source: TRW (1999a, Section 2).

b. B = boiling-water reactor (BWR).

c. P = pressurized-water reactor (PWR).

d. Morris is a storage facility located close to the three Dresden reactors.

e. WPPSS = Washington Public Power Supply System.

Under the mostly legal-weight truck scenario for the Proposed Action, a total of about 11,800 truck shipments of DOE spent nuclear fuel and high-level radioactive waste would be shipped to the repository. In addition, due to the size and weight of the shipping casks for canisters that would contain naval spent fuel, DOE would transport 300 shipments of naval spent fuel by rail from the Idaho National Engineering and Environmental Laboratory to the repository. For Modules 1 and 2, under the mostly legal-weight truck scenario, the analysis estimated 3,740 DOE spent nuclear fuel and 22,300 high-level radioactive waste truck shipments and 300 naval spent nuclear fuel shipments by rail.

Under the mostly rail scenario for the Proposed Action, the analysis estimated that 770 railcar shipments of DOE spent nuclear fuel, including 300 railcar shipments of naval spent nuclear fuel (one naval spent nuclear fuel canister per rail cask), and 1,660 railcar shipments of high-level waste would travel to the repository. For Modules 1 and 2, under this scenario 800 railcar shipments of DOE spent nuclear fuel, including 300 railcar shipments of naval spent nuclear fuel, and 4,460 railcar shipments of high-level radioactive waste would be shipped. Table J-7 lists the estimated number of shipments of DOE spent nuclear fuel from each of the four sites for both the Proposed Action and Modules 1 and 2. Table J-8 lists the number of shipments of high-level radioactive waste for the Proposed Action and for Modules 1 and 2.

Table J-7. DOE spent nuclear fuel shipments by site.

	Proposed Action		Module 1 or 2	
Site	Mostly truck	Mostly rail	Mostly truck	Mostly rail
INEEL[a,b]	1,388	434	1,467	443
Savannah River Site	1,316	149	1,411	159
Hanford	754	147	809	157
Fort St. Vrain	312	36	334	38
Totals	**3,770**	**766**	**4,021**	**797**

a. INEEL = Idaho National Engineering and Environmental Laboratory.

b. Includes 300 railcar shipments of naval spent nuclear fuel.

Table J-8. Number of canisters of high-level radioactive waste and shipments from DOE sites.

	Proposed Action			Module 1 or 2	
Site	Canisters	Mostly truck	Mostly rail	Mostly truck	Mostly rail
INEEL[a]	1,300	0	0	1,300	260
Hanford	14,500	1,960	400	14,500	2,900
Savannah River Site	6,200	6,055	1,200	6,200	1,240
West Valley[b]	300	300	60	300	60
Totals	**22,300**	**8,315**	**1,660**	**22,300**	**4,460**

a. INEEL = Idaho National Engineering and Environmental Laboratory.

b. High-level radioactive waste at West Valley is commercial rather than DOE waste.

J.1.2.1.3 *Greater-Than-Class-C and Special-Performance-Assessment-Required Waste Shipments*

Reasonably foreseeable future actions could include shipment of Greater-Than-Class-C and Special-Performance-Assessment-Required waste to the Yucca Mountain Repository (Appendix A describes Greater-Than-Class-C and Special-Performance-Assessment-Required wastes). Commercial nuclear powerplants, research reactors, radioisotope manufacturers, and other manufacturing and research institutions generate low-level radioactive waste that exceeds the Nuclear Regulatory Commission Class

C shallow-land-burial disposal limits. In addition to DOE-held material, there are three other sources or categories of Greater-Than-Class-C low-level radioactive waste:

- Nuclear utilities
- Sealed sources
- Other generators

The activities of nuclear electric utilities and other radioactive waste generators to date have produced relatively small quantities of Greater-Than-Class-C low-level radioactive waste. As the utilities take their reactors out of service and decommission them, they could generate more waste of this type.

DOE Special-Performance-Assessment-Required low-level radioactive waste could include the following materials:

- Production reactor operating wastes
- Production and research reactor decommissioning wastes
- Non-fuel-bearing components of naval reactors
- Sealed radioisotope sources that exceed Class C limits for waste classification
- DOE isotope production-related wastes
- Research reactor fuel assembly hardware

The analysis estimated the number of shipments of Greater-Than-Class-C and Special-Performance-Assessment-Required waste by assuming that 10 cubic meters (about 350 cubic feet) would be shipped in a rail cask and 2 cubic meters (about 71 cubic feet) would be shipped in a truck cask. Table J-9 lists the resulting number of commercial Greater-Than-Class-C shipments in Inventory Module 2 for both truck and rail shipments. The shipments of Greater-Than-Class-C waste from commercial utilities would originate among the commercial reactor sites. Typically, boiling-water reactors would ship a total of about 9 cubic meters (about 318 cubic feet) of Greater-Than-Class-C waste per site, while pressurized-water reactors would ship about 20 cubic meters (about 710 cubic feet) per site (see Appendix A). The impacts of transporting this waste were examined for each reactor site. The analysis assumed that sealed sources and Greater-Than-Class-C waste identified as "other" would be shipped from the DOE Savannah River Site (see Table J-10).

Table J-9. Commercial Greater-Than-Class-C waste shipments.

Category	Volume (cubic meters)[a,b]	Truck	Rail
Commercial utilities	1,350	740	210
Sealed sources	240	120	25
Other	470	230	50
Total	**2,060**	**1,090**	**285**

a. Source: Appendix A.
b. To convert cubic meters to cubic feet, multiply by 35.314.

The analysis assumed DOE Special-Performance-Assessment-Required waste would be shipped from 4 DOE sites listed in Table J-10. Naval reactor and Argonne East Special-Performance-Assessment-Required waste is assumed to be shipped from the Idaho National Engineering and Environmental Laboratory.

J.1.2.1.4 *Sensitivity of Transportation Impacts to Number of Shipments*

As discussed in Section J.1.2.1, the number of shipments from commercial and DOE sites to the repository would depend on the mix of legal-weight truck and rail shipments. Because DOE has decided

Table J-10. DOE Special-Performance-Assessment-Required waste shipments.

Site[a]	Volume (cubic meters)[b,c]	Rail	Truck
Hanford	20	2	10
INEEL	520	57[d]	260
SRS (ORNL)	2,900	290	1,470
West Valley	550	56	280
Total	**3,990**	**405**	**2,020**

a. Abbreviations: INEEL = Idaho National Engineering and Environmental Laboratory; SRS = Savannah River Site; ORNL = Oak Ridge National Laboratory.

b. Source: Appendix A.

c. To convert cubic meters to cubic feet, multiply by 35.314.

d. Includes 55 shipments from naval reactors.

not to determine this mix at this time (10 years before the projected start of shipping operations), the analysis used two scenarios to provide results that bound the range of anticipated impacts. Thus, for a mix of legal-weight truck and rail shipments within the range of the mostly legal-weight truck and mostly rail scenarios, the impacts would be likely to lie within the bounds of the impacts predicted by the analysis. For example, a mix that is different from the scenarios analyzed could consist of 5,000 legal-weight truck shipments and 9,000 rail shipments over 24 years (compared to 2,600 and 10,800, respectively, for the mostly rail scenario). In this example, the number of traffic fatalities would be between 3.6 (estimated for the Proposed Action under the mostly rail scenario) and 3.9 (estimated for the mostly legal-weight truck scenario). Other examples that have different mixes within the ranges bounded by the scenarios would lead to results that would be within the range of the evaluated impacts.

In addition to mixes within the brackets, the number of shipments could fall outside the ranges used for the mostly legal-weight truck and rail transportation scenarios. If, for example, the mostly rail scenario used smaller rail casks than the analysis assumed, the number of shipments would be greater. If spent nuclear fuel was placed in the canisters before they were shipped, the added weight and size of the canisters would reduce the number of fuel assemblies that a given cask could accommodate; this would increase the number of shipments. However, for the mostly rail scenario, even if the capacity of the casks was half that used in the analysis, the impacts would remain below those forecast for the mostly legal-weight truck scenario. Although impacts would be related to the number of shipments, because the number of rail shipments would be very small in comparison to the total railcar traffic on the Nation’s railroads, increases or decreases would be small for impacts to biological resources, air quality, hydrology, noise, and other environmental resource areas. Thus, the impacts of using smaller rail casks would be covered by the values estimated in this EIS.

For legal-weight truck shipments, the use of casks carrying smaller payloads than those used in the analysis (assuming the shipment of the same spent nuclear fuel) would lead to larger impacts for incident-free transportation and traffic fatalities and about the same level of radiological accident risk. The relationship is approximately linear; if the payloads of truck shipping casks in the mostly legal-weight truck scenario were less by one-half, the incident-free impacts would increase by approximately a factor of 2. Conversely, because the amount of radioactive material in a cask would be less (assuming shipment of the same spent nuclear fuel), the radiological consequences of maximum reasonably foreseeable accident scenarios would be less with the use of smaller casks. If smaller casks were used to accommodate shipments of spent nuclear fuel with shorter cooling time and higher burnup, the radiological consequences of maximum reasonably foreseeable accident scenarios would be about the same.

J.1.2.2 Transportation Routes

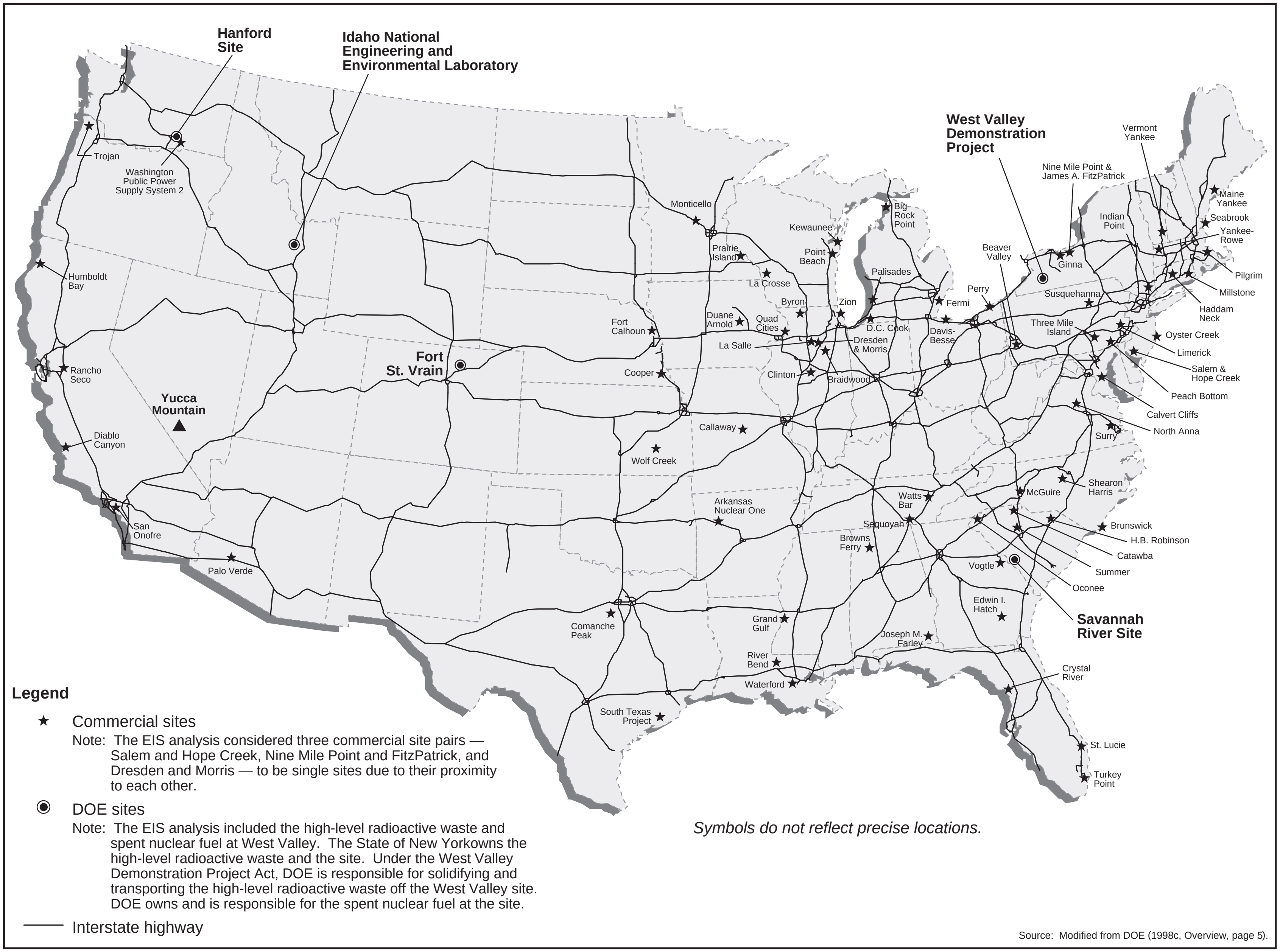
At this time, about 10 years before shipments could begin, DOE has not determined the specific routes it would use to ship spent nuclear fuel and high-level radioactive waste to the proposed repository. Nonetheless, this analysis used current regulations governing highway shipments and historic rail industry practices to select existing highway and rail routes to estimate potential environmental impacts of national transportation. Routing for shipments of spent nuclear fuel and high-level radioactive waste to the proposed repository would comply with applicable regulations of the Department of Transportation and the Nuclear Regulatory Commission in effect at the time the shipments occurred, as stated in the proposed DOE revised policy and procedures for implementing Section 180(c) of the Nuclear Waste Policy Act (DOE 1998b, all).

Approximately 4 years before shipments to the proposed repository began, the Office of Civilian Radioactive Waste Management plans to identify the preliminary routes that DOE anticipates using in state and tribal jurisdictions so it can notify governors and tribal leaders of their eligibility for assistance under the provisions of Section 180(c) of the Nuclear Waste Policy Act. DOE has published a revised proposed policy statement that sets forth its revised plan for implementing a program of technical and financial assistance to states and Native American tribes for training public safety officials of appropriate units of local government and tribes through whose jurisdictions the Department plans to transport spent nuclear fuel or high-level radioactive waste (63 *FR* 83, January 2, 1998).

The analysis of impacts of the Proposed Action and Modules 1 and 2 used characteristics of routes that shipments of spent nuclear fuel and high-level radioactive waste could travel from the originating sites listed in Tables J-5 through J-8. Existing routes that could be used were identified for the mostly legal-weight truck and mostly rail transportation scenarios and included the 10 rail and heavy-haul truck implementing alternatives evaluated in the EIS for transportation in Nevada. The route characteristics used were the transportation mode (highway, railroad, or navigable waterway) and, for each of the modes, the total distance between an originating site and the repository. In addition, the analysis estimated the fraction of travel that would occur in rural, suburban, and urban areas for each route. The fraction of travel in each population zone was determined using 1990 census data (see Section J.1.1.2 and J.1.1.3) to identify population-zone impacts for route segments. The highway routes were selected for the analysis using the HIGHWAY computer program and routing requirements of the Department of Transportation for shipments of Highway Route-Controlled Quantities of Radioactive Materials (49 CFR 397.101). Shipments of spent nuclear fuel and high-level radioactive waste would contain Highway Route-Controlled Quantities of Radioactive Materials.

J.1.2.2.1 *Routes Used in the Analysis*

Routes used in the analysis of transportation impacts of the Proposed Action and Inventory Modules 1 and 2 are highways and rail lines that DOE anticipates it could use for legal-weight truck or rail shipments from each origin to Nevada. For rail shipments that would originate at sites not served by railroads, routes used for analysis include highway routes for heavy-haul trucks or barge routes from the sites to railheads. Figures J-5 and J-6 show the Interstate System highways and mainline railroads, respectively, and their relationship to the commercial and DOE sites and Yucca Mountain. Tables J-11 and J-12 list the lengths of trips and the distances of the highway and rail routes, respectively, in rural, suburban, and urban population zones. Sites that would be capable of loading rail casks, but that do not have direct rail access, are listed in Table J-12. The analysis used four ending rail nodes in Nevada (Beowawe, Caliente, Jean, and Apex) to select rail routes from the 77 sites. These rail nodes would be starting points for the rail and heavy-haul truck implementing alternatives analyzed for transportation in Nevada.



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

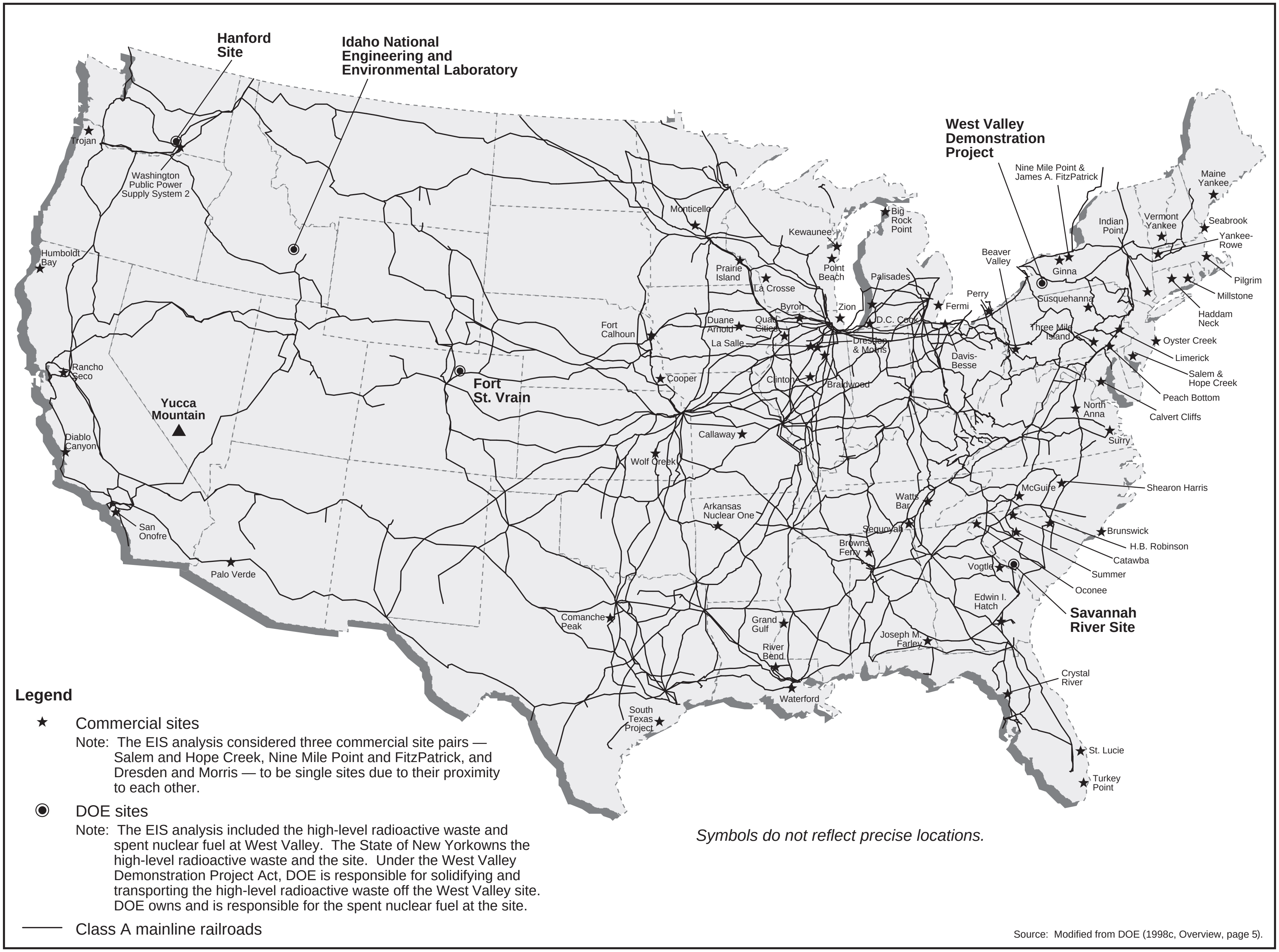
Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

—— Interstate highway

Symbols do not reflect precise locations.

Source: Modified from DOE (1998c, Overview, page 5).

Figure J-5. Commercial and DOE sites and Yucca Mountain in relation to the U.S. Interstate Highway System.



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

—— Class A mainline railroads

Source: Modified from DOE (1998c, Overview, page 5).

Figure J-6. Commercial and DOE sites and Yucca Mountain in relation to the U.S. railroad system.

Table J-11. Highway distances for legal-weight truck shipments from commercial and DOE sites to Yucca Mountain, mostly legal-weight truck transportation (kilometers)[a,b] (page 1 of 2).

Origin	State	Total[c]	Rural	Suburban	Urban
Browns Ferry	AL	3,442	3,022	374	45
Joseph M. Farley	AL	4,229	3,647	520	62
Arkansas Nuclear One	AR	2,810	2,588	192	30
Palo Verde	AZ	1,007	886	100	21
Diablo Canyon	CA	1,016	828	119	68
Humboldt Bay	CA	1,749	1,465	192	92
Rancho Seco	CA	1,228	1,028	124	76
San Onofre	CA	694	517	89	88
Haddam Neck	CT	4,519	3,708	736	75
Millstone	CT	4,527	3,673	746	109
Crystal River	FL	4,319	3,606	653	59
St. Lucie	FL	4,588	3,793	729	64
Turkey Point	FL	4,842	3,888	821	132
Edwin I. Hatch	GA	3,986	3,373	553	58
Vogtle	GA	3,938	3,301	573	63
Duane Arnold	IA	2,773	2,544	189	40
Braidwood	IL	3,063	2,796	231	36
Byron	IL	3,032	2,773	223	36
Clinton	IL	3,104	2,814	252	38
Dresden/Morris	IL	3,059	2,798	225	36
La Salle	IL	3,017	2,766	215	36
Quad Cities	IL	2,877	2,631	211	36
Zion	IL	3,167	2,834	284	50
Wolf Creek	KS	2,374	2,226	131	16
River Bend	LA	3,446	2,941	420	85
Waterford	LA	3,531	3,003	444	84
Pilgrim	MA	4,722	3,697	930	94
Yankee-Rowe	MA	4,616	3,692	831	92
Calvert Cliffs	MD	4,278	3,511	684	82
Maine Yankee	ME	4,894	3,733	1,052	108
Big Rock Point	MI	3,866	3,266	547	52
D. C. Cook	MI	3,196	2,827	319	51
Fermi	MI	3,524	3,014	449	61
Palisades	MI	3,244	2,855	338	51
Monticello	MN	3,003	2,702	261	41
Prairie Island	MN	2,993	2,720	233	41
Callaway	MO	2,633	2,399	206	27
Grand Gulf	MS	3,354	2,989	311	54
Brunswick	NC	4,418	3,672	680	66
Shearon Harris	NC	4,187	3,493	630	63
McGuire	NC	3,991	3,415	516	58
Cooper Station	NE	2,523	2,328	160	36
Fort Calhoun	NE	2,348	2,165	148	35
Seabrook	NH	4,725	3,676	942	107
Oyster Creek	NJ	4,424	3,530	825	69
Salem/Hope Creek	NJ	4,350	3,531	739	79
Ginna	NY	4,089	3,357	642	91
Indian Point	NY	4,382	3,695	620	67
James FitzPatrick/Nine Mile Point	NY	4,234	3,461	688	85

Table J-11. Highway distances for legal-weight truck shipments from commercial and DOE sites to Yucca Mountain, mostly legal-weight truck transportation (kilometers)[a,b] (page 2 of 2).

Origin	State	Total[c]	Rural	Suburban	Urban
Davis-Besse	OH	3,520	3,106	358	56
Perry	OH	3,693	3,157	464	73
Trojan	OR	2,137	1,865	237	36
Beaver Valley	PA	3,779	3,215	500	64
Limerick	PA	4,287	3,484	741	62
Peach Bottom	PA	4,205	3,479	662	64
Susquehanna	PA	4,126	3,539	528	59
Three Mile Island	PA	4,147	3,443	643	60
Catawba	SC	3,994	3,364	575	54
Oconee	SC	3,853	3,264	532	55
H. B. Robinson	SC	4,112	3,417	628	65
Summer	SC	3,996	3,383	557	55
Sequoyah	TN	3,500	3,039	414	45
Watts Bar	TN	3,578	3,138	394	45
Comanche Peak	TX	2,794	2,547	213	34
South Texas	TX	3,011	2,652	295	64
North Anna	VA	4,081	3,503	515	63
Surry	VA	4,255	3,577	610	67
Vermont Yankee	VT	4,616	3,675	847	94
WPPSS[d] 2	WA	1,880	1,669	178	32
Kewaunee	WI	3,347	2,979	314	55
La Crosse	WI	3,014	2,773	198	43
Point Beach	WI	3,341	2,972	314	55
Ft. St. Vrain[e]	CO	1,415	1,311	93	10
INEEL[f]	ID	1,201	1,044	130	27
West Valley[g]	NY	3,959	3,322	562	75
Savannah River[f]	SC	3,961	3,321	574	64
Hanford[g]	WA	1,881	1,671	178	32

a. To convert kilometers to miles, multiply by 0.62137.
b. Distances determined for purposes of analysis using HIGHWAY computer program.
c. Totals might differ from sums due to method of calculation and rounding.
d. DOE spent nuclear fuel site.
e. DOE spent nuclear fuel and high-level waste site.
f. DOE high-level waste site.
g. WPPSS = Washington Public Power Supply System.

STATE-DESIGNATED PREFERRED ROUTES

Department of Transportation regulations specify that states and tribes can designate preferred routes that are alternatives, or in addition to, Interstate System highways including bypasses or beltways for the transportation of Highway Route-Controlled Quantities of Radioactive Materials. Highway Route-Controlled Quantities of Radioactive Materials include spent nuclear fuel and high-level radioactive waste in quantities that would be shipped on a truck or railcar to the repository. If a state or tribe designated such a route, shipments of spent nuclear fuel and high-level radioactive waste would use the preferred route if (1) it was an alternative preferred route, (2) it would result in reduced time in transit, or (3) it would replace pickup or delivery routes. Ten states—Alabama, Arkansas, California, Colorado, Iowa, Kentucky, Nebraska, New Mexico, Tennessee, and Virginia—have designated alternative or additional preferred routes (Rodgers 1998, all). Although Nevada has designated a State routing agency to the Department of Transportation (Nevada Revised Statutes, Chapter 408.141), the State has not designated alternative preferred routes for Highway Route-Controlled Quantities of Radioactive Materials.

Table J-12. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 1 of 5)

Site	State	Destination	Total[d]	Rural	Suburban	Urban
Commercial sites with direct rail access						
Joseph M. Farley	AL	Apex	4,495	3,872	562	60
		Caliente	4,322	3,698	562	60
		Beowawe	4,177	3,593	535	48
		Jean	4,577	3,937	574	65
Arkansas Nuclear One	AR	Apex	3,170	2,960	181	29
		Caliente	2,996	2,786	181	29
		Beowawe	2,852	2,681	154	17
		Jean	3,251	3,024	193	34
Palo Verde	AZ	Apex	976	864	89	23
		Caliente	1,149	1,038	89	23
		Beowawe	1,908	1,524	274	109
		Jean	894	800	77	18
Rancho Seco	CA	Apex	985	781	151	53
		Caliente	1,159	955	151	53
		Beowawe	706	589	83	32
		Jean	904	717	139	48
San Onofre	CA	Apex	576	409	105	63
		Caliente	750	582	105	63
		Beowawe	1,576	1,167	286	121
		Jean	495	344	93	58
Millstone	CT	Apex	4,728	3,526	994	208
		Caliente	4,555	3,353	994	208
		Beowawe	4,411	3,247	966	197
		Jean	4,810	3,591	1,005	213
Edwin I. Hatch	GA	Apex	4,403	3,830	514	58
		Caliente	4,229	3,656	514	58
		Beowawe	4,085	3,551	486	47
		Jean	4,484	3,894	525	64
Vogtle	GA	Apex	4,459	3,877	523	58
		Caliente	4,286	3,703	523	58
		Beowawe	4,141	3,598	495	47
		Jean	4,541	3,942	534	64
Duane Arnold	IA	Apex	2,745	2,547	167	31
		Caliente	2,572	2,374	167	31
		Beowawe	2,428	2,268	140	20
		Jean	2,827	2,612	178	36
Braidwood	IL	Apex	3,166	2,798	284	85
		Caliente	2,993	2,624	285	85
		Beowawe	2,849	2,518	257	73
		Jean	3,248	2,862	296	90
Byron	IL	Apex	2,979	2,740	205	35
		Caliente	2,806	2,566	205	35
		Beowawe	2,662	2,461	177	24
		Jean	3,061	2,805	216	41
Clinton	IL	Apex	3,172	2,891	228	53
		Caliente	2,998	2,718	228	53
		Beowawe	2,854	2,612	201	42
		Jean	3,253	2,956	239	58
Dresden/Morris	IL	Apex	3,087	2,786	255	46
		Caliente	2,914	2,613	255	46
		Beowawe	2,769	2,507	227	35
		Jean	3,169	2,851	266	51
La Salle	IL	Apex	3,060	2,831	196	33
		Caliente	2,887	2,657	196	33
		Beowawe	2,953	2,691	225	37
		Jean	3,403	3,201	181	20
Quad Cities	IL	Apex	3,003	2,759	210	33
		Caliente	2,829	2,586	210	33
		Beowawe	2,895	2,619	238	38
		Jean	3,345	3,130	195	21

Table J-12. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 2 of 5).

Site	State	Destination	Total[d]	Rural	Suburban	Urban
Commercial sites with direct rail access (continued)						
Zion	IL	Apex	3,119	2,765	279	75
		Caliente	2,946	2,591	279	75
		Beowawe	2,801	2,486	252	64
		Jean	3,201	2,829	291	81
Wolf Creek	KS	Apex	2,685	2,528	131	27
		Caliente	2,512	2,354	131	27
		Beowawe	2,368	2,249	103	16
		Jean	2,767	2,593	142	32
River Bend	LA	Apex	3,509	3,114	322	73
		Caliente	3,380	2,944	377	59
		Beowawe	3,445	2,975	406	65
		Jean	3,428	3,049	311	68
Waterford	LA	Apex	3,551	3,173	304	74
		Caliente	3,423	3,003	359	61
		Beowawe	3,487	3,033	388	66
		Jean	3,470	3,108	293	69
Yankee-Rowe	MA	Apex	4,471	3,466	823	183
		Caliente	4,298	3,292	823	183
		Beowawe	4,153	3,187	796	171
		Jean	4,553	3,530	835	188
Maine Yankee	ME	Apex	4,908	3,629	1,075	204
		Caliente	4,734	3,455	1,075	204
		Beowawe	4,590	3,350	1,048	193
		Jean	4,989	3,693	1,087	209
Big Rock Point	MI	Apex	3,835	3,299	431	105
		Caliente	3,662	3,126	431	105
		Beowawe	3,517	3,020	404	93
		Jean	3,917	3,364	443	110
D. C. Cook	MI	Apex	3,209	2,799	324	86
		Caliente	3,035	2,625	324	86
		Beowawe	2,891	2,520	297	75
		Jean	3,290	2,863	336	91
Fermi	MI	Apex	3,649	3,046	469	135
		Caliente	3,476	2,872	469	135
		Beowawe	3,332	2,767	442	123
		Jean	3,731	3,110	481	140
Prairie Island	MN	Apex	2,980	2,715	238	28
		Caliente	2,807	2,541	238	28
		Beowawe	2,663	2,436	210	16
		Jean	3,062	2,780	249	33
Brunswick	NC	Apex	4,768	3,972	724	71
		Caliente	4,594	3,799	724	71
		Beowawe	4,450	3,693	697	59
		Jean	4,849	4,037	736	76
Shearon Harris	NC	Apex	4,669	3,910	689	69
		Caliente	4,495	3,737	689	69
		Beowawe	4,351	3,631	662	58
		Jean	4,751	3,975	701	75
McGuire	NC	Apex	4,539	3,779	683	77
		Caliente	4,366	3,605	683	77
		Beowawe	4,221	3,500	656	65
		Jean	4,621	3,844	694	82
Seabrook	NH	Apex	4,755	3,567	987	201
		Caliente	4,582	3,393	987	201
		Beowawe	4,437	3,288	960	190
		Jean	4,837	3,632	999	206
FitzPatrick/Nine Mile Point	NY	Apex	4,213	3,296	728	188
		Caliente	4,039	3,123	728	188
		Beowawe	3,895	3,017	701	177
		Jean	4,294	3,361	740	193

Table J-12. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 3 of 5).

Site	State	Destination	Total[d]	Rural	Suburban	Urban
Commercial sites with direct rail access (continued)						
Davis Besse	OH	Apex	3,590	3,133	342	114
		Caliente	3,416	2,960	342	114
		Beowawe	3,272	2,854	315	103
		Jean	3,671	3,198	354	120
Perry	OH	Apex	3,692	3,131	416	145
		Caliente	3,519	2,958	416	145
		Beowawe	3,374	2,852	389	133
		Jean	3,774	3,196	428	150
Trojan	OR	Apex	2,202	1,897	244	61
		Caliente	2,031	1,871	136	23
		Beowawe	1,539	1,445	85	9
		Jean	2,121	1,833	233	56
Beaver Valley	PA	Apex	3,819	3,212	499	108
		Caliente	3,645	3,039	499	108
		Beowawe	3,501	2,933	472	96
		Jean	3,901	3,277	510	113
Limerick	PA	Apex	4,389	3,349	843	197
		Caliente	4,216	3,175	843	197
		Beowawe	4,072	3,070	816	186
		Jean	4,471	3,414	855	203
Susquehanna	PA	Apex	4,406	3,412	819	175
		Caliente	4,232	3,238	819	175
		Beowawe	4,088	3,133	791	164
		Jean	4,487	3,477	830	180
Three Mile Island	PA	Apex	4,283	3,330	767	186
		Caliente	4,110	3,157	767	186
		Beowawe	3,966	3,051	739	175
		Jean	4,365	3,395	778	191
Catawba	SC	Apex	4,537	3,756	702	77
		Caliente	4,363	3,583	702	77
		Beowawe	4,219	3,477	675	66
		Jean	4,618	3,821	714	82
H. B. Robinson	SC	Apex	4,513	3,745	688	78
		Caliente	4,339	3,572	688	78
		Beowawe	4,195	3,466	661	67
		Jean	4,594	3,810	700	83
Summer	SC	Apex	4,472	3,782	621	68
		Caliente	4,299	3,609	621	68
		Beowawe	4,154	3,503	594	57
		Jean	4,554	3,847	633	74
Sequoyah	TN	Apex	3,890	3,480	361	48
		Caliente	3,716	3,307	361	48
		Beowawe	3,572	3,201	333	37
		Jean	3,971	3,545	372	53
Watts Bar	TN	Apex	3,887	3,544	286	57
		Caliente	3,714	3,370	286	57
		Beowawe	3,569	3,265	259	46
		Jean	3,969	3,608	298	62
Comanche Peak	TX	Apex	2,890	2,639	213	38
		Caliente	2,716	2,465	213	38
		Beowawe	2,791	2,512	236	43
		Jean	2,445	2,338	101	5
South Texas	TX	Apex	3,055	2,800	206	49
		Caliente	3,228	2,973	206	49
		Beowawe	3,320	2,948	330	43
		Jean	2,973	2,735	194	44
North Anna	VA	Apex	4,521	3,669	686	165
		Caliente	4,347	3,496	686	165
		Beowawe	4,203	3,390	659	153
		Jean	4,602	3,734	698	170

Table J-12. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 4 of 5).

Site	State	Destination	Total[d]	Rural	Suburban	Urban
Commercial sites with direct rail access (continued)						
Vermont Yankee	VT	Apex	4,551	3,519	846	186
		Caliente	4,378	3,345	846	186
		Beowawe	4,233	3,240	818	175
		Jean	4,633	3,584	857	192
WPPSS[j] 2	WA	Apex	1,946	1,807	116	22
		Caliente	1,772	1,634	116	22
		Beowawe	1,565	1,490	66	9
		Jean	2,027	1,872	128	28
Commercial sites with indirect rail access						
Browns Ferry	AL	Apex	3,741	3,332	357	52
HH – 55.4 kilometers		Caliente	3,567	3,158	357	52
		Beowawe	3,423	3,053	329	41
		Jean	3,822	3,397	368	57
Diablo Canyon	CA	Apex	893	609	174	110
HH – 43.5 kilometers		Caliente	1,067	783	174	110
		Beowawe	1,157	872	203	82
		Jean	812	544	162	105
St. Lucie	FL	Apex	4,938	4,073	780	85
HH – 23.3 kilometers		Caliente	4,765	3,899	780	85
		Beowawe	4,621	3,794	753	73
		Jean	4,863	4,006	732	125
Turkey Point	FL	Apex	5,285	4,305	841	138
HH – 17.4 kilometers						
		Caliente	5,111	4,132	841	138
		Beowawe	4,967	4,026	814	126
		Jean	5,366	4,370	853	143
Calvert Cliffs	MD	Apex	4,543	3,448	881	213
HH – 41.9 kilometers		Caliente	4,369	3,275	881	213
		Beowawe	4,225	3,169	854	201
		Jean	4,625	3,513	893	218
Palisades	MI	Apex	3,257	2,816	353	88
HH – 41.9 kilometers		Caliente	3,083	2,642	353	88
		Beowawe	2,939	2,537	326	77
		Jean	3,339	2,881	365	93
Callaway	MO	Apex	2,807	2,636	140	32
HH – 18.5 kilometers		Caliente	2,634	2,462	140	32
		Beowawe	2,490	2,357	113	20
		Jean	2,889	2,701	151	37
Grand Gulf	MS	Apex	3,686	3,355	291	39
HH – 47.8 kilometers		Caliente	3,512	3,181	291	39
		Beowawe	3,368	3,076	264	28
		Jean	3,767	3,419	303	44
Cooper Station	NE	Apex	2,429	2,252	141	36
HH – 53.8 kilometers		Caliente	2,256	2,078	141	36
		Beowawe	2,111	1,973	114	25
		Jean	2,511	2,317	153	42
Fort Calhoun	NE	Apex	2,313	2,189	102	21
HH – 6.0 kilometers		Caliente	2,139	2,015	102	21
		Beowawe	1,995	1,910	75	10
		Jean	2,394	2,254	114	27
Salem/Hope Creek	NJ	Apex	4,551	3,375	946	229
HH – 51.0 kilometers		Caliente	4,378	3,202	946	229
		Beowawe	4,234	3,097	919	218
		Jean	4,633	3,440	958	235
Oyster Creek	NJ	Apex	4,568	3,395	952	221
HH – 28.5 kilometers		Caliente	4,395	3,222	952	221
		Beowawe	4,251	3,116	925	209
		Jean	4,650	3,460	964	226

Table J-12. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 5 of 5).

Site	State	Destination	Total[d]	Rural	Suburban	Urban
Commercial sites with indirect rail access (continued)						
Peach Bottom	PA	Apex	4,304	3,335	778	190
HH – 58.9 kilometers		Caliente	4,131	3,161	778	190
		Beowawe	3,986	3,056	751	179
		Jean	4,386	3,400	790	196
Oconee	SC	Apex	4,257	3,662	534	61
HH – 17.5 kilometers		Caliente	4,084	3,488	534	61
		Beowawe	3,940	3,383	507	50
		Jean	4,339	3,726	545	66
Surry	VA	Apex	4,505	3,927	512	66
HH – 75.2 kilometers		Caliente	4,332	3,753	512	66
		Beowawe	4,188	3,648	484	55
		Jean	4,587	3,992	523	72
Kewaunee	WI	Apex	3,444	2,954	395	95
HH – 9.7 kilometers		Caliente	3,270	2,780	395	95
		Beowawe	3,126	2,675	368	84
		Jean	3,526	3,019	406	100
Point Beach	WI	Apex	3,397	2,938	370	89
HH – 36.4 kilometers		Caliente	3,224	2,765	370	89
		Beowawe	3,080	2,659	343	78
		Jean	3,479	3,003	381	94
DOE spent nuclear fuel and high-level waste (direct rail access)						
Ft. St. Vrain[g]	CO	Apex	1,561	1,453	93	14
		Caliente	1,387	1,280	93	14
		Beowawe	1,298	1,266	29	3
		Jean	1,643	1,518	105	20
INEEL[h]	ID	Apex	1,059	978	66	15
		Caliente	885	804	66	15
		Beowawe	741	699	39	4
		Jean	1,140	1,042	78	21
West Valley[i]	NY	Apex	3,972	3,169	638	165
		Caliente	3,798	2,995	638	165
		Beowawe	3,654	2,890	611	153
		Jean	4,053	3,234	650	170
Savannah River Site[h]	SC	Apex	4,374	3,690	609	75
		Caliente	4,201	3,517	609	75
		Beowawe	4,057	3,411	581	64
		Jean	4,456	3,755	620	80
Hanford Site[h]	WA	Apex	1,933	1,795	116	22
		Caliente	1,760	1,622	116	22
		Beowawe	1,553	1,477	66	9
		Jean	2,015	1,860	128	28

a. The ending rail nodes (INTERLINE computer program designations) are Apex-14763; Caliente-14770; Beowawe-14791; and Jean-16328.
b. To convert kilometers to miles, multiply by 0.62137.
c. This analysis used the INTERLINE computer program to estimate distances.
d. Totals might differ from sums due to method of calculation and rounding.
e. NP = nuclear plant.
f. DOE spent nuclear fuel.
g. DOE spent nuclear fuel and high-level radioactive waste.
h. DOE high-level radioactive waste.
i. WPPSS = Washington Public Power Supply System.

Selection of Highway Routes. The analysis of national transportation impacts used route characteristics of existing highways, such as distances, population densities, and state-level accident statistics. The analysis of highway shipments of spent nuclear fuel and high-level radioactive waste used the HIGHWAY computer model (Johnson et al. 1993a, all) to determine highway routes using regulations of the Department of Transportation (49 CFR 397.101) that specify how routes are selected. The selection of “preferred routes” is required for shipment of these materials. DOE has determined that the HIGHWAY program is appropriate for calculating highway routes and related information (Maheras and

Pippen 1995, pages 2 to 5). HIGHWAY is a routing tool that DOE has used in previous EISs [for example, the programmatic EIS on spent nuclear fuel (DOE 1995, page I-6) and the Waste Isolation Pilot Plant Supplement II EIS (DOE 1997a, pages 5 to 13)] to determine highway routes for impact analysis.

Because the regulations require that the preferred routes result in reduced time in transit, changing conditions, weather, and other factors could result in the use of more than one route at different times for shipments between the same origin and destination. However, for this analysis the program selected only one route for travel from each site to the Yucca Mountain site.

Although shipments could use more than one preferred route in national highway transportation to comply with Department of Transportation regulations (49 CFR 397.101), under current Department of Transportation regulations all preferred routes would ultimately enter Nevada on Interstate 15 and travel to the repository on U.S. Highway 95. States can designate alternative or additional preferred routes for highway shipments (49 CFR 397.103). At this time the State of Nevada has not identified any alternative or additional preferred routes that DOE could use for shipments to the repository.

Selection of Rail Routes. Rail transportation routing of spent nuclear fuel and high-level radioactive waste shipments is not regulated by the Department of Transportation. As a consequence, the routing rules used by the INTERLINE computer program (Johnson et al. 1993b, all) assumed that railroads would select routes using historic practices. DOE has determined that the INTERLINE program is appropriate for calculating routes and related information for use in transportation analyses (Maheras and Pippen 1995, pages 2 to 5). Because the routing of rail shipments would be subject to future, possibly different practices of the involved railroads, DOE could use other rail routes.

For the 19 commercial sites that have the capability to handle and load rail casks but do not have direct rail service, DOE used the HIGHWAY computer program to identify routes for heavy-haul transportation to nearby railheads. For such routes, routing agencies in affected states would need to approve the transport and routing of overweight and overdimensional shipments.

J.1.2.2.2 *Routes for Shipping Rail Casks from Sites Not Served by a Railroad*

In addition to routes for legal-weight trucks and rail shipments, 19 commercial sites that are not served by a railroad, but that have the capability to load rail casks, could ship spent nuclear fuel to nearby railheads using heavy-haul trucks (see Table J-12). Fourteen of these sites are on navigable waterways; some of these could ship by barge to railheads. Distances to the nearest railheads for barge shipments were estimated for each of the 14 reactor sites. These distances are listed in Table J-13.

J.1.2.2.3 *Sensitivity of Analysis Results to Routing Assumptions*

Routing for shipments of spent nuclear fuel and high-level radioactive waste to the proposed repository would comply with regulations of the Department of Transportation and the Nuclear Regulatory Commission in effect at the time shipments would occur. Unless the State of Nevada designates alternative or additional preferred routes, to comply with Department of Transportation regulations all preferred routes would ultimately enter Nevada on Interstate 15 and travel to the repository on U.S. Highway 95. States can designate alternative or additional preferred routes for highway shipments. At this time the State of Nevada has not identified any alternative or additional preferred routes DOE could use for shipments to the repository. Section J.3.1.3 examines the sensitivity of transportation impacts both nationally and regionally (within Nevada) to changes in routing assumption within Nevada.

Table J-13. Barge transportation distances from sites to intermodal rail nodes (kilometers).[a,b]

Site	State	Total[d]	Rural	Suburban	Urban
Browns Ferry	AL	57	52	5	0
Diablo Canyon	CA	143	143	0	0
St. Lucie	FL	140	50	52	39
Turkey Point	FL	54	53	0	1
Calvert Cliffs	MD	99	98	2	0
Palisades	MI	256	256	0	0
Grand Gulf	MS	51	51	0	0
Cooper	NE	117	100	16	1
Salem/Hope Creek	NJ	30	30	0	0
Oyster Creek	NJ	130	77	36	17
Surry	VA	71	60	8	3
Kewaunee	WI	293	285	2	7
Point Beach	WI	301	293	2	7

a. To convert kilometers to miles, multiply by 0.62137.

b. Distances estimated with INTERLINE (Johnson et al. 1993b, all).

c. Intermodal rail nodes selected for purpose of analysis. Source: TRW (1999a, Section 4).

d. Totals might differ from sums due to methods of calculation and rounding.

J.1.3 ANALYSIS OF IMPACTS FROM INCIDENT-FREE TRANSPORTATION

DOE analyzed the impacts of incident-free transportation for shipments of commercial and DOE spent nuclear fuel and DOE high-level radioactive waste that would be shipped under the Proposed Action and Inventory Modules 1 and 2 from 77 sites to the repository. The analysis estimated impacts to the public and workers and included impacts of loading shipping casks at commercial and DOE sites and other preparations for shipment as well as intermodal transfers of casks from heavy-haul trucks or barges to rail cars.

J.1.3.1 Methods and Approach for Analysis of Impacts for Loading Operations

The analysis used methods and assessments developed for spent nuclear fuel loading operations at commercial sites to estimate radiological impacts to involved workers at commercial and DOE sites. Previously developed conceptual radiation shield designs for shipping casks (Schneider et al. 1987, Sections 4 and 5), rail and truck shipping cask dimensions, and estimated radiation dose rates at locations where workers would load and prepare casks (Smith, Daling, and Faletti 1992, page 4.2) for shipment were the analysis bases for loading operations. In addition, tasks and time-motion evaluations from these studies were used to describe spent nuclear fuel handling and loading. These earlier evaluations were based on normal, incident-free operations that would be conducted according to Nuclear Regulatory Commission regulations that establish radiation protection criteria for workers.

The analysis assumed that noninvolved workers would not have tasks that would result in radiation exposure. In a similar manner, the analysis projected that the dose to the public from loading operations would be extremely small, resulting in no or small impacts. A separate evaluation of the potential radiation dose to members of the public from loading operations at commercial nuclear reactor facilities showed that the dose would be very low, less than 0.001 person-rem per metric ton uranium of spent nuclear fuel loaded (DOE 1986, page 2.42, Figure 2.9). Public doses from activities at commercial and DOE sites generally come from exposure to airborne emissions and, in some cases, waterborne effluents containing low levels of radionuclides. However, direct radiation at publicly accessible locations near these sites typically is not measurable and contributes negligibly to public dose and radiological impacts. Though DOE expects no releases from loading operations, this analysis estimated that the dose to the public would be 0.001 person-rem per metric ton uranium, and metric ton equivalents, for DOE spent nuclear fuel and high-level radioactive waste. Noninvolved workers could also be exposed to low levels of radioactive materials and radioactivity from loadout operations. However, because these workers would not work in radiation areas they would receive a very small fraction of the dose received by involved workers. DOE anticipates that noninvolved workers would receive individual doses similar to those received by members of the public. Because the population of noninvolved workers would be small compared to the population of the general public near the 77 sites, the dose to these workers would be a small fraction of the public dose.

The analysis used several basic assumptions to evaluate impacts from loading operations at DOE sites:

- Operations to load spent nuclear fuel and high-level radioactive waste at DOE facilities would be similar to loading operations at commercial facilities.

- Commercial spent nuclear fuel would be in storage pools or in dry storage at the reactors and DOE spent nuclear fuel would be in dry storage, ready to be loaded directly in Nuclear Regulatory Commission-certified shipping casks and then on transportation vehicles. In addition, DOE high-level radioactive waste could be loaded directly in casks. All preparatory activities, including packaging, repackaging, and validating the acceptability of spent nuclear fuel for acceptance at the repository would be complete prior to loading operations.

- Commercial spent nuclear fuel to be placed in the shipping casks would be uncanistered or canistered fuel assemblies, with at least one assembly in a canister. DOE spent nuclear fuel and high-level radioactive waste would be in disposable canisters. Typically, uncanistered assemblies would be loaded into shipping casks under water in storage pools (wet storage). Canistered spent nuclear fuel could be loaded in casks directly from dry storage facilities or storage pools.

In addition, because handling and loading operations for DOE spent nuclear fuel and high-level radioactive waste and commercial spent nuclear fuel would be similar, the analysis assumed that impacts to workers during the loading of commercial spent nuclear fuel could represent those for the DOE materials, even though the radionuclide inventory of commercial fuel and the resultant external dose rate would be higher than those of the DOE materials. This conservative assumption of selecting impacts from commercial handling and loading operations overestimated the impacts of DOE loading operations, but it enabled the use of detailed real information developed for commercial loading operations to assess impacts for DOE operations. Equivalent information was not available for operations at DOE facilities. To gauge the conservatism of the assumption DOE compared the radioactivity of contents of shipments of commercial and DOE spent nuclear fuel and high-level radioactive waste. Table J-14 compares typical inventories of important contributors to the assessment of worker and public health impacts. These are cesium-137 and actinide isotopes (including plutonium) for rail shipments of commercial spent nuclear fuel, DOE spent nuclear fuel, and DOE high-level radioactive waste. Although other factors are also important (for example, material form and composition), these indicators provide an index of the relative hazard potential of the materials. Appendix A contains additional information on the radionuclide inventory and characteristics of spent nuclear fuel and high-level radioactive waste.

J.1.3.1.1 *Radiological Impacts of Loading Operations at Commercial Sites*

In 1987, DOE published a study of the estimated radiation doses to the public and workers resulting from the transport of spent nuclear fuel from commercial nuclear power reactors to a hypothetical deep geologic repository (Schneider et al. 1987, all). This study was based on a single set of spent nuclear fuel characteristics and a single split [30 percent/70 percent by weight; 900 metric tons uranium/2,100 metric tons uranium per year] between truck and rail conveyances. DOE published its findings on additional radiological impacts on monitored retrievable storage workers in an addendum to the 1987 report (Smith, Daling, and Faletti 1992, all). The technical approaches and impacts summarized in these DOE reports

Table J-14. Typical cesium-137, actinide isotope, and total radioactive material content (curies) in a rail shipping cask.[a]

Material	Cesium-137	Actinides (excluding uranium)[b]	Total
Commercial spent nuclear fuel	810,000	650,000	2,000,000
High-level radioactive waste	120,000	40,000[c]	280,000
DOE spent nuclear fuel (except naval spent nuclear fuel)	260,000	160,000	620,000
Naval spent nuclear fuel	550,000	30,000	1,200,000

a. Source: Appendix A. Source estimated based on 36 typical pressurized-water reactor fuel assemblies for commercial spent nuclear fuel; one dual-purpose shipping canister for naval spent fuel; five canisters of DOE spent nuclear fuel; and five canisters of high-level radioactive waste.

b. Uranium would not be an important contributor to health and safety risk.

c. Includes plutonium can-in-canister with high-level radioactive waste.

were used to project involved worker impacts that would result from commercial at-reactor spent nuclear fuel loading operations. DOE did not provide a separate analysis of noninvolved worker impacts in these reports. For the analysis in this EIS, DOE assumed that noninvolved workers would not receive radiation exposures from loading operations. This assumption is appropriate because noninvolved workers would be personnel with managerial or administrative support functions directly related to the loading tasks but at locations, typically in offices, away from areas where loading activities took place.

In the DOE study, worker impacts from loading operations were estimated for a light-water reactor with pool storage of spent nuclear fuel. The radiological characteristics of the spent nuclear fuel in the analysis was 10-year-old, pressurized-water reactor fuel with an exposure history (burnup) of 35,000 megawatt-days per metric ton. In addition, the reference pressurized-water reactor and boiling-water reactor fuel assemblies were assumed to contain 0.46 and 0.19 MTU, respectively, prior to reactor irradiation. These parameters for spent nuclear fuel are similar to those presented in Appendix A of this EIS. The use of the parameters for spent nuclear fuel presented in Appendix A would be likely to lead to similar results.

In the 1987 study, radiation shielding analyses were done to provide information on (1) the conceptual configuration of postulated reference rail and truck transportation casks, and (2) the direct radiation levels at accessible locations near loaded transportation casks. The study also presented the results of a detailed time-motion analysis of work tasks that used a loading concept of operations. This task analysis was coupled with cask and at-reactor direct radiation exposure rates to estimate radiation doses to involved workers (that is, those who would participate directly in the handling and loading of the transportation casks and conveyances). Impacts to members of the public from loading operations had been shown to be small [fraction of a person-millirem population dose; (Schneider et al. 1987, page 2.9)] and were eliminated from further analysis in the 1987 report. The at-reactor-loading concept of operations included the following activities:

1. Receiving the empty transportation cask at the site fence

2. Preparing and moving the cask into the facility loading area

3. Removing the cask from the site prime mover trailer

4. Preparing the cask for loading and placing it in the water-filled loading pit

5. Transferring spent nuclear fuel from its pool storage location to the cask

6. Removing the cask from the pool and preparing it for shipment

7. Placing the cask on the site prime mover trailer

8. Moving the loaded cask to the site fence where the trailer is connected to the transportation carrier's prime mover for offsite shipment

The results for loading operations are listed in Table J-15.

Table J-15. Principal logistics bases and results for the reference at-reactor loading operations.[a]

	Conveyance		
Parameter	Rail[b]	Truck[c]	Total
Annual loading rate (MTU/year)[d]	2,100	900	3,000
Transportation cask capacity, PWR - BWR (MTU/cask)	6.5/6.70	0.92/0.93	NA[e]
Annual shipment rate (shipments/year)	320	970	1,290
Average loading duration,[f] PWR - BWR (days)	2.3/2.5	1.3/1.4	NA
Involved worker specific CD,[g] PWR - BWR (person-rem/MTU)	0.06/0.077	0.29/0.31	NA

a. Source: Schneider et al. (1987, pages 2.5 and 2.7).
b. 14 pressurized-waste reactor and boiling-water reactor spent nuclear fuel assemblies per rail transportation cask.
c. 2 pressurized-waste reactor and boiling-water reactor spent nuclear fuel assemblies per truck transportation cask.
d. MTU = metric tons of uranium.
e. NA = not applicable.
f. Based on single shift operations; carrier drop-off and pick-up delays were not included.
g. Collective dose expressed as the sum of the doses accumulated by all loading (involved) workers, regardless of the total number of workers assigned to loading tasks.

The loading activities that the study determined would produce the highest collective unit impacts are listed in Table J-16. As listed in this table, the involved worker collective radiation doses would be dominated by tasks in which the workers would be near the transportation cask when it contained spent nuclear fuel, particularly when they were working around the cask lid area. These activities would deliver at least 40 percent of the total collective worker doses. Worker impacts from the next largest dose-producing tasks (working to secure the transportation cask on the trailer) would account for 12 to 19 percent of the total impact. The impacts are based on using crews of 13 workers [the number of workers assumed in the Schneider et al. (1987, Section 2) study] dedicated solely to performing cask-handling work. The involved worker collective dose was calculated using the following formula:

$$\text{Collective dose (person-rem)} = A \times B \times C \times D \times E$$

where: A = number of pressurized-water or boiling-water reactor spent nuclear fuel shipments being analyzed under each transportation scenario (from Tables J-5 and J-6)

B = number of transportation casks included in a shipment (set at 1 for both transportation scenarios)

C = number of pressurized-water or boiling-water reactor spent nuclear fuel assemblies in a transportation cask (from Table J-3)

D = amount of uranium in the spent nuclear fuel assembly prior to reactor irradiation, expressed as metric tons uranium per assembly (from Table J-15)

E = involved worker-specific collective dose in person-rem/metric ton uranium for each fuel type (from Table J-15)

Table J-16. At-reactor reference loading operations—collective impacts to involved workers.[a]

Task description	Rail CD/MTU[b] (PWR - BWR)[c]	Rail Percent of total impact	Truck CD/MTU (PWR - BWR)	Truck Percent of total impact
Install cask lids; flush cask interior; drain, dry and seal cask	0.025/0.024	40/31	0.126/0.126	43/40
Install cask binders, impact limiters, personnel barriers	0.010/0.009	15/12	0.056/0.055	19/18
Load SNF into cask	0.011/0.027	17/35	0.011/0.027	4/9
On-vehicle cask radiological decontamination and survey	0.003/0.003	5/4	0.018/0.018	6/6
Final inspection and radiation surveys	0.002/0.002	4/3	0.016/0.015	5/5
All other (19) activities	0.011/0.012	19/16	0.066/0.073	23/23
Task totals	**0.062/0.077**	**100/100**	**0.29/0.31**	**100/100**

a. Source: Schneider et al. (1987, page 2.9).

b. CD/MTU = Collective dose (person-rem effective dose equivalent) per metric ton uranium. The at-reactor loading

c. crew size is 13 involved workers.

d. PWR = pressurized-water reactor; BWR = boiling-water reactor.

Because worker doses are linked directly to the number of loading operations performed, the highest average individual doses under each transportation scenario would occur at the reactor sites having the most number of shipments. Accordingly, the average individual dose impacts were calculated for the limiting site using the equation:

$$\text{Average individual dose (rem per involved worker)} = (A \times B \times C \times D \times E) \div F$$

where: A = largest value for the number of shipments from a site under each transportation scenario (from Tables J-5 and J-6)

B = number of transportation casks included in a shipment (set at 1 for both transportation options)

C = number of spent nuclear fuel assemblies in a transportation cask (from Table J-3)

D = amount of uranium in the spent nuclear fuel assembly prior to reactor irradiation in metric tons uranium per assembly (from Table J-15)

E = involved worker-specific collective dose in person-rem per metric ton uranium for each fuel type (from Table J-15)

F = involved worker crew size (set at 13 persons for both transportation options; from Table J-16)

J.1.3.1.2 *Radiological Impacts of DOE Spent Nuclear Fuel and High-Level Radioactive Waste Loading Operations*

The methodology used to estimate impacts to workers during loading operations for commercial spent nuclear fuel was also used to estimate impacts of loading operations for DOE spent nuclear fuel and high-level radioactive waste. The exposure factor for loading boiling-water reactor spent nuclear fuel in truck casks at commercial facilities (person-rem per MTU) was used (see Table J-16). The exposure factor for truck shipments of boiling-water reactor spent nuclear fuel was based on a cask capacity of five boiling-water reactor spent nuclear fuel assemblies (about 0.9 MTHM). The analysis used this factor because it would result in the largest estimates for dose per operation.

J.1.3.2 Methods and Approach for Analysis of Impacts from Incident-Free Transportation

The potential exists for human health impacts to workers and members of the public from incident-free transportation of spent nuclear fuel and high level radioactive waste. *Incident-free* transportation means normal accident-free shipment operations during which traffic accidents and accidents in which radioactive materials could be released do not occur; these are addressed separately in Section J.1.4. Incident-free impacts could occur from exposure to (1) external radiation in the vicinity of the transportation casks, or (2) transportation vehicle emissions, both during normal transportation.

J.1.3.2.1 *Incident-Free Radiation Dose to Populations*

The analysis used the RADTRAN4 computer program (Neuhauser and Kanipe 1992, all) to evaluate incident-free impacts for populations. The RADTRAN4 input parameters used to estimate incident-free impacts are listed in Table J-17. Through extensive review (Maheras and Pippen 1995, Section 3 and 4), DOE has determined that this program provides valid estimates of population doses for use in the evaluation of risks of transporting radioactive materials, including spent nuclear fuel and high-level radioactive waste. DOE has used the RADTRAN4 code to analyze transportation impacts for other environmental impact statements (for example, DOE 1995, Appendix E; DOE 1997b, Appendixes F and G). The program used population densities from 1990 census data to calculate the collective dose to populations that live along transportation routes [within 800 meters (0.5 mile) of either side of the route]. Table J-18 lists the estimated number of people who live within 800 meters of national routes.

The analysis used five kinds of information to estimate collective doses to populations:

- External radiation dose rate around shipping casks
- Number of people who would live within 800 meters (0.5 mile) along the routes of travel
- Distances individuals would live from the routes
- Amount of time each individual would be exposed as a shipment passed by
- Number of shipments that would be transported over each route

The first four were developed using the data listed in Table J-19. The fifth kind of information (the number of shipments that would use a transportation route) was developed with the use of the CALVIN computer program discussed in Section J.1.1.1, the DOE Throughput Study (TRW 1997, Section 6.1.1), data on DOE spent nuclear fuel and high-level radioactive waste inventories in Appendix A, and data from DOE sites (Jensen 1998, all). The analysis used CALVIN to estimate the number of shipments from each commercial site. The Throughput Study provided the estimated number of shipments of high-level radioactive waste from the four DOE sites. Information provided by the DOE National Spent Nuclear Fuel Program (Jensen 1998, all) and in Appendix A was used to estimate shipments of DOE spent nuclear fuel.

The analysis used a value of 10 millirem per hour at a distance of 2 meters (6.6 feet) from the side of a transport vehicle for the external dose rate around shipping casks. This value is the maximum allowed by regulations of the Department of Transportation for shipments of radioactive materials [49 CFR 173.441(b)]. Dose rates at distances greater than 2 meters from the side of a vehicle would be less. The dose rate at 30 meters (100 feet) from the vehicle would be less than 0.2 millirem per hour; at a distance of 800 meters (2,625 feet) the dose rate would be less than 0.0002 millirem per hour.

Table J-17. Input parameters and parameter values used for the incident-free national truck and rail transportation analysis.

Parameter	Legal-weight truck transportation	Rail transportation	Legal-weight truck and rail
Package type			Type B shipping cask
Package dimension			4.77 meters[a] long
Dose rate			10 millirem per hour, 2 meters from side of vehicle
Number of crewmen	2	5	
Distance from source to crew	3 meters	152 meters	
Speed			
Rural	88 km[b] per hour	64 km per hour	
Suburban			40 km per hour
Urban			24 km per hour
Stop time per km	0.011 hours per km	0.033 hours per km[c]	
Number of people exposed while stopped	50	Based on suburban population density	
Number of people per vehicle sharing route	2	3	
Population densities (persons per km^2)[d]			
Rural			(e)
Suburban			(e)
Urban			(e)
One-way traffic count (vehicles per hour)			
Rural	470	1	
Suburban	780	5	
Urban	2,800	5	

a. To convert meters to feet, multiply by 3.2808.

b. To convert kilometers (km) to miles, multiply by 0.62137.

c. Assumes general freight rather than dedicated service.

d. To convert square kilometers to square miles, multiply by 0.3861.

e. Population densities along transportation routes were estimated using the HIGHWAY and INTERLINE computer programs. These programs used 1990 Census data.

Table J-18. Population within 800 meters (0.5 mile) of routes for incident-free transportation using 1990 census data.

Transportation scenario	1990 Census data
Mostly legal-weight truck	7,200,000
Mostly rail	11,100,000

a. Source: TRW (1999a, pages 18 and 19).

The second kind of information used in the analysis was the number of people who potentially would be close enough to shipments to be exposed to radiation from the casks. The analysis determined the estimated offlink number of people [those within the 1.6-kilometer (1-mile) region of influence] by multiplying the population densities (persons per square kilometer) in population zones through which a route would pass by the 1.6-kilometer width of the region of influence and by the length of the route through the population zones. Onlink populations (those sharing the route and people at stops along the route) were estimated using assumptions from other EISs that have evaluated transportation impacts (DOE 1995, Appendix I; DOE 1996a, Appendix E; DOE 1997b, Appendixes F and G). The travel distance in each population zone was determined for legal-weight truck shipments by using the HIGHWAY computer program (Johnson et al. 1993a, all) and for rail shipments by using the

Table J-19. Information used for analysis of incident-free transportation impacts.

Population zones	Population within 800 meters[a] (per kilometer of route)	Travel speed (kilometers per hour) Legal-weight truck	Heavy-haul truck	Rail	Dose rate 2 meters[b] from vehicle (millirem per hour)
Urban	(c)	24	24	24[d]	10
Suburban	(c)	40[d]	40	40	10
Rural	(c)	88	40	64	10

a. 800 meters = about 2,600 feet.

b. 2 meters = about 6.6 feet.

c. Estimates of population within 800 meters of a route are based on analysis of census block data using HIGHWAY (Johnson et al. 1993a, all) and INTERLINE (Johnson et al. 1993b, all) computer programs. The analysis used actual populations along routes based on the 1990 Census.

d. Analysis of impacts for shipments of naval spent nuclear fuel used 40 kilometers (25 miles) per hour for heavy-haul truck speed and 24 kilometers (15 miles) per hour for train speed in urban, suburban, and rural zones.

INTERLINE program (Johnson et al. 1993b, all). These programs used 1990 census block group data to identify where highways and railroads enter and exit each type of population zone, which the analysis used to determine the total lengths of the highways and railroads in each population zone.

The third kind of information—the distances individuals live from the route used in the analysis—is the estimated the number of people who live within 800 meters (about 2,600 feet) of the route. The analysis assumed that population density is uniform in population zones.

The determination of the fourth kind of information used in the analysis—the time that people could be exposed as shipments passed—was based on the assumed travel speed of shipments in each population zone along the route. For example, travel at 24 kilometers (15 miles) an hour in urban areas would lead to a longer exposure time than travel at 88 kilometers (55 miles) an hour in rural areas. Persons in vehicles traveling along a route with a shipment of spent nuclear fuel or high-level radioactive waste or persons who lived near railyards where shipments would be switched between trains could be exposed for longer periods.

With the five kinds of information, the analysis used RADTRAN4 to calculate exposures for the following groups:

- *Public along the route (Offlink Exposure):* Collective doses for persons living or working within 0.8 kilometer (0.5 mile) on each side of the transportation route.

- *Public sharing the route (Onlink Exposure):* Collective doses for persons in vehicles sharing the transportation route; this includes persons traveling in the same or opposite direction and those in vehicles passing the shipment.

- *Public during stops (Stops):* Collective doses for people who could be exposed while a shipment was stopped en route. For truck transportation, these would include stops for refueling, food, and rest. For rail transportation, stops would occur in railyards along the route to switch railcars from inbound trains to outbound trains traveling toward the Yucca Mountain site, and to change train crews and equipment (locomotives).

- *Worker exposure (Occupational Exposure):* Collective doses for truck and rail transportation crew members.

- *Security escort exposure (Occupational Exposure):* Collective doses for security escorts. In calculating doses to workers the analysis conservatively assumed that the maximum number of escorts required by regulations (10 CFR 73.37) would be present for urban, suburban, and rural population zones.

The sum of the doses for the first three categories is the total nonoccupational (public) dose.

Unit dose factors were used to calculate collective dose. These factors, which are listed in Table J-20, represent the dose that would be received by a population of 1 person per square kilometer for one shipment of radioactive material moving a distance of 1 kilometer (0.62 mile) in the indicated population density zone. The unit dose factors for incident-free transportation reflect the assumption that the dose rate external to shipments of spent nuclear fuel and high-level radioactive waste would be the maximum value allowed by Department of Transportation regulations—10 millirem per hour at 2 meters (6 feet) from the side of the transport vehicle (49 CFR 173.441). The incident-free dose from transporting a single shipment was determined by multiplying the appropriate unit dose factors by corresponding distances in each of the population zones the shipment route passes through and the population density of the zone. The collective dose from all shipments from a site were determined by multiplying the dose from a single shipment by the number of shipments that would be required to transport the site's spent nuclear fuel or high-level radioactive waste to the repository. Collective dose was converted to the estimated number of latent cancer fatalities using conversion factors recommended by the International Commission on Radiological Protection (ICRP 1991, page 22). These values are 0.0004 for radiation workers and 0.0005 for the general population.

Table J-20. Unit dose factors for incident-free national truck and rail transportation of spent nuclear fuel and high-level radioactive waste.

		Unit dose factors (person-rem per kilometer)[a]		
Mode	Exposure group	Rural	Suburban	Urban
Truck	*Involved worker*	4.56×10^{-5}	1×10^{-4}	1.67×10^{-4}
	Public			
	Offlink[b]	3.2×10^{-8}	3.52×10^{-8}	4.33×10^{-8}
	Onlink[c]	7.81×10^{-6}	2.25×10^{-5}	2.32×10^{-4}
	Stops	1.87×10^{-4}	1.87×10^{-4}	1.87×10^{-4}
Rail	*Involved worker*[d]	1.22×10^{-5}	1.22×10^{-5}	1.22×10^{-5}
	Public			
	Offlink	4.38×10^{-8}	7.02×10^{-8}	1.17×10^{-7}
	Onlink	1.03×10^{-7}	1.32×10^{-6}	3.65×10^{-6}
	Stops[e]	7.42×10^{-6}	7.42×10^{-6}	7.42×10^{-6}

a. The methodology, equations, and data used to develop the unit dose factors are discussed in Madsen et al. (1986, all) and Neuhauser and Kanipe (1992, page 4-15). Cashwell et al. (1986, page 44) contains a detailed explanation of the use of unit factors.

b. Offlink general population included persons within 800 meters (2,625 feet) of the road or railway.

c. Onlink general population included persons sharing the road or railway.

d. The nonlinear component of incident-free rail dose for crew workers because of railcar inspections and classifications is 0.014 person-rem per shipment. Ostmeyer (1986, all) contains a detailed explanation of the rail exposure model.

e. The nonlinear component of incident-free rail dose for the general population because of railcar inspections and classifications is 0.0014 person-rem per shipment. Ostmeyer (1986, all) contains a detailed explanation of the rail exposure model.

J.1.3.2.2 *Methods Used To Evaluate Incident-Free Impacts to Maximally Exposed Individuals.*

To estimate impacts to maximally exposed individuals, the same kinds of information as those used for population doses (except for population size) was needed. The analysis of doses to maximally exposed individuals used projected exposure times, the distance a hypothetical individual would be from a shipment, the number of times an exposure event could occur, and the assumed external radiation dose rate 2 meters (6.6 feet) from a shipment (10 millirem per hour). These analyses used the RISKIND computer program (Yuan et al. 1995, all). DOE has used RISKIND for analyses of transportation impacts in other environmental impact statements (DOE 1995, Appendix J; DOE 1996a, Appendix E; DOE 1997b, Appendix E). RISKIND provides appropriate results for analyses of incident-free transportation and transportation accidents involving radioactive materials (Maheras and Pippen 1995, Sections 5.2 and 6.2; Biwer et al. 1997, all).

The maximally exposed individual is a hypothetical person who would receive the highest dose. Because different maximally exposed individuals can be postulated for different exposure scenarios, the analysis evaluated the following exposure scenarios.

- *Crew Members.* In general, truck crew members, including security escorts and rail security escorts, would receive the highest doses during incident-free transportation (see discussion in J.1.3.2.2.1 below). The analysis assumed that the crews would be limited to a total job-related exposure of 2 rem per year (DOE 1994, Article 211).

- *Inspectors (Truck and Rail).* Inspectors would be Federal or state vehicle inspectors. On the basis of information provided by the Commercial Vehicle Safety Alliance (Battelle 1998, all; CVSA 1999, all), the analysis assumed an average exposure distance of 1 meter (3 feet) and an exposure duration of 1 hour (see discussion in J.1.3.2.2).

- *Railyard Crew Member.* For a railyard crew member working in a rail classification yard assembling trains, the analysis assumed an average exposure distance of 10 meters (33 feet) and an exposure duration of 2 hours (DOE 1997b, page E-50).

- *Resident.* The analysis assumed this maximally exposed individual is a resident who lives 30 meters (100 feet) from a point where shipments would pass. The resident would be exposed to all shipments along a particular route (DOE 1995, page I-52).

- *Individual Stuck in Traffic (Truck or Rail).* The analysis assumed that a member of the public could be 1.2 meter (4 feet) from the transport vehicle carrying a shipping cask for 1 hour. Because these circumstances would be random and unlikely to occur more than once for the same individual, the analysis assumed the individual to be exposed only once.

- *Resident near a Rail Stop.* The analysis assumed a resident who lives within 200 meters (660 feet) of a switchyard and an exposure time of 20 hours for each occurrence. The analysis of exposure for this maximally exposed individual assumes that the same resident would be exposed to all rail shipments to the repository (DOE 1995, page I-52).

- *Person at a Truck Service Station.* The analysis assumed that a member of the public (a service station attendant) would be exposed to shipments for 1 hour for each occurrence at a distance of 20 meters (70 feet). The analysis also assumed this individual would work at a location where all truck shipments would stop.

As discussed above for exposed populations, the analysis converted radiation doses to estimates of radiological impacts using dose-to-risk conversion factors of the International Commission on Radiological Protection.

J.1.3.2.2.1 Incident-Free Radiation Doses to Inspectors. DOE estimated radiation doses to the state inspectors who would inspect shipments of spent nuclear fuel and high-level radioactive waste originating in, passing through, or entering a state. For legal-weight truck and railcar shipments, the analysis assumed that:

- Each inspection would involve one individual working for 1 hour at a distance of 2 meters (6.6 feet) from a shipping cask.
- The radiation field surrounding the cask would be the maximum permitted by regulations of the Department of Transportation (49 CFR 173.441).
- There would be no shielding between an inspector and a cask.

For rail shipments, the analysis assumed that:

- There would be a minimum of two inspections per trip—one at origin and one at destination—with additional inspections in route occurring about once every 500 kilometers (300 miles) of railcar travel.
- Rail crews would conduct the remaining along-the-route inspections.

For legal-weight truck shipments, the analysis assumed that:

- On average, state officials would conduct two inspections during each trip – one at the origin and one at the destination.
- The inspectors would use the Enhanced North American Uniform Inspection Procedures and Out-of-Service Criteria for Commercial Highway Vehicles Transporting Transuranics, Spent Nuclear Fuel, and High-Level Radioactive Waste (CVSA 1999, all).
- The shipments would receive a Commercial Vehicle Safety Alliance inspection sticker on passing inspection and before departing from the 77sites.
- Display of such a sticker would provide sufficient evidence to state authorities along a route that a shipment complied with Department of Transportation regulations (unless there was contradictory evidence), and there would be no need for additional inspections.

The analysis determined doses to state inspectors in two ways. For rail shipments, inspector doses were based on the equations and assumptions used in the RADTRAN4 computer program. The program uses an empirically derived equation that is based on observations of rail classification yard operations, as follows:

$$\text{Dose} = K_0 \times \text{dose rate} \times \text{casks per shipment} \times \text{number of shipments} \times 0.\ 16 \times 0.001$$

where:

dose = rem of exposure to an inspector

K_0 = a shape factor for the cask assumed for purposes of analysis (meters); 6 meters for rail cask that would ship spent nuclear fuel

dose rate = the dose rate in millirem per hour 1 meter from the surface of the cask; set to 14 millirem per hour for the analysis

casks per shipment = the average number of casks (one cask per railcar) in a train; set to 1 for the analysis

number of shipments = number of shipments inspected (set to 1 for the analysis)

0.16 = exposure factor that translates the product of cask dose rate and shape factor into inspector dose (meters per hour)

0.001 = conversion factor to convert millirem per hour to rem per hour.

The equation shows that the calculated value for whole-body dose to an individual inspector for one inspection would be 13.4 millirem. An inspector in Nevada who inspected all rail shipments under the mostly rail scenario would receive a whole body dose of 470 × 13.4 = 6.3 rem in a year. If the same inspector inspected all shipments over the 24 years of the Proposed Action, he or she would be exposed to 150 rem. Using the dose to risk conversion factors published by the International Commission on Radiation Protection, this exposure would increase the likelihood of the inspector incurring a fatal cancer. This would add 6 percent to the likelihood for fatal cancers from all other causes, increasing the likelihood from approximately 23 percent (ACS 1998, page 10) to 29 percent.

For shipments by legal-weight truck, the analysis used the RISKIND computer program to estimate doses to inspectors (Yuan et al. 1995, all). The data used by the code to calculate dose includes the estimated value for dose rate at 1 meter (3.3 feet) from a cask surface, the length and diameter of the cask, the distance between the location of the individual and the cask surface, and the estimated time of exposure. For this calculation, the analysis assumed that an inspector following Commercial Vehicle Safety Alliance procedures (CVSA 1999, all) would work for 1 hour at an average distance of 2 meters (6.6 feet) from the cask. The analysis assumed that a typical legal-weight truck cask would be about 1 meter in diameter and about 5 meters (16 feet) long and that the dose rate 1 meter from the cask surface would be 14 millirem per hour. A dose rate of 14 millirem per hour 1 meter from the surface of a truck cask is approximately equivalent to the maximum dose rate allowed by Department of Transportation regulations for exclusive-use shipments of radioactive materials (49 CFR 173.441).

Using this data, the RISKIND computer code calculated an expected dose of 18 millirem for an individual inspector. Under the mostly legal-weight truck scenario in which approximately 2,100 legal-weight truck shipments would arrive in Nevada annually, a Nevada inspector working 1,800 hours per year could inspect as many as 470 shipments in a year. This inspector would receive a whole-body dose of 8.5 rem. If this same inspector inspected all shipments over the 24 years of the Proposed Action, he or she would be exposed to 204 rem. Using the dose to risk conversion factors published by the International Commission on Radiation Protection, this exposure would increase the likelihood of this individual contracting a fatal cancer. This would add about 8 percent to the likelihood for fatal cancers from all other causes, increasing the likelihood from approximately 22 percent (ACS 1998, page 10) to 32 percent.

Under the mostly legal-weight truck scenario, the annual committed dose to inspectors in a state that inspected all incoming legal-weight truck shipments containing spent nuclear fuel or high-level radioactive waste would be about 38 person-rem. Over 24 years, the population dose for these inspectors would be about 910 person-rem. This would result in about 0.34 latent cancer fatality (this is equivalent to a 36-percent likelihood that there would be 1 additional latent cancer fatality among the exposed group).

DOE implements radiation protection programs at its facilities where there is the potential for worker exposure to cumulative doses from ionizing radiation. The Department anticipates that the potential for individual whole-body doses such as those reported above would lead an involved state to implement such a radiation protection program. If similar to those for DOE facilities, the administrative control limit on individual dose would not exceed 2 rem per year (DOE 1994, Article 211) and the expected maximum exposure for inspectors would be less than 500 millirem per year.

J.1.3.2.2.2 Incident-Free Radiation Doses to Escorts. Transporting spent nuclear fuel to the Yucca Mountain site would require the use of physical security and other escorts for the shipments. Regulations (10 CFR 73.37) require escorts for highway and rail shipments. These regulations require two escorts (individuals) for truck shipments traveling in highly populated (urban) areas. One of the escorts must be in a vehicle that is separate from the shipment vehicle. For rail shipments in urban areas, at least two escorts must maintain visual surveillance of a shipment from a railcar that accompanies a cask car.

In areas that are not highly populated (suburban and rural), one escort must accompany truck shipments. The escort can ride in the cab of the shipment vehicle. At least one escort is required for rail shipments in suburban and rural areas. However, for rail shipments, the escort must occupy a railcar that is separate from the cask car and must maintain visual surveillance of the shipment at all times.

For legal-weight truck shipments, the analysis assumed that a second driver, who would be a member of the vehicle crew, would serve as an escort in all areas. The analysis assigned a second escort for travel in urban areas and assumed that this escort would occupy a vehicle that followed or led the transport vehicle by at least 60 meters (about 200 feet). The analysis assumed that the dose rate at a location 2 meters (6.6 feet) behind the vehicle would be 10 millirem per hour, which is the limit allowed by Department of Transportation regulations (49 CFR 173.441). Using this information, the analysis used the RISKIND computer program to calculate a value of approximately 0.11 millirem per hour for the dose rate 60 meters behind the transport vehicle; this is the estimated value for the dose rate in a following escort vehicle. The value for the dose rate in an escort vehicle that preceded a shipment would be lower. Because the dose rate in the occupied crew area of the transport vehicle would be less than 2 millirem per hour, the dose rate 2 meters in front of the vehicle would be much less than 10 millirem per hour, the value assumed for a location 2 meters behind the vehicle. The value of 2 millirem per hour in normally occupied areas of transport vehicles is the maximum allowed by Department of Transportation regulations (49 CFR 173.441).

To calculate the dose to escorts, the analysis assumed that escorts in separate vehicles would be required in urban areas as shipments traveled to the Yucca Mountain site. The calculations used the RISKIND computer program (Yuan et al. 1995, all); the distance of travel in urban areas provided by the HIGHWAY and INTERLINE computer codes; and the estimated speed of travel in urban areas based on data in Table J-19 to estimate the total dose to escorts. For example, truck shipments could be escorted through an average of five urban areas on average for 30 minutes in each. Using these assumptions and the estimated dose rate in an escort vehicle, the estimated dose for escorts in separate vehicles is 0.28 millirem per shipment (0.28 millirem = 5 areas per shipment × 0.5 hour per area × 0.11 millirem per hour). For the 24 years of the Proposed Action, the total dose to escorts in separate vehicles would, therefore, be about 14 rem (0.28 millirem per shipment × 50,000 shipments). This dose would lead to 0.02 latent cancer fatality in the population of escorts who would be affected.

For rail shipments, the analysis assumed that escorts would be 30 meters (98 feet) away from the end of the shipping cask on the nearest railcar. This separation distance is the sum of the:

- Length of a buffer car [about 15 meters (49 feet)] between a cask car and an escort car required by Department of Transportation regulations (49 CFR 174.89),
- Normal separation between cars [a total of about 2 meters (6.6 feet) for two separations],
- Distance from the end of a cask to the end of its rail car [about 5 meters (16 feet)], and
- Assumed average distance from the escort car's near-end to its occupants [5 to 10 meters (16 to 32 feet)].

This analysis assumed that the dose rate at 2 meters (6.6 feet) from the end of the cask car would be 10 millirem per hour, the maximum allowed by Department of Transportation regulations (49 CFR 173.441). The analysis used these assumptions and the RISKIND computer program to estimate 0.46 millirem per hour as the dose rate in the occupied areas of the escort railcar. For example, an individual escort who occupied the escort car continuously for a 5-day cross-country trip would receive a maximum dose of about 55 millirem. Escorting 26 shipments in a year, this individual would receive a maximum dose of 1.4 rem. Over the 24 years of the Proposed Action, if the same individual escorted 26 shipments every year, he or she would receive a dose of about 34 rem. Using the dose-to-risk conversion factors recommended by the International Commission on Radiation Protection (ICRP 1991, page 22), this dose would increase the potential for the individual to contract a fatal cancer from about 22 percent (ACS 1998, page 10) to 24 percent.

J.1.3.2.3 *Vehicle Emission Impacts*

Human health impacts from exposures to vehicle exhaust depend principally on the distance traveled in an urban population zone and on the impact factors for particulates and sulfur dioxide from truck (including escort vehicles) or rail emissions, fugitive dust generation, and tire abrasion (DOE 1995, page I-52).

The analysis estimated incident-free impacts from nonradiological causes using unit risk factors that account for both fatalities associated with the emissions of pollution in urban, suburban, and rural areas by transportation vehicles, including escort vehicles. Because the impacts would occur equally for trucks transporting loaded or unloaded shipping casks, the analysis used round-trip distances. Escort vehicle impacts were included only for loaded shipment miles.

The analysis used impact factors for effects on urban areas of 0.00000016 fatality per urban mile traveled (0.0000001 fatality per kilometer) by trucks and 0.00000021 fatality per urban mile traveled (0.00000013 fatality per kilometer) by trains (Rao, Wilmot, and Luna 1982, all). The region of influence used in the analysis for exposure to vehicle emissions was a band between 30 and 805 meters (98 and 2,640 feet) wide on both sides of the transportation route.

In addition to unit risk factors used to estimate impacts from vehicle emissions in urban areas, an additional factor was used to estimate health effects from vehicle exhaust emissions in rural areas. Based on data in a study by the Environmental Protection Agency that addressed latent cancer consequences of vehicle exhausts, a factor of 0.000000000072 fatality per kilometer traveled was calculated for use in rural and suburban population zones (DOE 1995, page I-52).

Although the analysis estimated human health and safety impacts of transporting spent nuclear fuel and high-level radioactive waste, exhaust and other pollutants emitted by transport vehicles into the air would not measurably affect national air quality. National transportation of spent nuclear fuel and high-level radioactive waste, which would use existing highways and railroads would average 14.2 million truck kilometers per year for the mostly truck case and 3.5 million railcar kilometers per year from the mostly rail case. The national yearly average for total highway and railroad traffic is 186 billion truck kilometers and 49 billion railcar kilometers (BTS 1999, Table 3-22). Spent nuclear fuel and high-level radioactive waste transportation would represent a very small fraction of the total national highway and railroad traffic (0.008 percent of truck kilometers and 0.007 percent of rail car kilometers). In addition, the contributions to vehicle emissions in the Las Vegas air basin, where all truck shipments (an average of five per day) would travel under the mostly legal-weight truck scenario, would be small in comparison to those from other vehicle traffic in the area. The annual average daily traffic on I-15 0.3 kilometer (0.2 mile) north of the Sahara Avenue interchange is almost 200,000 vehicles (NDOT 1997, page 7), about 20 percent of which are trucks (Cerocke 1998, all). For these reasons, national transportation of spent nuclear fuel and high-level radioactive waste by truck and rail would not constitute a meaningful source of air pollution along the nation’s highways and railroads.

J.1.3.2.4 *Sensitivity of Dose Rate to Characteristics of Spent Nuclear Fuel*

For this analysis, DOE assumed that the dose rate external to all shipments of spent nuclear fuel and high-level radioactive waste would be the maximum value allowed by regulations (49 CFR 173.441). However, the dose rate for actual shipments would not be the maximum value of 10 millirem per hour at 2 meters (6.6 feet) from the sides of vehicles. Administrative margins of safety that are established to compensate for limits of accuracy in instruments and methods used to measure dose rates at the time shipments are made would result in lower dose rates. In addition, the characteristics of spent nuclear fuel and high-level radioactive waste that would be loaded into casks would always be within the limit values allowed by the cask’s design and its Nuclear Regulatory Commission certificate of compliance.

For example, DOE used data provided in the *GA-4 Legal-Weight Truck Cask Design Report* (General Atomics 1993, pages 5.5-18 and 5.5-19) to estimate dose rates 2 meters (6.6 feet) from transport vehicles for various characteristics of spent nuclear fuel payloads. Figure J-7 shows ranges of burnup and cooling times for spent nuclear fuel payloads for the GA-4 cask. The figure indicates the characteristics of a typical pressurized-water reactor spent nuclear fuel assembly (see Appendix A). Based on the design data for the GA-4 cask, a shipment of typical pressurized-water reactor spent nuclear fuel would result in a dose rate of about 6 millirem per hour at 2 meters from the side of the transport vehicle, or about 60 percent of the limit established by Department of Transportation regulations (49 CFR 173.441).

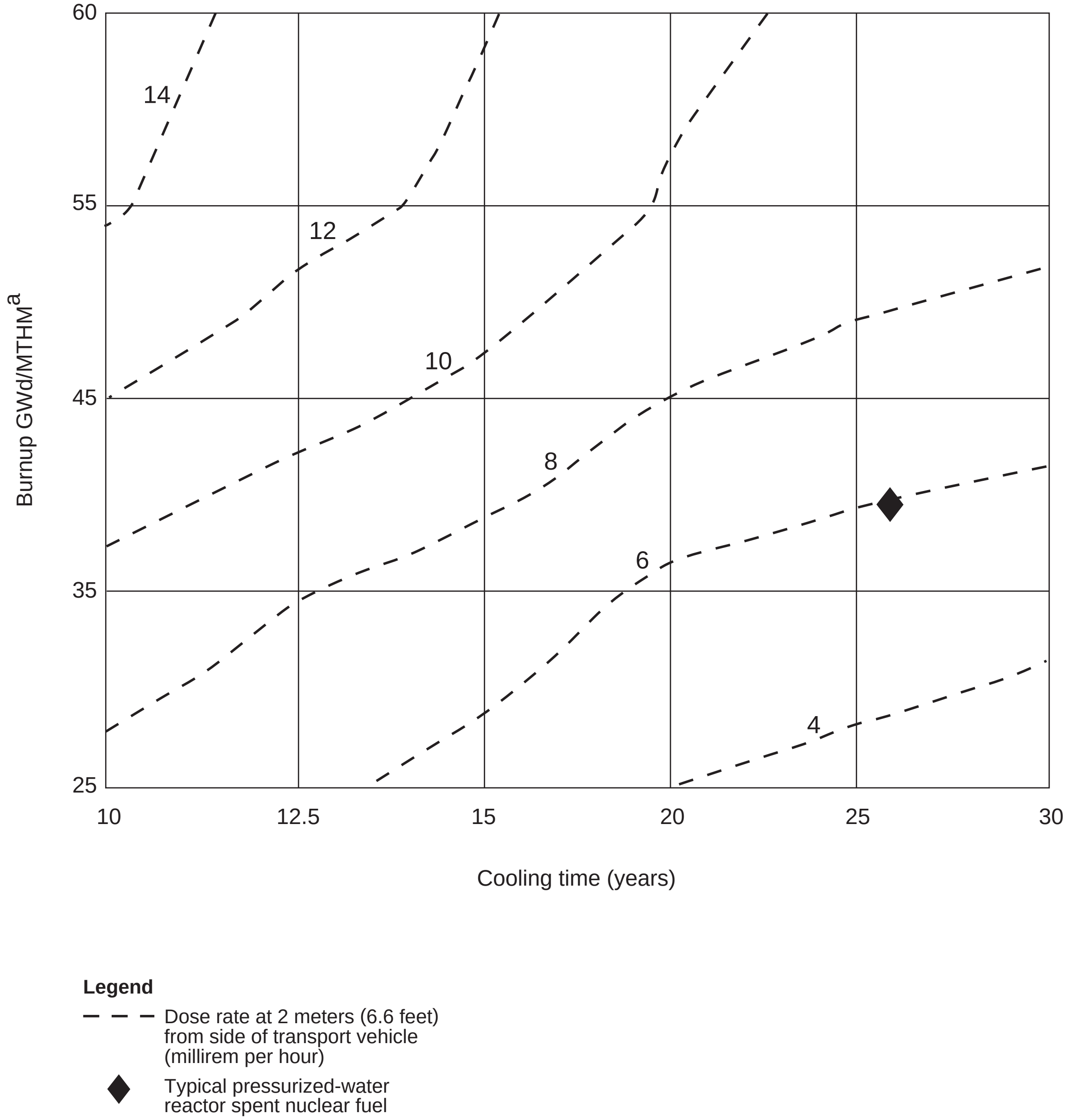
Therefore, DOE estimates that, on average, dose rates at locations 2 meters (6.6 feet) from the sides of transport vehicles would be about 50 to 70 percent of the regulatory limits. As a result, DOE expects radiological risks to workers and the public from incident-free transportation to be no more than 50 to 70 percent of the values presented in this EIS.

J.1.4 METHODS AND APPROACH TO ANALYSIS OF ACCIDENT SCENARIOS

J.1.4.1 Accidents in Loading Operations

J.1.4.1.1 *Radiological Impacts of Loading Accidents*

The analysis used information in existing reports to consider the potential for radiological impacts from accidents during spent nuclear fuel loading operations at the commercial and DOE sites. These included a report that evaluated health and safety impacts of multipurpose canister systems (TRW 1994, all) and two safety analysis reports for onsite dry storage of commercial spent nuclear fuel at independent spent fuel storage installations (PGE 1996, all; CP&L 1989, all). The latter reports address the handling and loading of spent nuclear fuel assemblies in large casks similar to large transportation casks. In addition,



a. Gigawatt days per metric ton of heavy metal.

Figure J-7. Comparison of GA-4 cask dose rate and spent nuclear fuel burnup and cooling time.

DOE environmental impact statements on the management of spent nuclear fuel and high-level radioactive waste (DOE 1995, all; DOE 1997b, all) provided information on radiological impacts from loading accidents.

TRW (1994, Sections 3.2 and 4.2) discusses potential accident scenario impacts of four cask management systems at electric utility and other spent nuclear fuel storage sites. This report concentrated on unplanned contact (bumping) during lift-handling of casks, canisters, or fuel assemblies. The two safety analysis reports for independent spent fuel storage installations for commercial spent nuclear fuel (PGE 1996, all; CP&L 1989, all) evaluated a comprehensive spectrum of accident-initiating events. These events included fires, chemical explosions, seismic events, nuclear criticality, tornado strikes and tornado-generated missile impacts, lightning strikes, volcanism, canister and basket drop, loaded shipping cask drop, and interference (bumping, binding) between the transfer cask and storage module. The DOE environmental impact statements for the interim management of spent nuclear fuel and high-level radioactive waste (DOE 1995, Appendix E; DOE 1997b, Appendixes F and G) included radiological impacts from potential accident scenarios associated with preparing, storing, and shipping these materials. These EISs do not discuss quantitative radiological impacts for accident scenarios associated with material loading, but do contain estimates of radiological impacts from accident scenarios for the spent nuclear fuel and high-level radioactive waste management activities considered. As discussed for routine loading operations, this analysis converted radiation doses to estimates of radiological impacts using dose-to-risk conversion factors of the International Commission on Radiological Protection.

J.1.4.1.2 *Industrial Safety Impacts of Loading Operations at Commercial Facilities*

The principal industrial safety impact parameters of importance to commercial industry and the Federal Government are (1) total recordable (injury and illness) cases, (2) lost workday cases associated with workplace injuries and illnesses, and (3) workplace fatalities. The frequency of these impacts under the Proposed Action and the inventory modules (Modules 1 and 2) was projected using the involved worker level of effort, expressed as the number of full-time equivalent worker multiples, that would be needed to conduct shipment tasks. The workplace loss incidence rate for each impact parameter [as shown in the DOE Computerized Accident/Incident Reporting and Recordkeeping System (CAIRS) data base (DOE 1999, all)] was used as a multiplier to convert the level of effort to expected industrial safety losses.

DOE did not explicitly analyze impacts to noninvolved workers in its earlier reports (Schneider et al. 1987, all; Smith, Daling, and Faletti 1992, all). However, for purposes of analysis in this EIS, DOE estimated that impacts to noninvolved workers would be 25 percent of the impacts to the involved workforce. This assumption is based on (1) the DOE estimate that about one of five workers assigned to a specific task would perform administrative or managerial duties, and (2) the fact that noninvolved worker loss incidence rates are generally less than those for involved workers (see Appendix F, Table F-2).

The estimated involved worker full-time equivalent multiples for each shipment scenario were estimated using the following formula:

$$\text{Involved worker full-time equivalent multiples} = (A \times B \times C \times D) \div E$$

where: A = number of shipments (from Tables J-5 and J-6)

B = average loading duration for each shipment by fuel type and conveyance mode (workdays; from Table J-15)

C = workday conversion factor = 8 hours per workday

D = involved worker crew size (13 workers; from Table J-16)

E = full-time equivalent conversion factor = 2,000 worker hours per full-time equivalent

The representative CAIRS data base loss incidence rate for each total recordable case, lost workday case, and fatality trauma category (for example, the number of total recordable cases per full-time equivalent) was then multiplied by the involved worker full-time equivalent multiples to project the associated incidence. The involved worker total recordable case incidence rate used was that reported in the DOE CAIRS data base (DOE 1999, all) for the 1992 to 1997 period of record because neither the Nuclear Regulatory Commission nor the Bureau of Labor Statistics maintains data on commercial power reactor industrial safety losses. The total recordable case incidence rate, 410 cases in a workforce of 15,000 workers (0.03 total recordable case per full-time equivalent), is the averaged loss experience at the three principal DOE sites: the Savannah River Site, Hanford Site, and Idaho National Environmental and Engineering Laboratory. The DOE sites were chosen because the operations and hazards would be representative of those encountered at commercial power reactor sites. Because lost workday cases are linked to the total recordable case experience (that is, each lost workday case would have to be included in the total recordable case category), the same DOE CAIRS data base period of record and facilities were used in the selection of the involved worker lost workday case incidence rate [200 lost workday cases in a workforce of 15,000 workers (0.013 lost workday case per full-time equivalent)].

The TRW (1994, all) study concluded that radiological impacts from handling incidents would be small. The total person-rem exposure for accidents in handling the four cask systems considered in the study would vary from 0.1 rem to 0.04 rem. This exposure would be the total for all persons who would be exposed, onsite workers as well as the public. The highest estimated exposure (0.1 person-rem) would result in 0.00005 latent cancer fatality in the exposed population.

The involved worker fatality incidence rate used was that also reported in the DOE CAIRS data base, but for the 1996 to 1997 (through the third quarter) period of record. The average DOE and contractor fatality rates used (2.9 fatalities among 100,000 workers) represent losses among workers operating equipment and handling waste materials at the principal DOE sites. This fatality incidence rate represents government and contractor experience in the DOE complex and operations that are governed by safety and administrative controls that would be similar to those used at commercial power reactor sites.

For comparison, the noninvolved worker total recordable case, lost workday case, and fatality incidence rates using the same data base sources are 0.033, 0.016, and 0.000029, respectively. However, because the CAIRS data base did not include fatality rates for noninvolved workers, the involved worker rate was used.

J.1.4.1.3 *Industrial Safety Impacts of DOE Loading Operations*

The technical approach and loss multipliers discussed in Section J.1.4.1.2 for commercial power reactor sites analysis were used for the analysis of spent nuclear fuel and high-level radioactive waste loading impacts at DOE sites. Because no information existed on the high-level radioactive waste loading duration for the truck and rail transportation modes, DOE assumed that the number of full-time equivalent involved workers for the two transportation modes would be the same as that for the DOE sites shipping spent nuclear fuel. For those sites, the average number of full-time equivalent workers would be about 0.07 and 0.12 per shipment for the truck and rail transportation modes, respectively.

J.1.4.2 Transportation Accident Scenarios

J.1.4.2.1 *Radiological Impacts of Transportation Accidents*

A potential consequence and risk of transportation would be accidents that released and dispersed radioactive material from safe containment in transportation packages. Such releases and dispersals, if they occurred, would lead to impacts to human health and the environment. The following sections describe the methods for analyzing the risks and consequences of accidents that could occur in the course of transporting spent nuclear fuel and high-level radioactive waste to a nuclear waste repository at the Yucca Mountain site. They discuss the bases for, and methods for, determining rates at which accidents are assumed to occur, the severity of these accidents, and the amounts of materials that could be released. Accident rates, severities, and the corresponding quantities of radioactive materials that could be released are essential data used in the analyses. Appendix A presents the quantities of radioactive materials in a typical pressurized-water reactor spent nuclear fuel assembly used in the analysis of accident consequences and risks. Legal-weight truck casks would contain as many as four pressurized-water reactor spent nuclear fuel assemblies, and rail casks would contain as many as 36 (see Table J-3).

In addition to accident rates and severities, an important variable in assessing impacts from transportation accident scenarios is the type of material that would be shipped. Accordingly, this appendix presents information used in the analyses of impacts of accidents that could occur in the course of transporting commercial pressurized- and boiling-water reactor fuels, DOE spent nuclear fuels, and DOE high-level radioactive waste.

POTENTIAL EFFECTS OF HUMAN ERROR ON ACCIDENT IMPACTS

The accident scenarios described in this chapter would be mostly a direct consequence of error on the part of transport vehicle operators, operators of other vehicles, or persons who maintain vehicles and rights-of-way. The number and severity of the accidents would be minimized through the use of trained and qualified personnel.

Others have argued that other kinds of human error could also contribute to accident consequences: (1) undetected error in the design and certification of transportation packaging (cask) used to ship radioactive material, (2) hidden or undetected defects in the manufacture of these packages, and (3) error in preparing the packages for shipment. DOE has concluded that regulations and regulatory practices of the Nuclear Regulatory Commission and the Department of Transportation address the design, manufacture, and use of transportation packaging and are effective in preventing these kinds of human error by requiring:

- Independent Nuclear Regulatory Commission review of designs to ensure compliance with requirements (10 CFR Part 71)

- Nuclear Regulatory Commission-approved and audited quality assurance programs for design, manufacturing, and use of transportation packages

In addition, Federal provisions (10 CFR Part 21) provide additional assurance of timely and effective actions to identify and initiate corrective actions for undetected design or manufacturing defects. Furthermore, conservatism in the approach to safety incorporated in the regulatory requirements and practices provides confidence that design or manufacturing defects that might remain undetected or operational deficiencies would not lead to a meaningful reduction in the performance of a package under normal or accident conditions of transportation.

For exposures to ionizing radiation following accidents, risks were analyzed in terms of dose and latent cancer fatalities to the public and workers. The analyses of risk also addressed the potential for fatalities that would be the direct result of mechanical forces and other nonradiological effects that occur in everyday vehicle and industrial accidents.

The transportation of spent nuclear fuel and high-level radioactive waste from the 77 sites to the Yucca Mountain site would be conducted in a manner that complied fully with regulations of the U.S. Department of Transportation and Nuclear Regulatory Commission. These regulations specify requirements that promote safety and security in transportation. The requirements apply to carrier operations; in-transit security; vehicles; shipment preparations; documentation; emergency response; quality assurance; and the design, certification, manufacture, inspection, use, and maintenance of packages (casks) that would contain the spent nuclear fuel and high-level radioactive waste.

Because of the high level of performance required by regulations for transportation casks (49 CFR Part 173 and 10 CFR Part 71), the Nuclear Regulatory Commission estimates that in 99.4 percent of rail and truck accidents no cask contents would be released (Fischer et al. 1987, page 9-10). The 0.6 percent of accidents that could cause a release of radioactive materials from casks can be described by a spectrum of accident severity. As the severity of an accident increases, the fraction of radioactive material contents that would be released from transportation casks also increases. However, as the severity of an accident increases it is less likely to occur. In its Modal Study (Fischer et al. 1987, all), the Nuclear Regulatory Commission developed an accident analysis methodology that uses this concept of a spectrum of severe accidents to calculate the probabilities and consequences of unlikely accidents that could occur in transporting highly radioactive materials.

Although the Nuclear Regulatory Commission approach, which was used in this EIS, provides a method for determining the frequency with which severe accidents can be expected to occur, their severity, and their consequences, a method does not exist for predicting where along routes accidents would occur. Therefore, for the analyses of impacts presented here the method used in the RADTRAN4 computer code (Neuhauser and Kanipe 1992, all) is used. This method assumes that accidents could occur at any location along routes, with their frequency of occurrence being determined by the accident rate characteristic of the states through which the route passes and the number of shipments that travel the route.

The transportation accident scenario analysis evaluated radiological impacts to populations and to hypothetical maximally exposed individuals and estimated fatalities that could occur from traffic accidents. It included both rail and legal-weight truck transportation. The analysis used the RADTRAN4 (Neuhauser and Kanipe 1992, all) and RISKIND (Yuan et al. 1995, all) computer programs to determine accident consequences and risks. DOE has used both codes in recent DOE environmental impact statements (DOE 1995, Appendix J; DOE 1996a, Appendix E; DOE 1997b, Appendixes F and G) that address impacts of transporting radioactive materials. The analyses used seven kinds of information to determine the consequences and risks of accidents for populations:

- Routes from the 77 sites to the repository and their lengths in each state and population zone

- The number of shipments that would be transported over each route

- State-specific accident rates

- The kind and amount of radioactive material that would be transported in shipments

- Probabilities of release and fractions of cask contents that could be released in accidents

ESTIMATING ACCIDENT RISK

Assessing the radiological impact of accidents involves estimating the probability that an accident might occur and estimating the accident consequences. The probability, or chance, that an accident will occur is multiplied by the consequences of the accident to determine accident risk.

One method for estimating accident probabilities uses historic information on the rate at which accidents of a similar type or severity occur (accidents per vehicle-mile traveled). Information of this type is maintained as transportation accident data by the Department of Transportation and by transportation safety organizations in state governments. Accident rates are multiplied by the total number of miles that vehicles would travel to estimate the number of accidents.

Determining radiological accident consequences requires estimating the quantity of radionuclides likely to be released and the environmental transport mechanisms that would bring the radionuclides into contact with people and then calculating the resultant radiation dose. Because of the large amounts of data these calculations require, conservative or bounding assumptions are commonly used to simplify the calculation task. As a result, calculated risks tend to be overestimates.

- The number of people who could be exposed to accidents and how far they lived from the routes

- Exposure scenarios that include multiple exposure pathways, state-specific agricultural factors, and atmospheric dispersion factors for neutral and stable conditions applicable to the entire country for calculating radiological impacts

The analysis used the same routes and lengths of travel as the analysis of incident-free transportation impacts discussed above.

DOE used the CALVIN computer code discussed earlier, the DOE Throughput Study (TRW 1997, all), and information provided by the DOE National Spent Nuclear Fuel Program (Jensen 1998, all) to calculate the number of shipments from each site and, thus, the number of shipments that would use a particular route.

The state-specific accident rates (accidents and fatalities per kilometer of vehicle travel) used in the analysis included accident statistics for commercial motor carrier operations for the Interstate Highway System, other U.S. highways, and state highways for each of the 48 contiguous states (Saricks and Tompkins 1999, all). The analysis also used average accident and fatality rates for railroads in each state. The data specifically reflect accident and fatality rates that apply to commercial motor carriers and railroads.

Appendix A contains information on the radioactive material contents of shipments. Appendix A, Section A.2.1.5 describes the characteristics of the spent nuclear fuel and high-level radioactive waste that would be shipped. The analysis assumed that the average inventory of radioactive materials in shipments would be typical pressurized-water reactor spent nuclear fuel that had been removed from reactors for 25.8 years. Appendix A describes this inventory. The estimated impacts would be less if the analysis used the characteristics of a typical boiling-water reactor spent nuclear fuel, DOE spent nuclear fuel (including naval spent nuclear fuel, which the analysis assumed would be removed from reactors 5 years before its shipment to the repository), or high-level radioactive waste.

The analysis also used the number of people who potentially would be close enough to transportation routes at the time of an accident to be exposed to radiation or radioactive material released from casks, and the distances these people would be from the accidents. It used the HIGHWAY and INTERLINE computer programs to determine this estimated number of people and their distances from accidents. HIGHWAY and INTERLINE used 1990 Census data for this analysis. The analysis assumed that the region of influence extended 80 kilometers (50 miles) from an accident.

Accident Severity Categories and Conditional Probabilities

The classification scheme used in the Modal Study for both truck and rail transportation accidents is shown in Figure J-8. As shown, accident severity is a function of two variables. The first variable is the mechanical force that occurs in impacts. In the figure, mechanical force is represented by the deformation (strain) in a cask's containment (inner shell) that the force would cause. The second variable is thermal energy, or the heat input to a cask engulfed by fire. In the figure, thermal energy is represented by the midpoint temperature of a cask's lead shield wall following heating, as in a fire.

Because all accident scenarios that would involve casks can be described in these terms, the severity of accidents can be analyzed independently of specific accident sequences. In other words, any sequence of events that results in an accident in which a cask is subjected to mechanical forces, within a certain range of values, and possibly fire is assigned to the accident severity category associated with the applicable ranges for the two parameters. This accident severity scheme enables analysis of a manageable number of accident situations while accounting for all reasonably foreseeable transportation accidents, including accidents with low probabilities but high consequences and those with high probabilities but low consequences.

For the analysis of impacts, a conditional probability was assigned to each accident severity category. Figure J-8 also shows the conditional probabilities developed in the Modal Study for the accident severity matrix. These conditional probabilities are used in the analysis of impacts presented in this chapter. The conditional probabilities are the chances that accidents will involve the mechanical forces and the heat energy in the ranges that apply to the categories. For example, accidents that would fall into the category labeled R(1,1), which represents the least severe accident in the matrix, would be likely to make up 99.4 percent of all accidents that would involve truck and railcar shipments of casks carrying spent nuclear fuel or high-level radioactive waste. The mechanical forces and heat in accidents in this category would not exceed the regulatory design standards for casks. Using the information in the figure, an accident in this category could cause a maximum of 0.2 percent strain (deformation) in a cask's containment and could heat the lead shielding to 260ºC (500ºF) degrees. These damage conditions are within the range of damage that would occur to casks subjected to the hypothetical accident conditions tests that Nuclear Regulatory Commission regulations require a cask to survive (10 CFR Part 71). Category R(4,5)-accidents, which would cause extensive damage to a cask, are very severe but very infrequent. The Category R(4,5) accidents would occur an estimated 3.4 times in each 100 trillion rail accidents and less than one time in each 10 quadrillion truck accidents.

The analysis of accident risks presented in this appendix used the frequency that would be likely for accidents in each of the severity categories. This frequency was determined by multiplying the category's conditional probability by the accident rates for each state's urban, suburban, and rural population zones and by the shipment distances in each of these zones, and then adding the results. The accident rates in the population density zones in each state are distinct and correspond to traffic conditions, including average vehicle speed, traffic density, and other factors, including rural, suburban, or urban location.

In terms of potential to release radioactivity to the environment, the most severe of reasonably foreseeable accidents are those that would fall into one of the eight categories of very severe accidents. For these eight categories, the fractions and characteristics of radioactive materials that would be released in an

	P_t P_r	R(4,1) 1.532×10^{-7} 1.786×10^{-9}	R(4,2) 3.926×10^{-14} 3.290×10^{-13}	R(4,3) 1.495×10^{-14} 2.137×10^{-13}	R(4,4) 7.681×10^{-16} 1.644×10^{-13}	R(4,5) $<1 \times 10^{-16}$ 3.459×10^{-14}
S_3 (30)	P_t P_r	R(3,1) 1.7984×10^{-3} 5.545×10^{-4}	R(3,2) 1.574×10^{-7} 1.021×10^{-7}	R(3,3) 2.034×10^{-7} 6.634×10^{-8}	R(3,4) 1.076×10^{-7} 5.162×10^{-8}	R(3,5) 4.873×10^{-8} 5.296×10^{-8}
S_2 (2)	P_t P_r	R(2,1) 3.8192×10^{-3} 2.7204×10^{-3}	R(2,2) 2.330×10^{-7} 5.011×10^{-7}	R(2,3) 3.008×10^{-7} 3.255×10^{-7}	R(2,4) 1.592×10^{-7} 2.531×10^{-7}	R(2,5) 7.201×10^{-8} 1.075×10^{-8}
S_1 (0.2)	P_t P_r	R(1,1) 0.994316 0.993962	R(1,2) 1.687×10^{-5} 1.2275×10^{-3}	R(1,3) 2.362×10^{-5} 7.9511×10^{-4}	R(1,4) 1.525×10^{-5} 6.140×10^{-4}	R(1,5) 9.570×10^{-6} 1.249×10^{-4}
			T_1 (500)	T_2 (600)	T_3 (650)	T_4 (1,050)

Structural response (maximum strain on inner shell, percent)

Thermal response (lead mid-thickness temperature, °F)

Legend

R(x,y) = The label used to identify the cell in the accident response matrix located at the x row from the bottom of the matrix and y column from the left of the matrix. Thus, (R1,1) is the identifier for the cell in the lower left corner of the matrix.

P_t = Probability of occurrence assuming a truck accident occurs.

P_r = Probability of occurrence assuming a rail accident occurs.

Note:

- Maximum strain between 0 and 0.2 percent (S_1) for the inner shell of a cask would be within the design conditions for a Nuclear Regulatory Commission-certified shipping cask. There would be permanent deformation after the load is removed. S_1 strains could occur in impacts against medium hardness structures (for example, bridge abutments) at speeds up to 100 kilometers (60 miles per hour).
- Strains between 0.2 and 2 percent (S_2) would result in small permanent deformations. S_2 strains could occur in impacts against medium hardness structures at speeds up to 130 kilometers (80 miles per hour).
- Strains between 2 and 30 percent (S_3) would result in large permanent deformations. S_3 strains could occur in impacts against medium hardness structures at speeds greater than 130 kilometers (80 miles per hour).

Source: Fischer et al. (1987, pages 4-8, 7-25, and 7-26).

Figure J-8. Probability matrix for mechanical forces and heat in transportation accidents.

accident were estimated to be the same. That is, for a shipment of spent nuclear fuel that is involved in an accident classified as Category R(4,1), the amount and characteristics of radioactive material assumed to be released would be the same as those for an accident that would fall into Category R(4,2), R(4,3), R(4,4), R(4,5), R(1,5), R(2,5), or R(3,5). Because the releases of radioactive materials that could occur are assumed to be the same for each of these eight categories, the probabilities of occurrence can be summed. This sum is used to calculate a collective probability for the most severe of the accidents addressed in this analysis. Thus, the conditional probability of a truck accident of the greatest severity that is analyzed would be 0.0000098 per accident event (about 1 chance in 100,000 per accident).

By combining categories for which the releases of radioactive materials are assumed to be equivalent, the 20 accident categories in Figure J-8 are reduced to six collective categories. The first is the same as severity category R(1,1); the second collects severity categories R(1,2) and R(1,3); the third R(2,1), R(2,2) and R(2,3); the fourth R(3,1), R(3,2) and R(3,3); the fifth, R(1,4), R(2,4), and R(3,4); and, as discussed above, the sixth collects R(4,1) through R(4,5) and R(1,5) through R(3,5).

Accident Releases

Radiological consequences were calculated by assigning cask release fractions to each accident severity category for each chemically and physically distinct radioisotope. The *release fraction* is defined as the fraction of the radioactivity in the cask that could be released from the cask in a given severity of accident. Release fractions vary according to spent nuclear fuel type and the physical/chemical properties of the radioisotopes. Most radionuclides in spent nuclear fuel are in chemically and physically stable, solid, nondispersible forms. Gaseous radionuclides, such as krypton-85, would be released if both the fuel cladding and cask containment boundary were compromised.

The Modal Study developed release fractions for commercial spent nuclear fuel from pressurized-water reactors. These release fractions, listed in Table J-21, are based on best engineering judgment and are believed to be conservative. The analysis estimated the amount of radioactive material released from a cask in an accident by multiplying the approximate release fraction by the number of fuel assemblies in a cask (see Table J-3) and the radionuclide activity of a spent nuclear fuel assembly (see Appendix A). To provide perspective, the release fraction for a category 6 accident involving a large rail cask results in an estimated release of about 1,600 curies of cesium isotopes. For this analysis, the release fractions developed by the Modal Study were used only for commercial pressurized-water reactor fuel and spent nuclear fuel from training, research and isotope reactors built by General Atomics (commonly called *TRIGA* spent nuclear fuel), both of which are rod-type fuels. The availability of fuel-specific data for other types of spent nuclear fuel that would be shipped to the repository allowed the use of release fractions that more closely approximate expected release characteristics.

Table J-21. Fractions of selected radionuclides in commercial spent nuclear fuel projected to be released from casks in transportation accidents for cask response regions.

		Release fraction[a]				
Cask response region	Severity category	Inert gas	Iodine-129	Cesium-134, -135, -137	Ruthenium -106	Particulates
R(1,1)	1	0.0	0.0	0.0	0.0	0.0
R(1,2),R(1,3)	2	9.9×10^{-3}	7.5×10^{-5}	6.0×10^{-6}	8.1×10^{-7}	6.0×10^{-8}
R(2,1),R(2,2),R(2,3)	3	3.3×10^{-2}	2.5×10^{-4}	2.0×10^{-5}	2.7×10^{-6}	2.0×10^{-7}
R(3,1),R(3,2),R(3,3)	4	3.3×10^{-1}	2.5×10^{-3}	2.0×10^{-4}	2.7×10^{-5}	2.0×10^{-6}
R(1,4),R(2,4),R(3,4)	5	3.9×10^{-1}	4.3×10^{-3}	2.0×10^{-4}	4.8×10^{-5}	2.0×10^{-6}
R(1,5),R(2,5),R(3,5),R(4,5), R(4,1),R(4,2),R(4,3),R(4,4)	6	6.3×10^{-1}	4.3×10^{-2}	2.0×10^{-3}	4.8×10^{-4}	2.0×10^{-5}

a. Source: (DOE 1995, page I-86).

Release fractions for aluminum fuels (aluminum alloy fuel, aluminum cladding) were based on laboratory measurements and the U.S. Nuclear Regulatory Commission Modal Study (Fischer et al. 1987, all). Because of the lower melting point of aluminum compared to metals used in other metallic fuels, the aluminum fuel release fractions are considered bounding for metallic fuels (that is, Savannah River Production Reactor, Hanford N-Reactor, and Experimental Breeder Reactor-II Mark V spent nuclear fuel). Release fractions for the aluminum and other metallic fuel types are listed in Table J-22. The estimates of fractions for cask contents released in severe accidents were assumed to be independent of the type of cask.

Table J-22. Fractions of selected radionuclides in aluminum and metallic spent nuclear fuel projected to be released from casks in transportation accidents for cask response regions.[a]

		Release fraction[b]				
Cask response region	Severity category	Inert gas	Iodine-129	Cesium-134, -135, -137	Ruthenium-106	Particulates
R(1,1)	1	0.0	0.0	0.0	0.0	0.0
R(1,2),R(1,3)	2	9.9×10^{-3}	1.1×10^{-7}	3.0×10^{-8}	4.1×10^{-9}	3.0×10^{-10}
R(2,1),R(2,2),R(2,3)	3	3.3×10^{-2}	3.5×10^{-7}	1.0×10^{-7}	1.4×10^{-8}	1.0×10^{-9}
R(3,1),R(3,2),R(3,3)	4	3.3×10^{-1}	3.5×10^{-6}	1.0×10^{-6}	1.4×10^{-7}	1.0×10^{-8}
R(1,4),R(2,4),R(3,4)	5	3.9×10^{-1}	6.0×10^{-6}	1.0×10^{-6}	2.4×10^{-7}	1.0×10^{-8}
R(1,5),R(2,5),R(3,5),R(4,5), R(4,1),R(4,2), R(4,3),R(4,4)	6	6.3×10^{-1}	6.0×10^{-5}	1.0×10^{-5}	2.4×10^{-6}	1.0×10^{-7}

a. Source: DOE (1995, page I-87).

b. These release fractions are applicable to N-Reactor, Savannah River Site production reactor, and DOE research/test reactor spent nuclear fuel types.

Atmospheric Conditions

For the analyses of accident risk and consequences, releases of radioactive materials from casks during and following severe accidents were assumed to be into the atmosphere where these materials would be carried by wind. Because it is not possible to predict specific locations where transportation accidents would occur, atmospheric conditions that generally apply throughout the continental United States were used.

Table J-23 lists the frequency at which atmospheric stability and wind speed conditions occur in the contiguous United States. The data, which are averages for 177 meteorological data collection locations, were used in conjunction with the RISKIND computer program (Yuan et al. 1995, all) to develop estimates of the consequences of maximum reasonably foreseeable accidents and acts of sabotage.

In calculating estimated values for consequences, RISKIND used the atmospheric stability and wind speed data to analyze the dispersion of radioactive materials in the atmosphere that could follow releases in severe accidents. The dispersions were modeled as plumes of gases and particles. Using the results of the dispersion analysis, RISKIND calculated values for radiological consequences (population dose and dose to a maximally exposed individual). These results were placed in order from lowest to highest. Following this order, the probabilities of the atmospheric conditions associated with each set of consequences were accumulated. As the accumulated probability increased and the likelihood of an exceedance of a set of atmospheric conditions decreased, estimated consequences increased. This procedure was followed to identify the level of severe accident and sabotage consequences that would not be exceeded 50 percent and 95 percent of the time. For atmospheric conditions that are called neutral, or average, the consequences would not be exceeded 50 percent of the time. Thus, neutral atmospheric conditions would be the conditions likely to prevail during a severe accident or act of sabotage. Under stable, or quiescent, conditions the consequences would not be exceeded 95 percent of the time. The

Table J-23. Frequency of atmospheric and wind speed conditions – U.S. averages.[a]

Atmospheric stability class	Wind speed condition						Total
	WS(1)	WS(2)	WS(3)	WS(4)	WS(5)	WS(6)	
A	0.00667	0.00444	0.00000	0.00000	0.00000	0.00000	0.01111
B	0.02655	0.02550	0.01559	0.00000	0.00000	0.00000	0.06764
C	0.01400	0.02931	0.05724	0.01146	0.00122	0.00028	0.11351
D	0.03329	0.07231	0.15108	0.16790	0.03686	0.01086	0.47230
E	0.00040	0.04989	0.06899	0.00146	0.00016	0.00003	0.12093
F	0.10771	0.08710	0.00110	0.00000	0.00000	0.00000	0.19591
G	0.01713	0.00146	0.00000	0.00000	0.00000	0.00000	0.01859
F+G	0.12485	0.08856	0.00110	0.00000	0.00000	0.00000	0.21451
Totals	**0.20576**	**0.27000**	**0.29401**	**0.18082**	**0.03825**	**0.01117**	**1.00000**
Wind speed (meters per second)[b]	0.89	2.46	4.47	6.93	9.61	12.52	

a. Source: TRW (1999a, page 40).
b. To convert meters per second to miles per hour, multiply by 2.237.

analysis assumed that these conditions, which would be unlikely, would occur only for maximum reasonably foreseeable accidents that had an annual probability greater than 2 chances in 1 million in a year.

Exposure Pathways

Radiation doses were calculated for an individual who is postulated to be near the scene of an accident and for populations within 80 kilometers (50 miles) of an accident location. Doses were determined for rural, suburban, and urban population groups. Dose calculations considered a variety of exposure pathways, including inhalation and direct exposure (cloudshine and immersion in a plume of radioactive material) from a passing cloud of contaminants; ingestion from contaminated crops; direct exposure from radioactivity deposited on the ground (groundshine); and inhalation of radioactive particles resuspended by wind from the ground.

Emergency Response, Interdiction, Dose Mitigation, and Evacuation

The RADTRAN4 computer program that DOE used to estimate radiological risks includes assumptions about the postaccident remediation of radioactive material contamination of land where people live. The program assumed that, after an accident, contaminants would continue to contribute to population dose through three pathways—groundshine, inhalation of resuspended particulates, and, for accidents in rural areas, ingestion of foods produced on the contaminated lands. It also assumed that medical and other interdiction would not occur to reduce concentrations of radionuclides absorbed or deposited in human tissues as a result of accidents.

Similarly, the RISKIND (Yuan et al. 1995, all) computer program includes assumptions about response, interdiction, dose mitigation, and evacuation for calculating radiological consequences (dose to populations and maximally exposed individuals). In estimating consequences of maximum reasonably foreseeable accidents during the transportation of spent nuclear fuel and high-level radioactive waste to the repository, the analysis assumed the following:

- Populations would continue to live on contaminated land for 1 year.

- There would be no radiological dose to populations from ingestion of contaminated food. Food produced on land contaminated by a maximum reasonably foreseeable accident would be embargoed from consumption.

- Medical and other interdiction would not occur to reduce concentrations of radionuclides absorbed or deposited in human tissues as a result of an accident.

The analysis of radiological risks to populations and estimates of consequences of maximum reasonably foreseeable accidents did not explicitly address local, difficult-to-evacuate populations such as those in prisons, hospitals, nursing homes, or schools. However, the analysis addressed the potential for accidents to occur in urban areas with high population densities and used the assumptions regarding interdiction, evacuation, and other intervention actions discussed above. These assumptions encompass the consequences and risks that could arise from slowness in preventing the consequences of an accident for some population groups.

Health Risk Conversion Factors

The health risk conversion factors used to estimate expected latent cancer fatalities from radiological exposures are presented in International Commission on Radiological Protection Publication 60 (ICRP 1991, page 22). These factors are 0.0005 latent cancer fatality per person-rem for members of the public and 0.0004 latent cancer fatality per person-rem for workers. For accidents in which individuals would receive doses greater than 20 rem over a short period (high dose/high dose rate), the factors would be 0.0010 latent cancer fatality per rem for a member of the public and 0.0008 latent cancer fatality per rem for workers.

Assessment of Accident Risk

The RADTRAN4 computer code (Neuhauser and Kanipe 1992, all) was used in calculating risks from transportation of spent nuclear fuel and high-level radioactive waste. The code determined unit-risk factors (person-rem per curie) for the radionuclides of concern in the inventory being shipped. The unit-risk factors from RADTRAN4 were combined with conditional accident probabilities, state-specific accident rates, release fractions for each of the six accident severity collective categories, and state-specific food transfer factors to obtain risk per shipment for routes. The accident risks were estimated in terms of collective radiation dose to the population within 80 kilometers (50 miles).

The analysis first calculated unit risk factors for a shipment for each state through which shipments would pass. This was done for the three types of population zones in each state (using population density data from the 1990 census) and for each accident severity category. The unit risk factors used actual population densities within 800 meters (0.5 mile) of routes based on 1990 census data to estimate populations within 80 kilometers (50 miles). This yielded values for each transportation mode, for each type of impact, and for each state through which a shipment would pass. The unit risk factors for all the applicable accident severity categories were summed for each population zone for each state. Also, for the three types of population zone in a state, the lengths through areas of each type were summed for the route used in the analysis. This yielded route lengths for each population zone in each state. The sum of the route lengths and the sum of the unit risk factors for each population zone were multiplied together. This was repeated for each population zone in each state through which a shipment would pass. The results were summed to provide estimates of the accident risk for a shipment.

Estimating Consequences of Maximum Reasonably Foreseeable Accident Scenarios

In addition to analyzing the radiological and nonradiological risks that would result from the transportation of spent nuclear fuel and high-level radioactive waste to the repository, DOE assessed the consequences of maximum reasonably foreseeable accidents. This analysis provided information about the magnitude of impacts that could result from the most severe accident that could reasonably be expected to occur, although it could be highly unlikely. DOE concluded that, as a practical matter, events with a probability less than 1×10^{-7} (1 chance in 10 million) per year rarely need to be examined (DOE 1993, page 28). This would be equivalent to about once in the course of 15 billion legal-weight truck shipments. For perspective, an accident this severe in commercial truck transportation would occur about once in 50 years on U.S. highways. Thus, the analysis of maximum reasonably foreseeable accidents postulated to occur during the transportation of spent nuclear fuel and high-level radioactive waste evaluated only consequences for accidents with a probability greater than 1×10^{-7} per year. The consequences were determined for atmospheric conditions that could prevail during accidents and for physical and biological pathways that would lead to exposure of members of the public and workers to radioactive materials and ionizing radiation. The analysis used the RISKIND code (Yuan et al. 1995, all) to estimate doses for individuals and populations.

The analysis assumed maximum reasonably foreseeable accident scenarios could occur anywhere, either in rural or urbanized areas. The probability of such an accident would depend on the amount of exposure to the transportation accident environment. In this case, exposure would be the product of the cumulative shipment distance and the applicable accident rates. However, because of large differences in exposure, principally because of the large differences in the distances traveled in the two types of population areas, a severe accident scenario that might be reasonably foreseeable, in a rural area might not be reasonably foreseeable in an urbanized area. Thus, a reasonably foreseeable accident postulated to occur in a rural area (most travel would occur in rural areas) under meteorological conditions that would be exceeded (resulting in greater consequences) only 5 percent of the time, might not be reasonably foreseeable in an urbanized area where shipments would travel relatively few kilometers. For the mostly legal-weight truck and mostly rail scenarios, Table J-24 lists the probability of a severe accident during national transportation. These probabilities are for accidents that would:

- Occur in urbanized and rural areas
- Occur under median (50-percent) meteorological conditions and 95-percent conditions (95-percent conditions would be exceeded, in terms of dose consequences, only 5 percent of the time)
- Occur for accidents in collective severity categories 5 and 6 that are postulated to result in the largest releases of radioactive materials from shipping casks
- Involve rail and legal-weight truck casks

Table J-24. Annual probability of severe accidents in urbanized and rural areas – category 5 and 6 accidents, national transportation.

		Probability of exceeding threshold for Category 5		Probability of exceeding threshold for Category 6	
Scenario	Meteorologic conditions exceeded	Annual probability for urbanized area	Annual probability for rural area	Annual probability for urbanized area	Annual probability for rural area
Mostly rail					
Truck shipments	50%	4×10^{-7}[a]	2×10^{-6}	3×10^{-7}	1×10^{-6}
	95%	**2×10^{-8}**[b]	1×10^{-7}	**1×10^{-8}**	**7×10^{-8}**
Rail shipments	50%	1×10^{-5}	4×10^{-5}	3×10^{-6}	8×10^{-6}
	95%	7×10^{-7}	2×10^{-6}	2×10^{-7}	4×10^{-7}
Mostly legal-weight truck					
Truck shipments	50%	6×10^{-6}	4×10^{-5}	4×10^{-6}	2×10^{-5}
	95%	3×10^{-7}	2×10^{-6}	2×10^{-7}	1×10^{-6}
Rail shipments	50%	**4×10^{-8}**	1×10^{-6}	**8×10^{-9}**	4×10^{-7}
	95%	**2×10^{-9}**	**5×10^{-8}**	**4×10^{-10}**	**2×10^{-8}**

a. Probabilities not in bold are reasonably foreseeable.

b. Probabilities in bold would occur less than one time in 10 million and therefore are not reasonably foreseeable.

For the mostly legal-weight truck scenario, in which only naval spent nuclear fuel would be shipped by rail, the likelihood would be less than 1×10^{-7} per year for the most severe rail accident (severity category 6) to occur in an urbanized area. Thus, the highest severity rail accidents would only be reasonably foreseeable in rural areas under average (50-percent) meteorological conditions (probability greater than 1 in 10 million per year).

Table J-24 also lists the probabilities of other severe accidents the analysis considered. Under the mostly rail scenario, the most severe types of legal-weight truck accidents (collective category 6) in rural and urbanized areas under meteorological conditions that would be exceeded only 5 percent of the time would not be reasonably foreseeable.

In total, 9 sets of accident conditions defined by scenario, shipment mode, meteorology, accident severity category, and location (identified in the table by shaded cells) would not be reasonably foreseeable. Nonetheless, although the probabilities would be remote for some accidents, the RADTRAN4 analysis of radiological dose-risks (discussed above) included risk contributions of all accidents, including ones in categories 1 through 4, regardless of their probability of occurrence or consequences. Thus, the analysis addressed the contributions to risk from the spectrum of accidents that would range from low-consequence, high-probability events to high-consequence, low-probability events.

The analysis of maximum reasonably foreseeable accidents evaluated only accidents from the 23 listed in Table J-24 that would be reasonably foreseeable and that could result in maximum consequences.

From this collection of 23 possible accidents, the analysis evaluated three sets of accident conditions that were determined as those with the greatest consequences—one for the mostly rail scenario and two for the mostly legal-weight truck scenario—to identify the maximum reasonably foreseeable accident that would have the greatest consequences. The results for these cases are listed in Table J-25. Based on these results, the analysis identified one maximum reasonably foreseeable accident each for the mostly rail and mostly legal-weight truck national transportation analysis scenarios. For the mostly legal-weight truck scenario, the maximum reasonably foreseeable accident would be a severity category 6 accident involving a legal-weight truck cask in an urbanized area under stable weather (meteorological conditions that would be exceeded only about 5 percent of the time) conditions. For the mostly rail scenario, the accident would also be a category 6 accident involving a rail cask in an urbanized area under stable weather conditions.

The analysis of consequences of maximum reasonably foreseeable accidents used data from the 1990 census to estimate the size of populations in urbanized areas that could receive exposures to radioactive materials. The analysis used estimated populations in successive 8-kilometer (5-mile)-wide annular rings around the centers of the 21 large urbanized areas (cities and metropolitan areas) in the continental United States (TRW 1999a, page 22). The average population for each ring was used to form a population distribution for use in the analysis. To be conservative in estimating consequences, the analysis assumed that accidents in urbanized areas would occur at the center of the population zone, where the population density would be greatest. This assumption resulted in conservative estimates of collective dose to exposed populations.

J.1.4.2.2 *Methods and Approach for Analysis of Nonradiological Impacts of Transportation Accidents*

Nonradiological accident risks are risks of traffic fatalities. Traffic fatality rates are reported by state and Federal transportation departments as fatalities per highway vehicle- or train-kilometer traveled. The fatalities are caused by physical trauma in accidents. For nonradiological accident risks estimated in this EIS for legal-weight truck transportation, accident fatality risks were based on state-level fatality rates for Interstate Highways (Saricks and Tompkins 1999, all). Accident fatality risks for rail transportation were

Table J-25. Consequences of maximum reasonably foreseeable accidents in national transportation.

		Severity category 5 accidents		Severity category 6 accidents	
Scenario	Meteorologic conditions exceeded	Consequences in urbanized area	Consequences in rural area	Consequences in urbanized area	Consequences in rural area
Mostly rail					
Truck accident	50%	+[a]	+	+	+
	95%	--[b]	+	--	--
Rail accident	50% population dose	+	+	+	+
	50% MEI[c] dose	+	+	+	+
	95% population dose	+	+	61,000 (31)[d]	+
	95% MEI dose	+	+	26 (0.013)[e]	+
Mostly legal-weight truck					
Truck accident	50% population dose	++[f]	++	++	++
	50% MEI dose	++	++	++	++
	95% population dose	++	++	9,400 (5)	430 (0.2)
	95% MEI dose	++	++	4 (0.002)	3.9 (0.002)
Rail accident	50%	--	++	--	++
	95%	--	--	--	--

a. + = Consequences of these accidents are bounded by the rail accident in an urbanized area.
b. = probability less than 1 × 10-7 (not reasonably foreseeable).
c. MEI = maximally exposed individual.
d. Population consequence in person-rem (latent cancer fatality).
e. MEI consequences in rem (probability of increasing a latent cancer fatality).
f. ++ = Consequences of these accidents are bounded by the truck accident in an urbanized area.

also calculated using state-specific rates (Saricks and Tompkins 1999, all). Section J.2.1 discusses methods and data used to analyze accidents for barge transportation.

For truck transportation, the rates in Saricks and Tompkins (1999, Table 4) are specifically for heavy combination trucks involved in interstate commerce. Heavy combination trucks are multiaxle tractor-trailer trucks having a tractor and one to three freight trailers connected to each other. This kind of truck with a single trailer would be used to ship spent nuclear fuel and high-level radioactive waste. Truck accident rates were determined for each state based on statistics compiled by the Department of Transportation Office of Motor Carriers for 1994 through 1996. The report presents accident involvement and fatality counts, estimated kilometers of travel by state, and the corresponding average accident involvement, fatality, and injury rates for the 3 years investigated. Fatalities include crew members and all others attributed to accidents. Although escort vehicles would not be heavy combination trucks, the fatality rate data used for truck shipments of loaded and empty spent fuel casks were also used to estimate fatalities from accidents that would involve escort vehicles.

Rail accident rates were computed and presented similarly to truck accident rates, but a railcar is the unit of haulage. The state-specific rail accident involvement and fatality rates are based on statistics compiled by the Federal Railroad Administration for 1994 through 1996. Rail accident rates include both mainline accidents and those occurring in railyards (Saricks and Tompkins 1999, page 9).

The accident rates used to estimate traffic fatalities were computed using data for all interstate shipments, independent of the cargoes. Shippers and carriers of radioactive material generally have a higher-than-average awareness of transport risk and prepare cargoes and drivers accordingly (Saricks and Kvitek 1994, all). These effects were not given credit in the assessment.

J.1.4.2.3 *Data Used To Estimate Incident Rates for Rail and Motor Carrier Accidents*

In analyzing potential impacts of transporting spent nuclear fuel and high-level radioactive waste, DOE considered both incident-free transportation and transportation accidents. Potential incident-free transportation impacts would include those caused by exposing the public and workers to low levels of radiation and other hazards associated with the normal movement of spent nuclear fuel and high-level radioactive waste by truck, rail, or barge. Impacts from accidents would be those that could result from exposing the public and workers to radiation, as well as vehicle-related fatalities.

In its analysis of impacts from transportation accidents, DOE relied on data collected by the U.S. Department of Transportation and others (for example, the American Petroleum Institute) to develop estimates of accident likelihood and their ranges of severity (see Fischer et al. 1987, pages 7-25 and 7-26). Using these data, the analysis estimated that as many as 40 accidents could occur over 24 years in the course of shipping spent nuclear fuel to the repository by legal-weight trucks; 1 or 2 rail accidents that involved a railcar carrying a cask could occur if most shipments were by rail; and no accidents would be likely for the limited use of barges.

Furthermore, in using data collected by the Department of Transportation, the analysis considered the range of accidents, from slightly more than "fender benders" to high-speed crashes, that the DOE carrier would have to report in accordance with the requirements of Department of Transportation regulations. The accidents that could occur would be unlikely to be severe enough to affect the integrity of the shipping casks.

The following paragraphs discuss reporting and definitions for transportation accidents and the relationships of these to data used in analyzing transportation impacts in this EIS.

J.1.4.2.3.1 Transportation Accident Reporting and Definitions. In the United States, the reporting of transportation accidents and incidents involving trucks, railroads, and barges follows requirements specified in various Federal and state regulations.

Motor Carrier Accident Reporting and Definitions

Regulations generally require the reporting of motor carrier accidents (regardless of the cargo being carried) if there are injuries, fatalities, or property damage. These regulations have evolved through the years, mostly in response to increasing values of transportation equipment and commodities. For example, the Federal requirements in the following text box establish a functional threshold for damage to vehicles rather than a value-of-damage threshold, which was used until the 1980s. Nonetheless, many states continue to use value thresholds (for example, Ohio uses $500) for vehicle damage when documenting reportable accidents.

Until March 4, 1993, Federal regulations (49 CFR Part 394) required motor carriers to submit accident reports to the Federal Highway Administration Motor Carrier Management Information System using the so-called "50-T" reporting format. The master file compiled from the data on these reports in the Federal Highway Administration Office of Motor Carriers was the basis of accident, fatality, and injury rates developed for the 1994 study of transportation accident rates (Saricks and Kvitek 1994, all).

The Final Rule of February 2, 1993 (58 *FR* 6726, February 2, 1993), modified the carrier reporting requirement; rather than submitting reports, carriers now must maintain a register of accidents that meet the definition of an accident for 1 year after such an accident occurs. Carriers must make the contents of such a register available to Federal Highway Administration agents investigating specific accidents. They must also give "…all reasonable assistance in the investigation of any accident including providing a full, true, and correct answer to any question of inquiry" to determine if hazardous materials other than spilled

COMMERCIAL MOTOR VEHICLE ACCIDENT
(49 CFR 390.5)

An occurrence involving a commercial motor vehicle operating on a public road in interstate or intrastate commerce that results in:

- A fatality
- Bodily injury to a person who, as a result of the injury, immediately receives medical treatment away from the scene of the accident
- One or more motor vehicles incurring disabling damage as a result of the accident, requiring the motor vehicle to be transported away from the scene by a tow truck or other motor vehicle

The term accident does not include:

- An occurrence involving only boarding and alighting from a stationary motor vehicle
- An occurrence involving only the loading or unloading of cargo
- An occurrence in the course of the operation of a passenger car or a multipurpose passenger vehicle by a motor carrier and is not transporting passengers for hire or hazardous materials of a type and quantity that require the motor vehicle to be marked or placarded in accordance with 49 CFR Part 177, Subpart 823

fuel from the fuel tanks were released, and to furnish copies of all state-required accident reports [49 CFR 390.15]. The reason for this rule change was the emergence of an automated State accident reporting system compiled from law enforcement accident reports that, pursuant to provisions of the Intermodal Surface Transportation Efficiency Act of 1991 [P.L. 102-240, 105 STAT. 1914], was established under the Motor Carrier Safety Assistance Program.

Under Section 408 of Title IV of the Motor Carrier Act of 1991, a component of the Intermodal Surface Transportation Efficiency Act, the Secretary of Transportation is authorized to make grants to states to help them achieve uniform implementation of the police reporting system for truck and bus accidents recommended by the National Governors Association. Under this system, called SAFETYNET, accident data records generated by each state follow identical formatting and content instructions. They are entered in a Federally maintained SAFETYNET data base on approximately a weekly basis. The SAFETYNET data base, in turn, is compiled and managed as part of the Motor Carrier Management Information System.

Accident data compiled from the Bureau of Motor Carrier Safety (now the Office of Motor Carriers in the Federal Highway Administration), American Petroleum Institute, California Highway Patrol, and California Department of Transportation provided the basis used by the Modal Study (Fischer et al. 1987, page B-1) for estimating characteristics of accidents that might involve shipments of spent nuclear fuel using “large trucks.” Although reporting requirements have changed, these data were similar to data being compiled by the SAFETYNET system for motor carrier accidents in 1999. Most important, the definition of a motor carrier accident, the basis for reporting and data compilation, has remained basically unchanged over the 40 years of data collection.

Because the Modal Study is the fundamental source for data that describes the severity of transportation accidents used in this EIS, the relative constancy of the definition of *accident* is important in establishing confidence in estimated impact results. Thus, although the transportation environment has changed over the 40 years of data collection, the constancy of the definition of *accident* tends to provide confidence that the distribution of severity for reported accidents has remained relatively the same. That is, low-consequence, fender-bender accidents are the most common, high-consequence, highly energetic accidents are rare, and the proportions of these have remained roughly the same.

Changes in the transportation environment, such as changes in speed limits and safety technology, tend to change the accident rate (accidents per vehicle-kilometer of travel). Overall, however, given that the definition of *accident* does not change, such changes do not greatly affect the distribution of accident severities. For example, recent increases in speed limits from 105 to 121 kilometers (65 to 75 miles) per hour represent about a 25-percent increase in the maximum mechanical energy of vehicles. Other information aside, this increase could lead to the conclusion that the resulting distribution of accidents would show an increase for the most severe accidents in comparison to minor accidents. However, the speed limit increases do not represent a corresponding increase in actual traffic speeds, and would be unlikely to change the distribution of velocities and, thus, mechanical energies, of severe accidents from those reported in the Modal Study. These velocities ranged to faster than 137 kilometers (85 miles) per hour, even though at the time the National speed limit was 89 kilometers (55 miles) per hour.

Rail Carrier Accident Reporting and Definitions

As with regulations governing the reporting of motor carrier accidents, Federal Railroad Administration regulations generally require the reporting of accidents if there are injuries, fatalities, or property damage. These regulations have evolved through the years, mostly in response to increasing values of transportation equipment and commodities. For example, the Federal requirements in the following text box establish a value-based reporting threshold for damage to vehicles; the value has been indexed to inflation since 1975.

RAILROAD ACCIDENT/INCIDENT
(49 CFR 225.11)

- An impact between railroad on-track equipment and an automobile, bus, truck, motorcycle, bicycle, farm vehicle or pedestrian at a highway-rail grade crossing

- A collision, derailment, fire, explosion, act of God, or other event involving operation of railroad on-track equipment (standing or moving) that results in reportable damages greater than the current reporting threshold to railroad on-track equipment, signals, track, track structures, and roadbed

- An event arising from the operation of a railroad which results in:
  - Death to any person
  - Injury to any person that requires medical treatment
  - Injury to a railroad employee that results in:
- A day away from work
- Restricted work activity or job transfer
- Loss of consciousness
- Occupational illness

Rail carriers covered by these requirements must fulfill several bookkeeping tasks. The Federal Railroad Administration requires the submittal of a monthly status report, even if there were no reportable events during the period. This report must include accidents and incidents, and certain types of incidents require immediate telephone notification. Logs of reportable injuries and on-track incidents must be maintained by the railroads on which they occur, and a listing of such events must be posted and made available to employees and to the Federal Railroad Administration, along with required records and reports, on request. The data entries extracted from the reporting format are consolidated into an accident/incident data base that separates reportable *accidents* from grade-crossing *incidents*. These are processed annually into event, fatality, and injury count tables in the Federal Railroad Administration's *Accident/Incident*

Bulletin (Saricks and Tompkins 1999, all), which the Office of Safety publishes on the Internet (*http://safetydata.fra.dot.gov/officeofsafety/Prelim/1999/r01.htm*).

In contrast to the regulations for motor carriers discussed above, the Federal Railroad Administration regulations cited above call for the reporting of accidents and incidents. According to the Modal Study, the Administration defines an *accident* as “any event involving on-track railroad equipment that results in damage to the railroad on-track equipment, signals, track, or track structure, and roadbed at or exceeding the dollar damage threshold.” Train *incidents* are defined as “events involving on-track railroad equipment [and non-train incidents arising from the operation of a railroad] that result in the reportable death and/or injury or illness of one or more persons, but do not result in damage at or beyond the damage threshold.” The Modal Study, because “damage to casks containing spent nuclear fuel will necessarily involve severe accidents” (hence, substantial damage), used only “train accidents” to form the basis for developing the conditional probabilities of accident severities.

As with motor carrier operations, the constancy of the definition of a train accident is important in establishing confidence in the impact. For rail accidents the transportation environment has not changed dramatically over the years of data collection, and the definition of *accident* has remained essentially unchanged (with adjustments for inflation). The constancy of the definition provides confidence that the distribution of severity for reported accidents has remained relatively the same—low-consequence, limited-damage accidents are the most common and high-consequence, highly energetic accidents are rare, and their proportions have remained about the same. Changes in the rail transportation environment, as in safety and operations technology (for example, shelf-type couplers and tankcar head protection), have resulted in lower accident rates (per railcar-kilometer of travel) and, in some cases, less severe accidents. However, because the definition of *accident* has not changed appreciably, the changes that have occurred are not the kind that would greatly affect the relative proportions of minor and severe accidents.

Reporting and Definitions for Marine Casualties and Incidents

As with the regulations governing the reporting of motor carrier and rail accidents, U.S. law (46 USC 6101-6103) requires operators to report marine casualties and incidents if there are injuries, fatalities, or property damage. In addition, the law requires the reporting of significant harm to the environment.

MARINE CASUALTY AND INCIDENT
(46 USC 6101-6103)

Criteria have been established for the required reporting (by vessel operators and owners) of marine casualties and incidents involving all United States flag vessels occurring anywhere in the world and any foreign flag vessel operating on waters subject to the jurisdiction of the United States. An incident must be reported within five days if it results in:

- The death of an individual
- Serious injury to an individual
- “Material” loss of property (threshold not specified; previously was $25,000)
- Material damage affecting the seaworthiness or efficiency of the vessel
- Significant harm to the environment

The states collect casualty data for incidents occurring in navigable waterways within their borders, and there is a uniform state marine casualty reporting system for transmitting these reports to Federal jurisdiction (the U. S. Coast Guard). Coast Guard Headquarters receives quarterly extracts of the Marine

Safety Information System developed from these sources. This system is a network data base into which Coast Guard investigators enter cases at each marine safety unit. The analysis uses a Relational Database Management System. The Coast Guard Office of Investigations and Analysis compiles and processes the casualty reports into the formats and partitioned data sets that comprise the Marine Safety Information System data base, which includes maritime accidents, fatalities, injuries, and pollution spills dating to 1941 (however, the file is complete only from about 1991 to the present).

Hazardous Material Transportation Accident and Incident Reporting and Definitions

Radioactive material is a subset of the more general term *hazardous material*, which includes commodities such as gasoline and chemical products. The U.S. Department of Transportation Office of Hazardous Materials estimates that there are more than 800,000 hazardous materials shipments per day, of which about 7,700 shipments contain radioactive materials.

Hazardous materials transportation regulations (49 CFR 171) contain no distinction between an *accident* and an *incident*, and *incident* is the term used to describe situations that must be reported. Hazardous materials regulations (49 CFR 171.15) require the reporting of incidents if:

- A person is killed
- A person receives injuries requiring hospitalization
- The estimated property damage is greater than $50,000
- An evacuation of the public occurs lasting one or more hours
- One or more major transportation arteries are closed or shutdown for one or more hours
- The operational flight pattern or routine of an aircraft is altered
- Fire, breakage, spillage, or suspected radioactive contamination occurs involving shipment of radioactive material
- Fire, breakage, spillage, or suspected contamination occurs involving shipment of infectious agents
- There has been a release of a marine pollutant in a quantity exceeding 450 liters (about 120 gallons) for liquids or 400 kilograms (about 880 pounds) for solids
- There is a situation that, in the judgement of the carrier, should be reported to the U.S. Department of Transportation even though it does not meet the above criteria

These criteria apply to loading, unloading, and temporary storage, as well as to transportation. The criteria involving infectious agents or aircraft are unlikely to be used for spent nuclear fuel or high-level radioactive waste shipments. Based on these criteria, reportable motor vehicle and rail transportation situations are far more exclusionary than hazardous material situations.

Carriers (not law enforcement officials) are required to report hazardous materials incidents to the U.S. Department of Transportation. These reports are compiled in the Hazardous Materials Incident Report data base. In addition, U.S. Nuclear Regulatory Commission regulations (20 CFR 20.2201, 20.2202, 20.2203) require the reporting of a loss of radioactive materials, exposure to radiation, or release of radioactive materials.

Sandia National Laboratories maintains the Radioactive Materials Incident Report (RMIR) data base, which contains incident reports from the Hazardous Materials Incident Report data base that involve radioactive material. In addition, RMIR contains data from the U.S. Nuclear Regulatory Commission, state radiation control offices, the DOE Unusual Occurrence Report data base, and media coverage of radioactive materials transportation incidents. DOE (1995, pages I-117) and McClure and Fagan (1998, all) discuss historic incidents involving spent nuclear fuel that are reported in RMIR as well as incidents that took place prior to the existence of this data base. RMIR characterizes incidents in three categories: transportation accidents, handling accidents, and reported incidents. However, the definitions of these categories are not consistent with the definitions used in other U.S. Department of Transportation data bases. For example, from 1971 through 1998, RMIR lists one transportation accident involving a loaded rail shipment of spent nuclear fuel. However, based on current Federal Railroad Administration reporting requirements, this occurrence probably would be listed as a grade-crossing incident, not an accident. For this reason and because of the small number of occurrences in the data base involving spent nuclear fuel, the EIS analysis did not use RMIR to estimate transportation accident rates.

J.1.4.2.3.2 Accident Rates for Transportation by Heavy-Combination Truck, Railcar, and Barge in the United States. Saricks and Tompkins (1999, all) developed estimates of accident rates for heavy-combination trucks, railcars, and barges based on data available for 1994 through 1996. The estimates provide an update for accident rates published in 1994 (Saricks and Kvitek 1994, all) that reflected rates from almost a decade earlier.

Rates for Accidents in Interstate Commerce for Heavy-Combination Trucks

Saricks and Tompkins (1999, all) developed basic descriptive statistics for state-specific rates of accidents involving interstate-registered combination trucks for 1994, 1995, and 1996. The accident rate over all road types for 1994 was 2.98×10^{-7} accident per truck-kilometer (Saricks and Tompkins, 1999, Table 3a); for 1995 it was 2.97×10^{-7} accident per truck-kilometer (Saricks and Tompkins, 1999, Table 3b); and for 1996 it was 3.46×10^{-7} accident per truck-kilometer (Saricks and Tompkins, 1999, Table 3c). The composite mean from 1994 through 1996 was 3.21×10^{-7} accident per truck-kilometer.

During the 24 years of the Proposed Action, the *mostly legal-weight truck* national transportation scenario would involve as many as 50,000 truck shipments of spent nuclear fuel and high-level radioactive waste. Based on the data in Saricks and Tompkins (1999, Table 4), the transportation analysis estimated that those shipments could involve as many as 40 accidents. During the same period, the *mostly rail* scenario would involve about 2,600 truck shipments, and the analysis estimated that as many as two accidents could occur during these shipments. More than 99 percent of these accidents would not generate forces capable of causing functional damage to the casks, and would have no radiological consequences. A small fraction of the accidents could generate forces capable of damaging the cask.

Rates for Freight Railcar Accidents

Results for accident rates for freight railcar shipments from Saricks and Tompkins (1999, all), show that domestic rail freight accidents, fatalities, and injuries on Class 1 and 2 railroads have remained stable or declined slightly since the late 1980s. Based on data from 1994 through 1996, these rates are 5.39×10^{-8}, 8.64×10^{-8}, and 1.05×10^{-8} per railcar-kilometer, respectively (Saricks and Tompkins, 1999, Table 6). This conclusion is based on applying denominators that do *not* include train and car kilometers for intermodal shipments (containers and trailers-on-flatcar) not loaded by the carriers themselves. Thus, the actual denominators are probably higher and the rates consequently lower, by about 20 percent.

During the 24 years of the Proposed Action, the *mostly rail* national transportation scenario would involve as many as 11,000 rail shipments of spent nuclear fuel and high-level radioactive waste. Based on the data in Saricks and Tompkins (1999, Table 6), the analysis estimated that these shipments could involve one or two accidents. More than 99 percent of these accidents would not generate forces capable of causing functional damage to the cask; these accidents would have no radiological consequences. A small fraction of the accidents could generate forces capable of damaging the cask. For the *mostly legal-weight truck* scenario, rail accidents would be unlikely during the 300 railcar shipments of naval spent nuclear fuel.

Rates for Barge Accidents

Waterway results show a general improvement over mid-1980s rates. The respective rates for 450-metric-ton (500-ton) shipments for waters internal to the coast (rivers, lakes, canals, etc.) for accident and incident involvements and fatalities were 1.68×10^{-6} and 8.76×10^{-9} per shipment-kilometer, respectively (Saricks and Tompkins 1999, Table 8b). Rates for lake shipping were lower—2.58×10^{-7} and 0 per shipment-kilometer, for accidents and incidents and for fatalities, respectively. Coastal casualty involvement rates have risen in comparison to the data recorded about 10 years ago, and are comparable to rates for internal waters—5.29×10^{-7} and 8.76×10^{-9} per shipment-kilometer (Saricks and Tompkins 1999, Table 9b).

During the 24 years of the Proposed Action, the *mostly rail* national transportation scenario could involve the use of barges to ship spent nuclear fuel from 14 commercial sites. Based on the data in Saricks and Tompkins (1999, all), the analysis estimated that less than one accident could occur during such shipments. A barge accident severe enough to cause measurable damage to a shipping cask would be highly unlikely.

Rates for Safe Secure Trailer Accidents

DOE uses safe secure trailers to transport hazardous cargoes in the continental United States. The criteria used for reporting accidents involving these trailers are damage in excess of $500, a fire, a fatality, or damage sufficient for the trailer to be towed. From 1975 through 1998, 14 accidents involved safe secure trailers over about 54 million kilometers (about 34 million miles) of travel, which yields a rate of 2.6×10^{-7} accident per kilometer (4.2×10^{-7} per mile). This rate is comparable to the rate estimated by Saricks and Tompkins (1999, Table 4) for heavy combination trucks, 3.2×10^{-7} accident per kilometer (5.1×10^{-7} per mile).

J.1.4.2.3.3 Accident Data Provided by the States of Nevada, California, South Carolina, Illinois, and Nebraska. In May 1998, DOE requested the 48 contiguous states to provide truck and rail transportation accident data for use in this EIS. Five states responded – Nevada, California, Illinois, Nebraska, and South Carolina (Denison 1998, all; Caltrans 1997, all; Wort 1998, all; Kohles 1998, all; SCDPS 1997, all**)**. No states provided rail information.

- *Nevada.* Nevada provided a highway accident rate of 1.1×10^{-6} accident per kilometer (1.8×10^{-6} per mile) for interstate carriers over all road types. This is higher than the accident rate estimated by Saricks and Tompkins (1999, Table 4); 2.5×10^{-7} accident per kilometer (3.9×10^{-7} per mile) for heavy trucks over all road types in Nevada from 1994 to 1996.

  The definition of *accident* used in Saricks and Tompkins (1999, page 4) is the Federal definition (fatality, injury, or tow-away); in Nevada the accident criteria are fatality, injury, or $750 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (FHWA 1997, page 2; FHWA 1998, pages 1 and 2), using the Federal definition would reduce the accident rate from 1.1×10^{-6} to about 4.1×10^{-7} accident per kilometer (1.8×10^{-6} to 6.7×10^{-7} per mile). The radiological accident risk in Nevada for the mostly legal-weight truck scenario would increase over 24 years from 0.0002 latent cancer fatality to about 0.0005 latent cancer fatality (a likelihood of 5 in 10,000 of one latent cancer fatality) if the accident rate reported by Saricks and Tompkins for Nevada were replaced by the rate of 4.1×10^{-7} per kilometer. Thus, the impacts of the rate for accidents involving large trucks on Nevada highways reported by Nevada (Denison 1998, all) would be comparable to the impacts derived using rate estimated by Saricks and Tompkins.

- *California.* California responded with highway accident rates that included all vehicles (cars, buses, and trucks). The accident rate for Interstate highways was 4.2×10^{-7} accident per kilometer (6.8×10^{-7} per mile) for all vehicles in 1996. This rate is higher than the accident rate estimated by Saricks and Tompkins (1999, Table 4), 1.6×10^{-7} accident per kilometer (2.6×10^{-7} per mile) for heavy trucks on California interstate highways from 1994 to 1996.

  The definition of *accident* in Saricks and Tompkins (1999, page 4) is the Federal definition (fatality, injury, or tow-away); in California the accident criteria are fatality, injury, or $500 property damage. Based on national data from FHWA (1997, page 2) and FHWA (1998, pages 1 and 2**),** using the Federal definition would reduce the accident rate from 4.2×10^{-7} to about 1.6×10^{-7} accident per kilometer (6.8×10^{-7} to 2.6×10^{-7} per mile). In addition, the rate provided by California was for all vehicles. Based on national data from the U.S. Department of Transportation Bureau of Transportation Statistics, using the accident rate for large trucks would reduce the all-vehicle accident rate from 1.6×10^{-7} to about 1.3×10^{-7} accident per kilometer (2.6×10^{-7} to 2.1×10^{-7} per mile) for large trucks. This rate is slightly less than the rate estimated by Saricks and Tompkins (1999, Table 4**)**, 1.6×10^{-7} accident per kilometer.

- *Illinois.* Illinois provided highway data for semi-trucks from 1991 through 1995 over all road types. Over this period, the accident rate was 1.8×10^{-6} accident per kilometer (2.9×10^{-6} per mile). From 1994 through 1996, Saricks and Tompkins (1999, all) estimated an accident rate of 3.0×10^{-7} accident per kilometer (4.8×10^{-7} per mile) for heavy trucks over all road types in Illinois.

  The definition of *accident* used in Saricks and Tompkins (1999, page 4) is the Federal definition (fatality, injury, or tow-away); in Illinois the accident criteria are fatality, injury, or $500 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (FHWA 1997, page 2; FHWA 1998, pages 1 and 2), using the Federal definition would reduce the accident rate from 1.8×10^{-6} to about 6.7×10^{-7} accident per kilometer (2.9×10^{-6} to 1.1×10^{-6} per mile). This rate is comparable to the rate estimated by Saricks and Tompkins (1999, all).

- *Nebraska.* Nebraska provided a highway accident rate of 2.4×10^{-7} accident per kilometer (3.8×10^{-7} per mile) for 1997. Nebraska did not specify if the rate was for interstate highways, but it is for interstate truck carriers. This rate is slightly less than the accident rate estimated by Saricks and Tompkins (1999, all) for Nebraska interstates, 3.2×10^{-7} accident per kilometer (5.1×10^{-7} per mile) for heavy trucks from 1994 through 1996.

- *South Carolina.* South Carolina responded with highway accident rates that included all types of tractor/trailers (for example, mobile homes, semi-trailers, utility trailers, farm trailers, trailers with boats, camper trailers, towed motor homes, petroleum tankers, lowboy trailers, auto carrier trailers, flatbed trailers, and twin trailers). The rate was 8.3×10^{-7} accident per kilometer (1.3×10^{-6} per mile), for all road types. [This is higher than the accident rate estimated by Saricks and Tompkins (1999, all), 4.7×10^{-7} accident per kilometer (7.6×10^{-7} per mile) for heavy trucks on all road types in South Carolina from 1994 through 1996].

  The definition of *accident* in Saricks and Tompkins (1999, page 4) is the Federal definition (fatality, injury, or tow-away); in South Carolina the accident criteria are fatality, injury, or $1,000 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (FHWA 1997, page 2; FHWA 1998, pages 1 and 2), using the Federal definition of an accident would reduce the accident rate from 8.3×10^{-7} to about 3.1×10^{-7} accident per kilometer (1.3×10^{-6} to 5.0×10^{-7} per mile), which is slightly less than the rate estimated by Saricks and Tompkins (1999, all), 4.7×10^{-7} accident per kilometer (7.6×10^{-7} per mile). In addition, the accident rate estimated by Saricks and Tompkins (1999, all) was based on Motor Carrier Management Information System vehicle configuration codes 4 through 8 (truck/trailer, bobtail, tractor/semi-trailer, tractor/double, and tractor/triple), while the rate obtained from South Carolina included all truck/trailer combinations. Including all of the combinations tends to increase accident rates; for example, light trucks have higher accident rates than heavy trucks (BTS 1999, Table 3-22).

DOE evaluated the effect of using the data provided by the five states on radiological accident risk for the mostly legal-weight truck national transportation scenario. If the data used in the analysis for the five states (Saricks and Tompkins 1999, Table 4) were replaced by the data provided by the states with the adjustments discussed, the change in the resulting estimate of radiological accident risk would be small, increasing from 0.067 to 0.071 latent cancer fatality. Using the unadjusted data provided by those states would result in an increase in accident risk from 0.067 to 0.093 latent cancer fatality.

J.1.4.2.4 *Transportation Accidents Involving Nonradioactive Hazardous Materials*

The analysis of impacts of transportation accidents involving the transport of nonradioactive hazardous materials to and from Yucca Mountain used information presented in two U.S. Department of Transportation reports (DOT 1998b, Table 1; BTS 1996, page 43) on the annual number of hazardous materials shipments in the United States and the number of deaths caused by hazardous cargoes in 1995. In total, there are about 300 million annual shipments of hazardous materials; only a small fraction involve radioactive materials. In 1995, 6 fatalities occurred because of hazardous cargoes. These data suggest a rate of 2 fatalities per 100 million shipments of hazardous materials. DOE anticipates about 40,000 shipments of nonradioactive hazardous materials (including diesel fuel and laboratory and industrial chemicals) to and from the Yucca Mountain site during construction, operation and monitoring, and closure of the repository. Assuming that the rate for fatalities applies to the transportation of nonradioactive hazardous materials to and from Yucca Mountain, DOE does not expect fatalities from 40,000 shipments of these materials.

J.2 Evaluation of Rail and Intermodal Transportation Options

DOE could use several modes of transportation to ship spent nuclear fuel from the 77 sites. Legal-weight trucks could be used to transport spent nuclear fuel and high-level radioactive waste contained in truck casks that would weigh approximately 22,500 kilograms (25 tons) when loaded. For sites served by railroads, rail casks placed on railcars could be used to ship directly to the Yucca Mountain site if a branch rail line was constructed in Nevada or to ship to an intermodal transfer station in Nevada if heavy-haul trucks were used.

For sites not served by a railroad that nonetheless have the capability to load rail casks, DOE could use heavy-haul trucks or, for sites located on navigable waterways, barges to transport the casks between the generating sites and nearby railheads.

For rail shipments, DOE could request the railroads provide dedicated trains to transport casks from sites to a destination in Nevada or could deliver railcars with loaded casks to the railroads as general freight for delivery in Nevada.

J.2.1 IMPACTS OF THE SHIPMENT OF COMMERCIAL SPENT NUCLEAR FUEL BY BARGE AND HEAVY-HAUL TRUCK FROM 19 SITES NOT SERVED BY A RAILROAD

An alternative to truck or rail transport of commercial spent nuclear fuel, barge transportation, was evaluated. Nineteen commercial sites that have the capability to handle and load rail casks are not served by a railroad. Accordingly, under the mostly rail transportation scenario the 19 sites were assumed to use heavy-haul trucks to move the rail casks to nearby railheads. However, because 14 of the sites are on navigable waterways (see Figure J-9), some could use barges to ship to nearby railheads. The following sections present the analysis of impacts of using barges and compares these impacts from one of the fourteen sites located on a navigable waterway (Turkey Point) to the impacts based on the use of heavy-haul trucks and legal-weight truck. The analysis assumed that all five of the DOE sites would have railroad service.

Unlike previous sections, where impacts were presented for all shipments by mode (mostly legal-weight truck and mostly rail), impacts are reported on a per shipment basis and compared on that basis to shipments via heavy-haul truck and legal-weight truck for the same reactor site.

J.2.1.1 Routes for Barges and Heavy-Haul Trucks

The heavy-haul truck-to-railhead distances for the 19 sites range from about 6 to 75 kilometers (4 to 47 miles). Routing for heavy-haul trucks was estimated using the HIGHWAY computer code (Johnson et al. 1993a, all). The INTERLINE computer code (Johnson et al. 1993b, all) was used to generate route-specific distances that would be traveled by barges. The resulting estimates for route lengths for barges and heavy-haul trucks are listed in Table J-26. Table J-27 lists the number of shipments from each site.

J.2.1.2 Analysis of Incident-Free Impacts for Barge and Heavy-Haul Truck Transportation

J.2.1.2.1 *Radiological Impacts of Incident-Free Transportation*

This section compares the radiological and nonradiological impacts to populations and maximally exposed individuals of incident-free transportation of spent nuclear fuel from one commercial spent nuclear fuel site (Turkey Point) for:

- Shipments using heavy-haul trucks to the nearest railhead and then to the Nevada Caliente node by rail and finally to the Yucca Mountain site by rail using the Caliente-Chalk Mountain corridor.

- Shipments using barge to a nearby railhead (Port of Miami for the Turkey Point site) and then to the Nevada Caliente node by rail and finally to the Yucca Mountain site by rail using the Caliente-Chalk Mountain corridor.

- Shipments using legal-weight trucks to the Yucca Mountain site.

The radiological impacts of intermodal transfers at the interchange from heavy-haul trucks to railcars or barges to railcars were included in the analysis. Workers would be exposed to radiation from casks during transfer operations. However, because the transfers would occur in terminals and berths that are remote from public access, public exposures would be small. Impacts of constructing intermodal transfer facilities were not included because intermodal transfers were assumed to take place at existing facilities.

The analysis assumed that heavy-haul trucks, though they would be slower moving vehicles, would result in the same types of impacts as, although somewhat higher than, an equal number of legal-weight truck shipments over the same routes. Because travel distances to nearby railheads would be short, impacts of

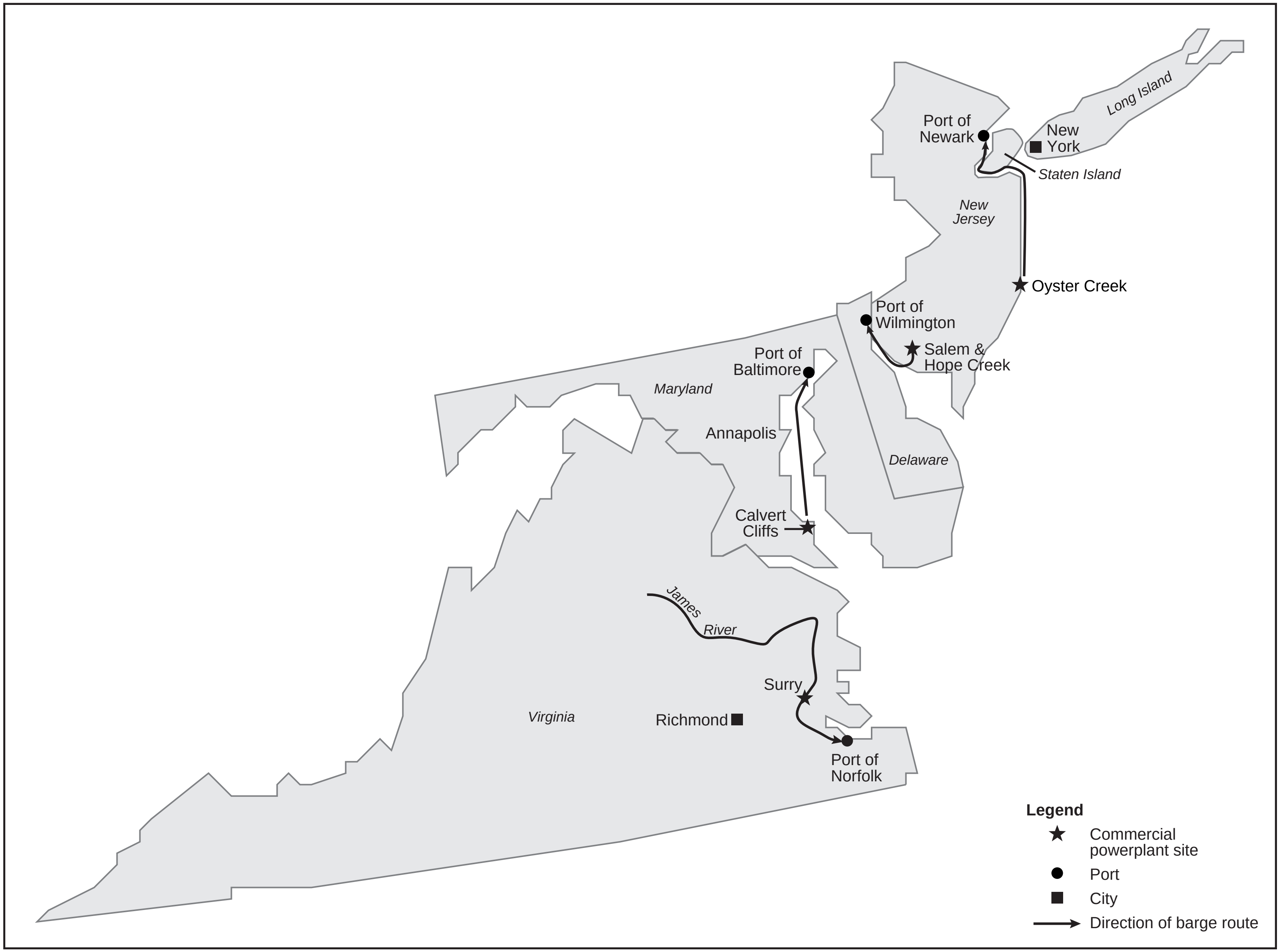


Figure J-9. Routes for barges from sites to nearby railheads (page 1 of 3).

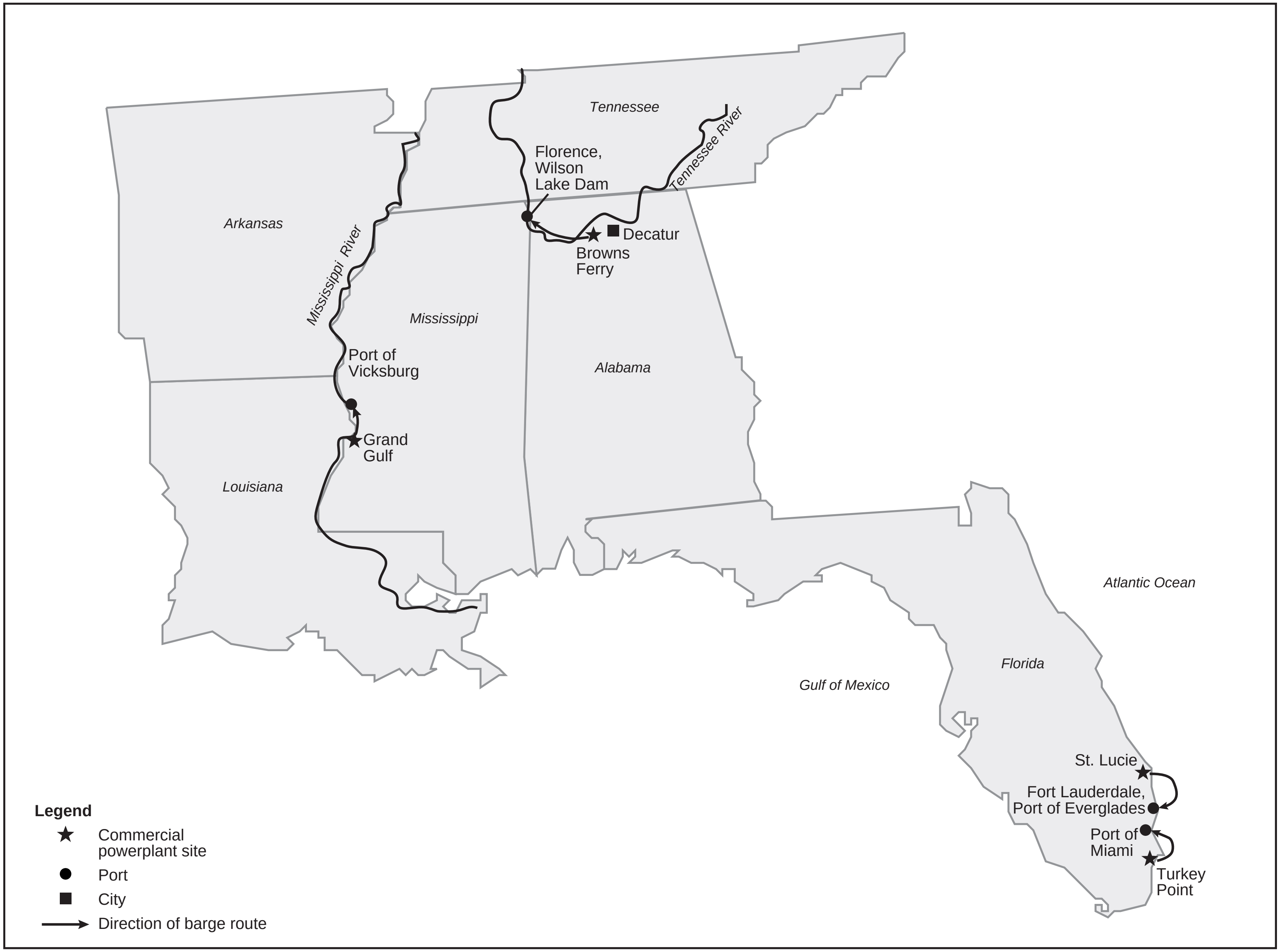


Figure J-9. Routes for barges from sites to nearby railheads (page 2 of 3).

Figure J-9. Routes for barges from sites to nearby railheads (page 3 of 3).

Table J-26. National transportation distances from commercial sites to Nevada ending rail nodes (kilometers)[a,b] (page 1 of 2).

Site			Rail transportation				Barge transportation			
(intermodal rail node)[c]	State	Destination	Total[d]	Rural	Suburban	Urban	Total[d]	Rural	Suburban	Urban
Browns Ferry NP[e]	AL	Apex	3,596	3,269	281	46	57	52	5	0
		Caliente	3,423	3,095	281	46	57	52	5	0
		Beowawe	3,278	2,990	254	34	57	52	5	0
		Jean	3,678	3,333	293	51	57	52	5	0
Diablo Canyon NP	CA	Apex	644	420	124	100	143	143	0	0
		Caliente	817	594	124	100	143	143	0	0
		Beowawe	1,439	1,005	291	141	143	143	0	0
		Jean	562	355	112	94	143	143	0	0
St. Lucie NP	FL	Apex	5,203	4,293	812	97	140	50	52	39
		Caliente	5,029	4,119	812	97	140	50	52	39
		Beowawe	4,885	4,014	784	86	140	50	52	39
		Jean	5,284	4,358	823	103	140	50	52	39
Turkey Point NP	FL	Apex	5,245	4,296	820	127	54	53	0	1
		Caliente	5,071	4,123	820	127	54	53	0	1
		Beowawe	4,927	4,017	793	116	54	53	0	1
		Jean	5,326	4,361	832	133	54	53	0	1
Calvert Cliffs NP	MD	Apex	4,344	3,558	645	140	99	98	2	0
		Caliente	4,170	3,385	645	140	99	98	2	0
		Beowawe	4,026	3,279	618	129	99	98	2	0
		Jean	4,425	3,623	657	145	99	98	2	0
Palisades NP	MI	Apex	3,375	2,895	391	90	256	256	0	0
		Caliente	3,202	2,722	391	90	256	256	0	0
		Beowawe	3,058	2,616	363	78	256	256	0	0
		Jean	3,457	2,960	402	95	256	256	0	0
Grand Gulf NP	MS	Apex	3,686	3,355	291	39	51	51	0	0
		Caliente	3,512	3,181	291	39	51	51	0	0
		Beowawe	3,368	3,076	264	28	51	51	0	0
		Jean	3,767	3,419	303	44	51	51	0	0
Cooper NP	NE	Apex	2,345	2,193	119	33	117	100	16	1
		Caliente	2,171	2,020	119	33	117	100	16	1
		Beowawe	2,027	1,914	92	21	117	100	16	1
		Jean	2,426	2,258	130	38	117	100	16	1
Salem/Hope Creek NP	NJ	Apex	4,423	3,410	818	194	30	30	0	0
		Caliente	4,250	3,236	818	194	30	30	0	0
		Beowawe	4,106	3,131	791	183	30	30	0	0
		Jean	4,505	3,475	830	200	30	30	0	0
Oyster Creek NP	NJ	Apex	4,532	3,371	933	227	130	77	36	17
		Caliente	4,358	3,198	933	227	130	77	36	17
		Beowawe	4,214	3,092	906	216	130	77	36	17
		Jean	4,613	3,436	944	232	130	77	36	17
Surry NP	VA	Apex	4,583	3,982	532	68	71	60	8	3
		Caliente	4,409	3,809	532	68	71	60	8	3
		Beowawe	4,265	3,703	505	57	71	60	8	3
		Jean	4,664	4,047	544	73	71	60	8	3
Kewaunee NP	WI	Apex	3,180	2,789	312	79	293	285	2	7
		Caliente	3,007	2,616	312	79	293	285	2	7
		Beowawe	2,863	2,510	285	68	293	285	2	7
		Jean	3,262	2,854	323	84	293	285	2	7
Point Beach NP	WI	Apex	3,180	2,789	312	79	301	293	2	7
		Caliente	3,007	2,616	312	79	301	293	2	7
		Beowawe	2,863	2,510	285	68	301	293	2	7
		Jean	3,262	2,854	323	84	301	293	2	7
Callaway NP	MO	Apex	2,796	2,625	140	31	--[f]	--	--	--
HH – 18.5 kilometers		Caliente	2,624	2,452	140	31	--	--	--	--
		Beowawe	2,491	2,358	113	20	--	--	--	--
		Jean	2,878	2,689	151	37	--	--	--	--
Fort Calhoun NP	NE	Apex	2,301	2,177	102	21	--	--	--	--
HH – 6.0 kilometers		Caliente	2,129	2,005	102	21	--	--	--	--
		Beowawe	1,996	1,911	75	10	--	--	--	--
		Jean	2,383	2,242	114	27	--	--	--	--

Table J-26. National transportation distances from commercial sites to Nevada ending rail nodes (kilometers)[a,b] (page 2 of 2).

Site (intermodal rail node)[c]	State	Destination	Rail transportation				Barge transportation			
			Total[d]	Rural	Suburban	Urban	Total[d]	Rural	Suburban	Urban
Peach Bottom NP[e]	PA	Apex	4,294	3,324	779	191	--[f]	--	--	--
HH – 58.9 kilometers		Caliente	4,121	3,151	779	191	--	--	--	--
		Beowawe	3,988	3,057	752	179	--	--	--	--
		Jean	4,375	3,388	790	196	--	--	--	--
Oconee NP	SC	Apex	4,247	3,651	534	61	--	--	--	--
HH – 17.5 kilometers		Caliente	4,074	3,479	534	61	--	--	--	--
		Beowawe	3,941	3,385	507	50	--	--	--	--
		Jean	4,328	3,716	546	66	--	--	--	--

a. To convert kilometers to miles, multiply by 0.62137.
b. Distances estimated using INTERLINE computer program.
c. Intermodal rail nodes selected for purpose of analysis. Source: TRW (1999a, all).
d. Totals might differ from sums of rural, suburban, and urban distances due to method of calculation and rounding.
e. NP = nuclear plant.
f. -- = the four sites that are not located on a navigable waterway.

Table J-27. Barge shipments and ports.

Plant name	State	Number of shipments		Barge ports assumed for barge-to-rail intermodal transfer
		Proposed Action	Modules 1 and 2	
Browns Ferry 1	AL	176	253	Wilson L/D
Browns Ferry 3	AL	67	114	Wilson L/D
Diablo Canyon 1	CA	64	129	Port Huememe
Diablo Canyon 2	CA	59	149	Port Huememe
St. Lucie 2	FL	56	103	Port Everglades
Turkey Point 3	FL	56	80	Port of Miami
Turkey Point 4	FL	57	89	Port of Miami
Calvert Cliffs 1	MD	144	204	Port of Baltimore
Palisades	MI	70	70	Port of Muskegan
Grand Gulf 1	MS	79	154	Port of Vicksburg
Cooper Station	NE	103	159	Port of Omaha
Hope Creek	NJ	59	146	Port of Wilmington
Oyster Creek 1	NJ	87	87	Port of Newark
Salem 1	NJ	63	104	Port of Wilmington
Salem 2	NJ	57	112	Port of Wilmington
Surry 1	VA	102	128	Port of Norfolk
Kewaunee	WI	57	70	Port of Milwaukee
Point Beach 1	WI	90	102	Port of Milwaukee
Totals		**1,833**	**2,970**	

heavy-haul truck transportation would be much less than the impacts of national rail shipments. The analysis of impacts for barge shipments assumed the transport would employ commercial vessels operated by maritime carriers on navigable waterways and that these shipments would follow direct routing from the sites to nearby railheads. For both modes, intermodal transfers would be necessary to transfer rail casks to railcars.

Radiological impacts were estimated for workers and the general population. For heavy-haul truck shipments, workers included vehicle drivers and escorts. For barge shipments, the work crew included five members on board during travel and workers close to the shipping casks during inspections or intermodal transfers. The general population for truck shipments included persons within 800 meters (about 2,600 feet) of the road (offlink), persons sharing the road (onlink), and persons at stops. The general population for barging included persons within a range of 200 to 1,000 meters (about 660 to 3,300 feet) of the route, and persons at stops. On-link exposures to members of the public during barging were assumed to be small. Incident-free unit risk factors were developed to calculate occupational and general population collective doses. Table J-28 lists the unit risk factors for heavy-haul truck and barge shipments. The unit risk factors for heavy-haul truck shipments reflect the effects of slower operating speeds for those vehicles in comparison to those for legal-weight trucks.

Table J-28. Risk factors for incident-free heavy-haul truck and barge transportation of spent nuclear fuel and high-level radioactive waste.

		Incident free risk factors (person-rem per kilometer)[a]		
Mode	Exposure group	Rural	Suburban	Urban
Heavy-haul truck	*Occupational*	1.1×10^{-5}	1.1×10^{-5}	1.9×10^{-5}
	General population			
	Offlink[b]	7.3×10^{-8}	7.7×10^{-8}	8.3×10^{-8}
	Onlink[c]	1.1×10^{-4}	1.2×10^{-4}	5.5×10^{-4}
	Stops	1.9×10^{-4}	1.9×10^{-4}	1.9×10^{-4}
	Storage[d]	1.9×10^{-3}	1.9×10^{-3}	1.9×10^{-3}
	Totals	$\mathbf{2.2\times10^{-3}}$	$\mathbf{2.3\times10^{-3}}$	$\mathbf{2.7\times10^{-3}}$
Barge	*Occupational* [d]	9.4×10^{-7}	1.9×10^{-6}	4.8×10^{-6}
	General population			
	Offlink[b]	8.6×10^{-8}	1.7×10^{-7}	4.3×10^{-7}
	Onlink[c]	0.0	0.0	0.0
	Stops	5.4×10^{-3}	5.4×10^{-3}	5.4×10^{-3}
	Totals	$\mathbf{5.4\times10^{-3}}$	$\mathbf{5.4\times10^{-3}}$	$\mathbf{5.5\times10^{-3}}$

a. The methodology, equations, and data used to develop the unit dose factors are discussed in Madsen et al. (1986, all) and Neuhauser and Kanipe (1992, all). Cashwell et al. (1986, all) contains a detailed explanation of the use of unit factors.

b. Offlink general population included persons within 800 meters (about 2,600 feet) of the road or railway.

c. Onlink general population included persons sharing the road or railway.

d. The storage unit risk factor is only applied for heavy-haul truck shipments requiring an overnight stop.

Table J-29 lists the incident-free impacts on a per shipment basis from the Turkey Point nuclear power plant using the three shipment scenarios listed above. This is presented to compare the impacts on a per shipment basis using barge, heavy-haul truck or legal weight truck. Impacts of intermodal transfers are included in the results. Occupational impacts would include the estimated radiological exposures of security escorts.

Table J-29. Comparison of population doses and impacts from incident-free national transportation for heavy-haul-to-rail, barge-to-rail, and legal-weight truck options.[a,b]

Category	Heavy-haul to rail	Barge to rail	Legal-weight truck
Involved worker			
Collective dose (person-rem)	0.15	0.13	0.32
Estimated LCFs[e]	0.00006	0.00005	0.00013
Public			
Collective dose (person-rem)	0.12	0.41	1
Estimated LCFs	0.00006	0.0002	0.0005
Maximally exposed individual	Impacts would be the same as those in Chapter 6, Tables 6-9 and 6-12		

a. Rail impacts are presented for the Caliente-Chalk Mountain rail implementing alternative.

b. Impacts presented on a per shipment basis for the Turkey Point site.

c. LCF = latent cancer fatality.

As indicated in Table J-29, differences in radiological impacts between the use of heavy-haul trucks and barges would be small. The impacts to maximally exposed individuals would be the same because both cases use the same assumptions for locations of such individuals in relation to shipments and times of exposure.

J.2.1.2.2 *Nonradiological Impacts of Incident-Free Transportation (Vehicle Emissions)*

Table J-30 compares the estimated number of fatalities from vehicle emissions from shipments, assuming the use of heavy-haul trucks or barges to ship to nearby railheads.

Table J-30. Population health impacts from vehicle emissions during incident-free national transportation for mostly legal-weight truck scenario.[a]

Category	Heavy-haul to rail	Barge to rail	Legal-weight truck
Estimated fatalities	0.00004	0.00004	0.00003

a. Impacts are presented on a per shipment basis for the Turkey Point site.

J.2.1.3 Analysis of Impacts of Accidents for Barge and Heavy-Haul Truck Transportation

J.2.1.3.1 *Radiological Impacts of Accidents*

The analysis of risks from accidents during heavy-haul truck, rail, and legal-weight truck transport of spent fuel and high-level radioactive waste used the RADTRAN4 computer code (Neuhauser and Kanipe 1992, all) and the analysis approach discussed in Section J.1.4.2. The analysis of risks due to barging used the same methodology with the exception of conditional probabilities. For barge shipments, the conditional accident probabilities (Table J-31) for each cask response category were based on a review of other barge accident analyses.

Table J-31. Conditional probabilities for barge transportation.

Severity category	1	2	3	4	5	6
Conditional probability	0.93794	0.005	0.000	0.057	0.000051	0.0000058

When radioactive material is shipped by barge, it is possible to have both water and land contamination. The analysis assumed that airborne releases could occur in accidents involving barges. Any portion of a release plume over water would result in water contamination. Thus, there are two mechanisms for contaminating water and one, the airborne release, for contaminating land surfaces.

For accident scenarios that result in releases of radioactive material, part of the plume would be deposited on water and part on land. For coastal and lake shipping, the analysis assumed that, 50 percent of the time, the plume would be entirely deposited on water. For the other 50 percent, the analysis assumed that the accident would occur about 200 meters (660 feet) from the shore and any material deposited in the first 200 meters would be into water. The analysis used the methods used by the RISKIND computer program (Yuan et al. 1995 all) to estimate plume depletion into water for D stability and a wind speed of 3 meters per second. For these conditions, about 20 percent of the plume would be depleted in the first 200 meters. Based on this information, the analysis assumed that for coastal and lake shipping, 60 percent of the plume would be deposited on water and for river transport only 20 percent of the release would occur over water.

The analysis accommodated this split by allocating 60 percent of coastal and lake shipping to what was called a “water” state and the remaining 40 percent to an adjoining state (Florida in the case of Turkey

Point). For river transport, 20 percent of the mileage was allocated to the water state representing the river and the remaining 80 percent of the mileage was allocated to the adjacent state (Mississippi in the case of Browns Ferry).

The dose from plume release to water was limited to an ingestion dose. The transfer coefficients that were used in the calculation are listed in Table J-32. The selection of isotopes and the transfer coefficients was based on models used in the Foreign Spent Nuclear Fuel EIS (DOE 1996a, page E-126). The same water uptake models were used. Both the freshwater and ocean models considered fish consumption. The freshwater model included irrigation and domestic water consumption by both the general population and livestock. The ocean model included uptake from eating shellfish.

Table J-32. Food transfer factors used in the barge analysis.

Isotope	Ocean release	Freshwater release
Hydrogen-3 (tritium)		0.000020
Niobium-95	0.080	
Ruthenium-106	0.00014	
Cesium-134	0.00037	0.000022
Cesium-137	0.00037	0.000022

In addition, the analysis of barge accident risks used the following assumptions:

- Release fractions that determine the source term for dispersion to the waterway are the same as those developed for airborne release scenarios

For freshwater river systems, the analysis assessed the following exposure pathways:

- Drinking water
- Ingestion of fish by humans
- Ingestion of irradiated foods
- Shoreline deposits
- External irradiation from immersion during swimming

For marine coastal systems, the following exposure pathways were assessed:

- Ingestion of fish and invertebrates by humans
- External irradiation from shoreline deposits
- External irradiation from immersion during swimming

Route-specific collective doses were calculated using population distributions along the routes developed from 1990 Census data. As an example, Table J-33 presents the dose risk per shipment for the Turkey Point nuclear power plant.

Table J-33. Accident risks for shipping spent nuclear fuel from Turkey Point.

Category	Heavy-haul to rail	Barge to rail	Legal-weight truck
Dose risk (person-rem)	0.0038	0.0019	0.0023
Dose risk (LCF)[a]	0.000002	0.0000009	0.000001
Traffic fatalities	0.00039	0.00039	0.00011

a. LCF = latent cancer fatality.

J.2.1.3.2 *Nonradiological Accident Risks*

The fatalities per shipment for heavy-haul truck, barge, and legal-weight truck transport from Turkey Point would be 3.9×10^{-4}, 3.9×10^{-4} and 1.1×10^{-4} , respectively.

J.2.1.3.3 *Maximum Reasonably Foreseeable Accidents*

With the relatively short barging distance relative to the rail distance traveled, the probability of a barge accident is much lower than the 1×10^{-7}-criteria used for accidents that are reasonably foreseeable.

J.2.2 EFFECTS OF USING DEDICATED TRAINS OR GENERAL FREIGHT SERVICE

The Association of American Railroads recommends that only special (dedicated) trains move spent nuclear fuel and certain other forms of radioactive materials (DOT 1998b, page 2-6). In developing its recommendation, the Association concluded that the use of special trains would provide operational (for railroads and shippers) and safety advantages over shipments that used general freight service. Notwithstanding this recommendation, the Department of Transportation study (DOT 1998b, all) compared dedicated and regular freight service using factors that measure impacts to overall public safety. The results of this study indicated that dedicated trains could provide advantages over regular trains for incident-free transportation but could be less advantageous for accident risks. However, available information does not indicate a clear advantage for the use of either dedicated trains or general freight service. Thus, DOE has not determined the commercial arrangements it would request from railroads for shipment of spent nuclear fuel and high-level radioactive waste. Table J-34 compares the dedicated and general freight modes. These comparisons are based on the findings of the Department of Transportation study and the Association of American Railroads.

J.3 Nevada Transportation

With the exceptions of the possible construction of a branch rail line or upgrade of highways for use by heavy-haul trucks and the construction of an intermodal transfer station, the characteristics of the transportation of spent nuclear fuel and high-level radioactive waste in Nevada would be similar to those for transportation in other states across the nation. Unless the State of Nevada designated alternative or additional preferred routes as prescribed under regulations of the Department of Transportation (49 CFR 397.103), Interstate System Highways (I-15) would be the preferred routes used by legal-weight trucks carrying spent nuclear fuel and high-level radioactive waste. Unless alternative or non-Interstate System routes have been designated by states, Interstate system Highways would also be the preferred routes used by legal-weight trucks in other states during transit to Nevada.

In Nevada as in other states, rail shipments would, for the most part, be transported on mainline tracks of major railroads. Operations over a branch rail line in Nevada would be similar to those on a mainline railroad, except the frequency of train travel would be much lower. Shipments in Nevada that used heavy-haul trucks would use Nevada highways in much the same way that other overdimensional, overweight trucks use the highways along with other commercial vehicle traffic.

In some cases State-specific assumptions were used to analyze human health and safety impacts in Nevada. A major difference would be that much of the travel in the State would be in rural areas where population densities are much lower than those of many other states. Another difference would be for travel in an urban area in the state. The most populous urban area in Nevada is the Las Vegas metropolitan area, which is also a major resort area with a high percentage of nonresidents. The analysis also addressed the channeling of shipments from the commercial and DOE sites into the transportation arteries in the southern part of the State. Finally, the analysis addressed the commuter and commercial

Table J-34. Comparison of general freight and dedicated train service.

Attribute	General freight	Dedicated train
Overall accident rate for accidents that could damage shipping casks	Same as mainline railroad accident rates	Expected to be lower than general freight service because of operating restrictions and use of the most up-to-date railroad technology.
Grade crossing, trespasser, worker fatalities	Same as mainline railroad rates for fatalities	Uncertain. Greater number of trains could result in more fatalities in grade crossing accidents. Fewer stops in classification yards could reduce work related fatalities and trespasser fatalities.
Security	Security provided by escorts required by NRC[a] regulations	Security provided by escorts required by NRC regulations; fewer stops in classification yards than general freight service.
Incident-free dose to public	Low, but more stops in classification yards than dedicated trains. However, classification yards would tend to be remote from populated areas.	Lower than general freight service. Dedicated trains could be direct routed with fewer stops in classification yards for crew and equipment changes.
Radiological risks from accidents	Low, but greater than dedicated trains	Lower than general freight service because operating restrictions and equipment could contribute to lower accident rates and reduced likelihood of maximum severity accidents.
Occupational dose	Duration of travel influences dose to escorts	Shorter travel time would result in lower occupational dose to escorts.
Utilization of resources	Long cross-country transit times could result in least efficient use of expensive transportation cask resources; best use of railroad resources; least reliable delivery scheduling; most difficult to coordinate state notifications.	Direct through travel with on-time deliveries would result in most efficient use of cask resources; least efficient use of railroad resources. Railroad resource demands from other shippers could lead to schedule and throughput conflicts. Easiest to coordinate notification of state officials.

a. NRC = U.S. Nuclear Regulatory Commission.

travel that would occur on highways in the southern part of the State as a consequence of the construction, operation and monitoring, and closure of the proposed repository.

This section presents information specific to Nevada that DOE used to estimate impacts for transportation activities that would take place in the State. It includes results for cumulative impacts that would occur in Nevada for transportation associated with Inventory Modules 1 and 2.

J.3.1 TRANSPORTATION MODES, ROUTES, AND NUMBER OF SHIPMENTS

J.3.1.1 Routes in Nevada for Legal-Weight Trucks

The analysis of impacts that would occur in Nevada used the characteristics of (1) highways in Nevada that would be used for shipments of spent nuclear fuel and high-level radioactive waste by legal-weight trucks, (2) rail routes from the border to rail nodes where the implementing alternatives would connect, and (3) rail corridors and highway routes analyzed for the rail and heavy-haul truck implementing alternatives in the State.

Figure J-10 shows the routes in Nevada that legal-weight trucks would use unless the State designated alternative or additional preferred routes. The figure shows estimates for the number of legal-weight truck shipments that would travel on each route segment for the mostly legal-weight truck and mostly rail transportation scenarios. The inset on Figure J-10 shows the proposed Las Vegas Beltway and the routes DOE anticipates legal-weight trucks traveling to the repository would use.

J.3.1.2 Routes in Nevada for Transporting Rail Casks

The rail and heavy-haul truck implementing alternatives for transportation in Nevada include five possible rail corridors and five possible routes for heavy-haul trucks; the corridors and routes for these implementing alternatives are shown in Figures J-11 and J-12. These figures also show the estimated number of rail shipments that would enter the State on mainline railroads. These numbers indicate shipments that would arrive from the direction of the bordering state for each of the implementing alternatives for the mostly rail transportation scenario.

Table J-35 lists the total length and cumulative distance in rural, suburban, and urban population zones in the State of Nevada used to analyze impacts of the implementing alternatives. Table J-36 lists the total population that lives within 800 meters (0.5 mile) of rail lines in Nevada. The estimated population that would live along each branch rail line was based on population densities along existing mainline railroads in Nevada.

Nevada Heavy-Haul Truck Scenario

Tables J-37 through J-41 summarize the road upgrades for each of the five possible routes for heavy-haul trucks that DOE estimates would be needed before routine use of a route to ship casks containing spent nuclear fuel and high-level radioactive waste.

Nevada Rail Corridors

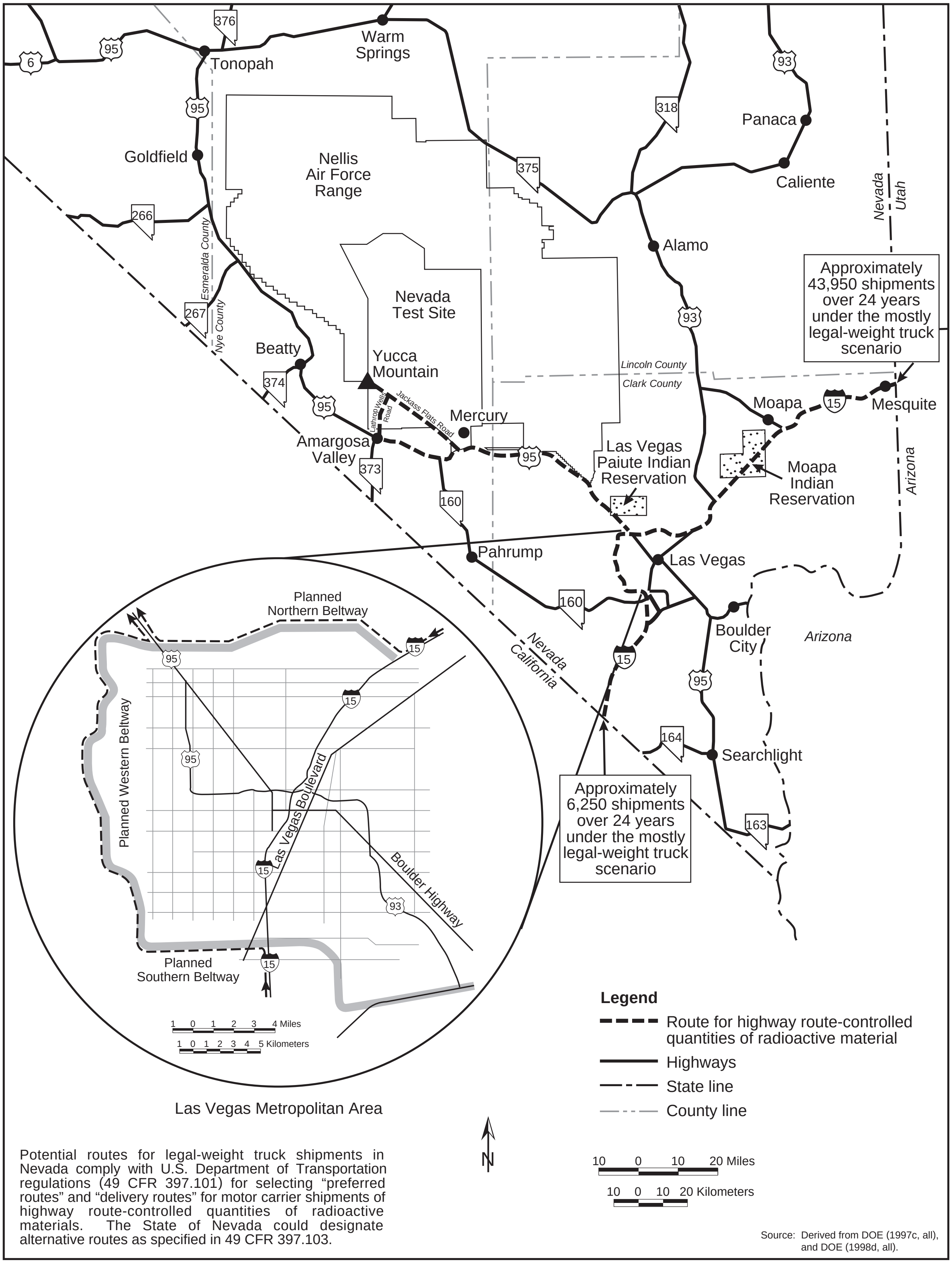
Under the mostly rail scenario, DOE could construct and operate a branch rail line in Nevada. Based on the studies listed below, DOE has narrowed its consideration for a new branch rail line to five potential rail corridors—the Carlin, Caliente, Caliente-Chalk Mountain, Jean, and Valley Modified routes. DOE identified the five rail corridors through a process of screening potential rail alignments that it had studied in past years. Several studies evaluated rail options.

- The *Feasibility Study for Transportation Facilities to Nevada Test Site* study (Holmes & Narver 1962, all) determined the technical and economic feasibility of constructing and operating a railroad from Las Vegas to Mercury.

- The *Preliminary Rail Access Study* (Tappen and Andrews 1990, all) identified 13 and evaluated 10 rail corridor alignment options. This study recommended the Carlin, Caliente, and Jean corridors for detailed evaluation.

- *The Nevada Railroad System: Physical, Operational, and Accident Characteristics* (DOE 1991, all) described the operational and physical characteristics of the current Nevada railroad system.

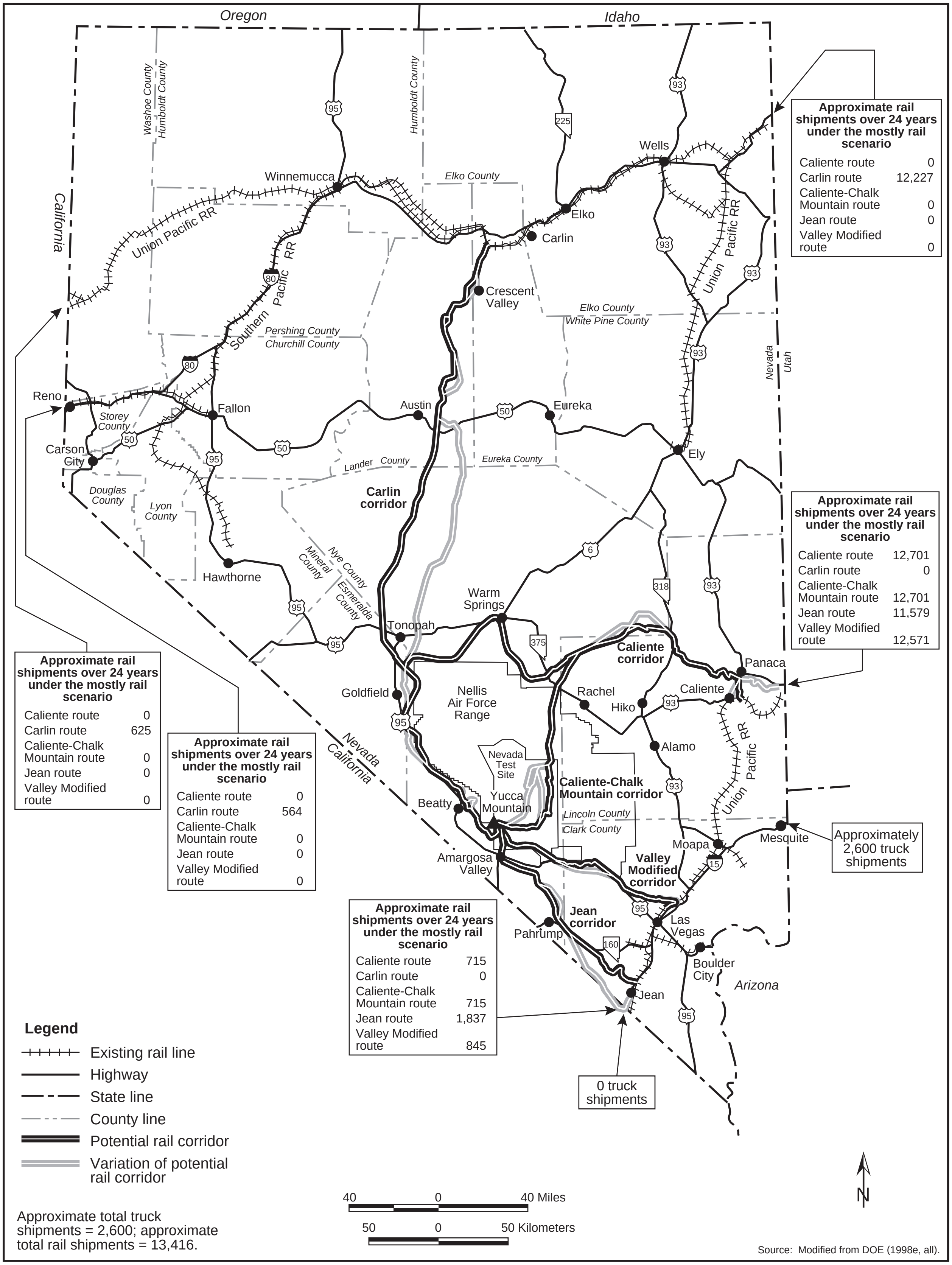
- The *High Speed Surface Transportation Between Las Vegas and the Nevada Test Site (NTS)* report (Raytheon 1994, all) explored the rationale for a potential high-speed rail corridor between Las Vegas and the Nevada Test Site to accommodate personnel.



Potential routes for legal-weight truck shipments in Nevada comply with U.S. Department of Transportation regulations (49 CFR 397.101) for selecting "preferred routes" and "delivery routes" for motor carrier shipments of highway route-controlled quantities of radioactive materials. The State of Nevada could designate alternative routes as specified in 49 CFR 397.103.

Source: Derived from DOE (1997c, all), and DOE (1998d, all).

Figure J-10. Potential Nevada routes for legal-weight truck shipments of spent nuclear fuel and high-level radioactive waste to Yucca Mountain.



Approximate rail shipments over 24 years under the mostly rail scenario

Caliente route	0
Carlin route	12,227
Caliente-Chalk Mountain route	0
Jean route	0
Valley Modified route	0

Approximate rail shipments over 24 years under the mostly rail scenario

Caliente route	12,701
Carlin route	0
Caliente-Chalk Mountain route	12,701
Jean route	11,579
Valley Modified route	12,571

Approximate rail shipments over 24 years under the mostly rail scenario

Caliente route	0
Carlin route	625
Caliente-Chalk Mountain route	0
Jean route	0
Valley Modified route	0

Approximate rail shipments over 24 years under the mostly rail scenario

Caliente route	0
Carlin route	564
Caliente-Chalk Mountain route	0
Jean route	0
Valley Modified route	0

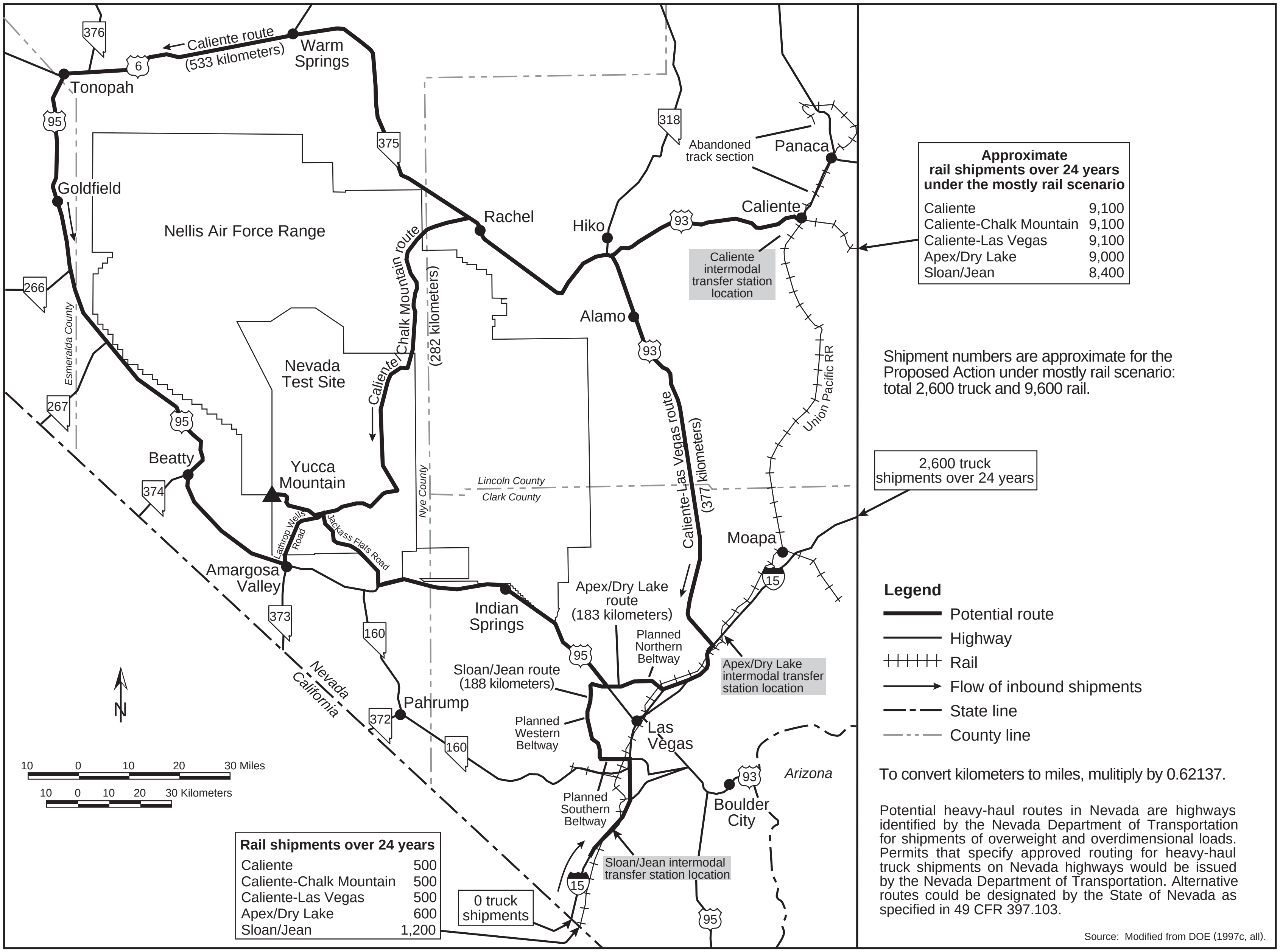
Approximate rail shipments over 24 years under the mostly rail scenario

Caliente route	715
Carlin route	0
Caliente-Chalk Mountain route	715
Jean route	1,837
Valley Modified route	845

Approximate total truck shipments = 2,600; approximate total rail shipments = 13,416.

Source: Modified from DOE (1998e, all).

Figure J-11. Potential Nevada rail routes to Yucca Mountain and approximate number of shipments for each route.



Approximate rail shipments over 24 years under the mostly rail scenario

Caliente	9,100
Caliente-Chalk Mountain	9,100
Caliente-Las Vegas	9,100
Apex/Dry Lake	9,000
Sloan/Jean	8,400

Rail shipments over 24 years

Caliente	500
Caliente-Chalk Mountain	500
Caliente-Las Vegas	500
Apex/Dry Lake	600
Sloan/Jean	1,200

Shipment numbers are approximate for the Proposed Action under mostly rail scenario: total 2,600 truck and 9,600 rail.

To convert kilometers to miles, mulitiply by 0.62137.

Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. Permits that specify approved routing for heavy-haul truck shipments on Nevada highways would be issued by the Nevada Department of Transportation. Alternative routes could be designated by the State of Nevada as specified in 49 CFR 397.103.

Figure J-12. Nevada routes for heavy-haul truck shipments of spent nuclear fuel and high-level radioactive waste to Yucca Mountain.

Table J-35. Route characteristics for rail and heavy-haul truck implementing alternatives.

Alternative	Rail node	Distance (kilometers)[a] Rural	Suburban	Urban	Total[b]
Rail					
Caliente	Caliente	513	0	0	513
Carlin	Beowawe	520	0	0	520
Caliente-Chalk Mountain	Caliente	345	0	0	345
Jean	Jean	181	0	0	181
Valley Modified	Apex	159	0	0	159
Heavy-haul [c]					
Caliente	Caliente	533	0	0	533
Caliente-Chalk Mountain	Caliente	282	0	0	282
Caliente-Las Vegas	Caliente	356	21	0	377
Apex/Dry Lake	Apex	162	21	0	183
Sloan/Jean	Jean	145	43	0	188

a. To convert kilometers to miles, multiply by 0.62137.
b. Rounded to the nearest kilometer.
c. Heavy-haul distances are based on using the Northern, Western, and Southern Beltways in the Las Vegas area. These beltways are assumed to have suburban population density.

Table J-36. Populations in Nevada within 800 meters (0.5 mile) of routes.

Transportation scenario	Population 1990 Census
Legal-weight truck routes[a]	60,000
Rail routes Nevada border to branch rail line[b]	
Caliente	30,000
Carlin	52,000
Caliente-Chalk Mountain	30,000
Jean	30,000
Valley Modified	30,000
Branch rail lines[c]	
Caliente	2,600
Carlin	2,700
Caliente-Chalk Mountain	1,800
Jean	900
Valley Modified	800

a. Source: TRW (1999a, Table 5-1).
b. Source: TRW (1999a, Table 5-2).
c. Estimated using 3.2 persons per square kilometer – the highest value for rural populations along mainline railroads in Nevada (TRW 1999a, Table 5-2).

- The *Nevada Potential Repository Preliminary Transportation Strategy*, *Study 1* (TRW 1995, all), reevaluated 13 previously identified rail routes and evaluated a new route called the Valley Modified route. This study recommended four rail routes for detailed evaluation—the Caliente, Carlin, Jean, and Valley Modified routes.

- The *Nevada Potential Repository Preliminary Transportation Strategy*, *Study 2* (TRW 1996, all), further refined the analyses of potential rail corridor alignments presented in Study 1.

Public comments submitted to DOE during hearings on the scope of this environmental impact statement resulted in addition of a fifth potential rail corridor—Caliente-Chalk Mountain.

Table J-37. Potential road upgrades for Caliente route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to State Route 375	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance of 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road.
State Route 375 to U.S. 6	Remove existing pavement, increase road base and overlay to remove frost restrictions, truck lanes where grade is greater than 4 degrees (minimum distance of 460 meters per lane), turnout lanes every 32 kilometers (distance of 305 meters per lane), widen road.
U.S. 6 to U.S. 95	Same as State Route 375 to U.S. 6.
U.S. 95 to Lathrop Wells Road	Remove existing pavement on frost restricted portion, increase base and overlay to remove frost restrictions, turnout lanes every 8 kilometers (distance of 305 meters per lane), construct bypass around intersection at Beatty, bridge upgrade near Beatty.
Lathrop Wells Road to Yucca Mountain site	Asphalt overlay on existing roads.

a. Source: TRW (1999b, Heavy-Haul Truck Files, Item 4).
b. To convert meters to feet, multiply by 3.2808.
c. To convert kilometers to miles, multiply by 0.62137.

Table J-38. Potential road upgrades for Caliente-Chalk Mountain route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to State Route 375	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road.
State Route 375 to Rachel	Remove existing pavement, increase road base and overlay to remove frost restrictions, turnout lanes every 32 kilometers (distance of 305 meters per lane), widen road.
Rachel to Nellis Air Force Range	Pave existing gravel road.
Nellis Airforce Range Roads	Rebuild existing road.
Nevada Test Site Roads	Asphalt overlay on existing roads.

a. Source: TRW (1999b, Heavy-Haul Truck Files, Item 9).
b. To convert meters to feet, multiply by 3.2808.
c. To convert kilometers to miles, multiply by 0.62137.

DOE has identified 0.4-kilometer (0.25-mile)-wide corridors along each route within which it would need to obtain a right-of-way to construct a rail line and an associated access road. A corridor defines the boundaries of the route by identifying an established "zone" for the location of the railroad. For this analysis, DOE identified a single alignment for each of the corridors. These single alignments are representative of the range of alignments that DOE has considered for the corridors from engineering design and construction viewpoints. The following paragraphs describe the alignments that have been identified for the corridors. Before siting a branch rail line, DOE would conduct engineering studies in each corridor to determine a specific alignment for the roadbed, track, and right-of-way for a branch rail line.

Carlin Rail Corridor Implementing Alternative. The Carlin corridor originates at the Union Pacific main line railroad near Beowawe in north-central Nevada. The corridor is about 520 kilometers (331

Table J-39. Potential road upgrades for Caliente-Las Vegas route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to Interstate 15	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road, rebuild Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes, asphalt overlay on U.S. 95.
U.S. 95 to Mercury	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: TRW (1999b, Heavy-Haul Truck Files, Item 4).
b. To convert meters to feet, multiply by 3.2808.
c. To convert kilometers to miles, multiply by 0.62137.

Table J-40. Potential road upgrades for Apex/Dry Lake route.[a]

Route	Upgrades
Intermodal transfer station to Interstate 15	Rebuild frontage road to U.S. 93. Rebuild U.S. 93/Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes.
U.S. 95 to Mercury Exit	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: TRW (1999b, Heavy-Haul Truck Files, Item 4).

Table J-41. Potential road upgrades for Sloan/Jean route.[a]

Route	Upgrades
Intermodal transfer station to Interstate 15	Overlay and widen existing road to Interstate 15 interchange, rebuild Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes.
U.S. 95 to Mercury Exit	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: TRW (1999b, Heavy-Haul Truck Files, Item 4).

miles) long from the tie-in point with the Union Pacific line to the Yucca Mountain site. Table J-42 lists possible variations in the alignment of this corridor.

Caliente Rail Corridor Implementing Alternative. The Caliente corridor originates at an existing siding to the Union Pacific mainline railroad near Caliente, Nevada. The Caliente and Carlin corridors converge near the northwest boundary of the Nellis Air Force Range. Past this point, they are identical. The Caliente corridor would be 513 kilometers (320 miles) long from the Union Pacific line connection to the Yucca Mountain site. Table J-43 lists possible alignment variations for this corridor.

Caliente-Chalk Mountain Rail Corridor Implementing Alternative. The Caliente-Chalk Mountain corridor is identical to the Caliente corridor until it approaches the northern boundary of the Nellis Air Force Range. At this point the Caliente-Chalk Mountain corridor turns south through the Nellis Air Force Range and the Nevada Test Site to the Yucca Mountain site. The corridor would be 345 kilometers (214 miles) long from the tie-in point at the Union Pacific line to the Yucca Mountain Site. Table J-44 lists possible alignment variations for this corridor.

Table J-42. Possible alignment variations of the Carlin corridor.[a]

Corridor	Description
Crescent Valley	Would diverge from the analyzed alignment near Cortez Mining Operation; would travel through nonagricultural lands adjacent to alkali flats but would affect larger area of private land.
Wood Spring	Would diverge from the analyzed alignment and use continuous 2-percent grade to descend from Dry Canyon Summit in Toiyabe range; would be shorter than the analyzed alignment but would have steeper grade.
Rye Patch	Would travel through Rye Patch Canyon, which has springs, riparian areas, and game habitats; would divert from the analyzed alignment, maintaining distance of 420 meters[b] from Rye Patch Spring and at least 360 meters from riparian areas throughout Rye Patch Canyon, except at crossing of riparian area near south end of canyon; would avoid game habitat (sage grouse strutting area).
Steiner Creek	Would diverge from the analyzed alignment at north end of Rye Patch Canyon. Would avoid crossing private lands, two known hawk-nesting areas, and important game habitat (sage grouse strutting area) in the analyzed alignment.
Monitor Valley	Would travel through less populated Monitor Valley (in comparison to Big Smokey Valley).
Mud Lake[c]	Would travel farther from west edge of Mud Lake, which has known important archaeological sites.
Goldfield[c]	Would avoid crossing Nellis Air Force Range boundary near Goldfield, avoiding potential land-use conflicts with Air Force.
Bonnie Claire[c]	Would avoid crossing Nellis Air Force Range boundary near Scotty’s Junction, avoiding potential land-use conflicts with Air Force.
Oasis Valley[c]	Would enable flexibility in crossing environmentally sensitive Oasis Valley area. If DOE selected route through this area, further studies would ensure small environmental impacts.
Beatty Wash[c]	Would provide a corridor through Beatty Wash that was longer, but required less severe earthwork than the analyzed alignment.

a. Source: TRW (1999b, Rail Files, Item 6).
b. To convert meters to feet, multiply by 3.2808.
c. Common with Caliente corridor.

Table J-43. Possible alignment variations of the Caliente corridor.[a]

Corridor	Description
Caliente[b]	Would connect with Union Pacific line at existing siding in Town of Caliente.
Crestline[b]	Would connect with Union Pacific line near east end of existing siding at Crestline.
White River	Would avoid potential conflict with Weepah Spring Wilderness Study Area.
Garden Valley	Would put more distance between rail corridor and private lands in Garden Valley and Coal Valley.
Mud Lake[c]	Would travel farther from west edge of Mud Lake, which has known important archaeological sites.
Goldfield[c]	Would avoid crossing Nellis Air Force Range boundary near Goldfield, avoiding potential land-use conflicts with Air Force.
Bonnie Claire[c]	Would avoid crossing Nellis Air Force Range boundary near Scotty’s Junction, avoiding potential land-use conflicts with Air Force.
Oasis Valley[c]	Would enable flexibility in crossing environmentally sensitive Oasis Valley area. If DOE selected route through this area, further studies would ensure small environmental impacts.
Beatty Wash[c]	Would provide corridor through Beatty Wash that was longer, but required less severe earthwork than the analyzed alignment.

a. Source: TRW (1999b, Rail Files, Item 6).
b. Common with Caliente-Chalk Mountain corridor.
c. Common with Carlin corridor.

Table J-44. Possible alignment variations of the Caliente-Chalk Mountain corridor.[a]

Corridor	Description
Mercury Highway	To provide flexibility in choosing path, would travel north through center of Nevada Test Site.
Tonopah	To provide flexibility in choosing path through Nevada Test Site; would travel north along western boundary of Nevada Test Site.
Mine Mountain	Would provide flexibility in minimizing impacts to local archaeological sites.
Area 4	Would provide flexibility in choosing path through Nevada Test Site.

a. Source: TRW (1999b, Rail Files, Item 8).

Jean Rail Corridor Implementing Alternative. The Jean corridor originates at the existing Union Pacific mainline railroad near Jean, Nevada. The corridor would be 181 kilometers (112 miles) long from the tie-in point at the Union Pacific line to the Yucca Mountain site. Table J-45 lists possible variations for this corridor.

Table J-45. Possible alignment variations of the Jean corridor.[a]

Corridor	Description
North Pahrump	Would minimize impacts to approximately 4 kilometers[b] of private land on northeast side of Pahrump.
Stateline Pass	Would provide option to crossing Spring Mountains at Wilson Pass; would diverge from analyzed alignment in Pahrump Valley; would parallel Nevada-California border, traveling along southwestern edge of Spring Mountains and crossing border twice.

a. Source: TRW (1999b, Rail Files, Item 6).
b. 4 kilometers = 2.5 miles (approximate).

Valley Modified Rail Corridor Implementing Alternative. The Valley Modified corridor originates at an existing rail siding off the Union Pacific mainline railroad northeast of Las Vegas. The corridor is about 159 kilometers (98 miles) long from the tie-in point with the Union Pacific line to the Yucca Mountain site. Table J-46 lists the possible variations in alignment for this corridor.

Table J-46. Possible alignment variations of the Valley Modified corridor.[a]

Corridor	Description
Indian Hills	Would avoid entrance to Nellis Air Force Range north of Town of Indian Springs by traveling south of town.
Sheep Mountain	Would increase distance from private land in Las Vegas and proposed 30-square-kilometer[b] Bureau of Land Management land exchange with city.
Valley Connection	Would locate transfer operations at Union Pacific Valley Yard rather than Dike siding. Overflights of Dike siding from Nellis Air Force Base could conflict with switching operations.

a. Source: TRW (1999b, Rail Files, Item 6).
b. 30 square kilometers = 7,410 acres (approximate).

J.3.1.3 Sensitivity of Analysis Results to Routing Assumptions

In addition to analyzing the impacts of using highway routes that would meet Department of Transportation requirements for transporting spent nuclear fuel, DOE evaluated how the estimated impacts would differ if legal-weight trucks used other routes in Nevada. Six other routes identified in a 1989 study by the Nevada Department of Transportation (Ardila-Coulson 1989, pages 36 and 45) were selected for this analysis. The Nevada Department of Transportation study described the routes as follows:

Route A. Minimum distance and minimum accident rate.
South on U.S. 93A, south on U.S. 93, west on U.S. 6, south on Nevada 318, south on U.S. 93, south on I-15, west on Craig Road, north on U.S. 95

Route B. Minimum population density and minimum truck accident rate.
South on U.S. 93A, south on U.S. 93, west on U.S. 6, south on U.S. 95.

Both of these two routes use the U.S. 6 truck bypass in Ely.

Alternative route possibilities were identified between I-15 at Baker, California and I-40 at Needles, California to Mercury. These alternative routes depend upon the use of U.S. 95 in California, California 127 and the Nipton Road.

Route C. From Baker with California 127.
North on California 127, north on Nevada 373, south on U.S. 95

Route D. From Baker without California 127.
North on I-15, west on Nevada 160, south on U.S. 95

Route E. From Needles with U.S. 95, California 127, and the Nipton Road.
North on U.S. 95, west on Nevada 164, west on I-15, north on California 127, north on Nevada 373, south on U.S. 95

Route F. From Needles without California 127 and the Nipton Road.
West on I-40, east on I-15, west on Nevada 160, south on U.S. 95

Table J-47 identifies the sensitivity cases evaluated based on the Nevada Department of Transportation routes. Table J-48 lists the range of impacts in Nevada of using these different routes for the mostly legal-weight truck analysis scenario. The tables compare the impacts estimated for the highways identified in the Nevada study to those estimated for shipments that would follow routes allowed by current Department of Transportation regulations for Highway Route-Controlled Quantities of Radioactive Materials. Because the State of Nevada has not designated alternative or additional preferred routes for use by these shipments, as permitted under Department of Transportation regulations (49 CFR 397.103), DOE has assumed that shipments of spent nuclear fuel and high-level radioactive waste would

Table J-47. Nevada routing sensitivity cases analyzed for a legal-weight truck.

Case	Description
Case 1	To Yucca Mountain via Barstow, California, using I-15 to Nevada 160 to Nevada 160 (Nevada D and F)
Case 2	To Yucca Mountain via Barstow using I-15 to California route 127 to Nevada 373 to US 95 (Nevada C)
Case 3	To Yucca Mountain via Needles using U.S. 95 to Nevada 164 to I-15 to California 127 to Nevada 373 and U.S. 95 (Nevada E)
Case 4	To Yucca Mountain via Needles using U.S. 95 to Nevada 164 to I-15 to Nevada 160 (variation of Nevada E)
Case 5	To Yucca Mountain via Wendover using U.S. 93 Alternate to U.S. 93 to US 6 to U.S. 95 (Nevada B)
Case 6	To Yucca Mountain via Wendover using U.S. 93 Alternate to U.S. 93 to Nevada 318 to U.S. 93 to I-15 to the Las Vegas Beltway to U.S. 95 (Nevada A)

Table J-48. Comparison of impacts from the sensitivity analyses (national and Nevada).

	Base case		Barstow via Nevada 160		Barstow via U.S. 95		Needles via Nevada 160		Needles via U.S. 95		Wendover via U.S. 95		Wendover via Las Vegas Beltway	
	National	Nevada	National	Nevada	National	Nevada	National	Nevada	National	Nevada	National	Nevada	National	Nevada
Public incident-free dose (person-rem)	35,000	2,700	39,000	2,500	38,000	710	39,000	2,900	37,000	1,100	38,000	7,100	38,000	7,600
Occupational incident-free dose (person-rem)	11,000	1,600	12,000	1,500	12,000	1,100	12,000	1,600	12,000	1,200	12,000	2,600	12,000	2,700
Pollution health effects nonradioactive	0.60	0.006	0.68	0.005	0.68	0.004	0.64	0.003	0.64	0.001	0.61	0.011	0.61	0.011
Public incident-free risk of latent cancer fatality	17	1.4	19	1.2	19	0.4	18	1.4	19	0.6	19	3.5	19	3.8
Occupational incident-free risk of latent cancer fatality	4.5	0.6	4.9	0.6	4.8	0.4	4.7	0.6	4.7	0.5	4.7	1.0	4.8	1.1
Radiological accident risk (person-rem)	130	0.5	100	0.4	100	0.0	98	0.4	98	0.1	140	1.0	140	1.0
Radiological accident risk of latent cancer fatality	0.067	0.00024	0.0	0.00020	0.050	0.00001	0.049	0.00021	0.049	0.00003	0.069	0.0005	0.069	0.0005
Traffic fatalities	3.9	0.5	4.3	0.4	4.0	0.1	4.2	0.5	4.0	0.2	4.7	1.2	4.8	1.3

enter Nevada on I-15 from either the northeast or southwest. The analysis assumed that shipments traveling on I-15 from the northeast would use the northern Las Vegas Beltway to connect to U.S. 95 and continue to the Nevada Test Site. Shipments from the southwest on I-15 would use the southern and western Las Vegas Beltway to connect to U.S. 95 and continue to the Nevada Test Site.

J.3.2 ANALYSIS OF INCIDENT-FREE TRANSPORTATION IN NEVADA

The analysis of incident-free impacts to populations in Nevada addressed transportation through urban, suburban, and rural population zones. The population densities that were assumed for the analysis were determined using the HIGHWAY and INTERLINE computer programs. The population in the 800-meter (0.5-mile) region of influence used to evaluate the impacts of incident-free transportation for both legal-weight truck and rail shipments is listed in Table J-36.

Results for incident-free transportation of spent nuclear fuel and high-level radioactive waste for Inventory Modules 1 and 2 are presented in Section J.3.4.

J.3.3 ANALYSIS OF TRANSPORTATION ACCIDENT SCENARIOS IN NEVADA

Section J.1.4 discusses the methodology for estimating the risks of accidents that could occur during rail and truck transportation of spent nuclear fuel and high-level radioactive waste. Section J.3.5 describes the results of the accident risk analysis for Inventory Modules 1 and 2.

J.3.3.1 Intermodal Transfer Station Accident Methodology

Shipping casks would arrive at an intermodal transfer station in Nevada by rail, and a gantry crane would transfer them from the railcars to heavy-haul trucks for transportation to the repository. The casks, which would not be opened or altered in any way at the intermodal transfer station, would be certified by the Nuclear Regulatory Commission and would be designed for accident conditions specified in 10 CFR Part 71. Impact limiters, which would protect casks against collisions during transportation, would remain in place during transfer operations at the intermodal transfer station.

DOE performed an accident screening process to identify credible accidents that could occur at an intermodal transfer station with the potential for compromising the integrity of the casks and releasing radioactive material. The external events listed in Table J-49 were considered, along with an evaluation of their potential applicability.

As indicated from Table J-49, the only accident-initiating event identified from among the feasible external events was the aircraft crash. Such events would be credible only for casks being handled or on transport vehicles at an intermodal transfer station in the Las Vegas area (Apex/Dry Lake or Sloan/Jean). For a station in the Las Vegas area, an aircraft crash would be from either commercial aircraft operations at McCarran airport or military operations from Nellis Air Force Base.

Among the internal events, the only potential accident identified was a drop of the cask during transfer operations. This accident would bound the other events considered, including drops from the railcar or truck (less fall height would be involved than during the transfer operations). Collisions, derailments, and other accidents involving the transport vehicles at the intermodal transfer would not damage the casks due to the requirement that they be able to withstand high-speed impacts and the low velocities of the transport vehicles at the intermodal transfer station.

Sabotage events were also considered as potential accident-initiating events at an intermodal transfer station. Section J.1.5 evaluates such events.

Table J-49. Screening analysis of external events considered potential accident initiators at intermodal transfer station.

Event	Applicability
Aircraft crash	Retained for further evaluation
Avalanche	(a)
Coastal erosion	(a)
Dam failure	See flooding
Debris avalanching	(a)
Dissolution	(b)
Epeirogenic displacement (tilting of the earth's crust)	(c)
Erosion	(b)
Extreme wind	(c)
Extreme weather	(e)
Fire (range)	(b)
Flooding	(d)
Denudation	(b)
Fungus, bacteria, algae	(b)
Glacial erosion	(b)
High lake level	(b)
High tide	(a)
High river stage	See flooding
Hurricane	(a)
Inadvertent future intrusion	(b)
Industrial activity	Bounded by aircraft crash
Intentional future intrusion	(b)
Lightning	(c)
Loss of off/on site power	(c)
Low lake level	(b)
Meteorite impact	(e)
Military activity	Retained for further evaluation
Orogenic diastrophism	(e)
Pipeline accident	(b)
Rainstorm	See flooding
Sandstorm	(c)
Sedimentation	(b)
Seiche	(a)
Seismic activity, uplifting	(c)
Seismic activity, earthquake	(c)
Seismic activity, surface fault	(c)
Seismic activity, subsurface fault	(c)
Static fracturing	(b)
Stream erosion	(b)
Subsidence	(c)
Tornado	(c)
Tsunami	(a)
Undetected past intrusions	(b)
Undetected geologic features	(b)
Undetected geologic processes	(c)
Volcanic eruption	(e)
Volcanism, magmatic activity	(e)
Volcanism, ash flow	(c)
Volcanism, ash fall	(b)
Waves (aquatic)	(a)

a. Conditions at proposed sites do not allow event.
b. Not a potential accident initiator.
c. Bounded by cask drop accident considered in the internal events analysis.
d. Shipping cask designed for event.
e. Not credible, see evaluation for repository.

Accident Analysis

1. *Cask Drop Accident.* The only internal event retained after the screening process was a failure of the gantry crane (due to mechanical failure or human error) during the transfer of a shipping cask from a railcar to a heavy-haul truck. The maximum height between the shipping cask and the ground during the transfer operation would be less than 6 meters (19 feet) (TRW 1999a, Heavy-Haul Files, Item 11). The casks would be designed to withstand a 9-meter (30-foot) drop. Therefore, the cask would be unlikely to fail during the event, especially because the impact energy from the 6-meter drop would be only 65 percent of the minimum design requirement.

2. *Aircraft Crash Accident.* Two of the three intermodal transfer station locations are near airports that handle large volumes of air traffic. The Apex/Dry Lake location is about 16 kilometers (10 miles) northeast of the Nellis Air Force Base runways. Between 60,000 and 67,000 takeoffs and landings occur at Nellis Air Force Base each year (Luedke 1997, all). The Sloan/Jean intermodal transfer area begins about 16 kilometers southwest of McCarran International Airport in Las Vegas. In 1996, McCarran had an average of 1,300 daily aircraft operations (Best 1998, all). Because of the large number of aircraft operations at these airports, the probability of an aircraft crash on the proposed intermodal transfer station could be within the credible range. To assess the consequences of an aircraft crash, an analysis evaluated the ability of large aircraft projectiles [jet engines and jet engine shafts (DOE 1996b, page 58)] to penetrate the shipping casks. The analysis used a recommended formula (DOE 1996b, page 69) for predicting the penetration of steel targets, as follows:

$$T^{1.5} = 0.5 \times M \times V^2 \div 17{,}400 \times K_s \times D^{1.5}$$

where:

T = predicted thickness to just perforate a steel plate (inches)
M = projectile mass (weight/gravitational acceleration)
V = projectile impact velocity (feet per second)
K_s = constant depending on the grade of steel (usually about 1.0)
D = projectile diameter (inches)

The projectile characteristics listed in Table J-50 are from Davis, Strenge, and Mishima (1998, all). The velocity used is about 130 meters (427 feet) per second, which is representative of aircraft velocities near airports (maximum velocity during takeoff and landing operations). A higher velocity [about 180 meters (590 feet) per second] was assumed for the projectile found to be limiting in terms of ability to penetrate (commercial engine shaft) to provide perspective on the influence of velocity on the penetration thickness. Table J-51 lists the results of the penetration calculation.

Table J-50. Projectile characteristics.[a]

Aircraft	Engine weight (kilograms)[b]	Engine diameter (centimeters)[c]
Small military	420	71
Commercial	3,900	270

a. Source: Davis, Strenge, and Mishima (1998, Table 1).
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert centimeters to inches, multiply by 0.3937.

The results indicate that none of the aircraft projectiles considered would penetrate the shipping casks, which would have metal shield walls about 18 centimeters (7 inches) thick (JAI 1996, all).

This evaluation found no credible accidents with the potential for radioactive release at an intermodal transfer station.

Table J-51. Results of aircraft projectile penetration analysis.[a]

Projectile	Velocity (meters per second)[b]	Penetration thickness (centimeters)[c,d]
Small military engine	130	2.5
Small military shaft	130	2.5
Commercial engine	130	3.0
Commercial shaft	130	3.7
Commercial shaft	180	5.9

a. Source: Davis, Strenge, and Mishima (1998, Table 2).
b. To convert meters to feet, multiply by 3.2808.
c. To convert centimeters to inches, multiply by 0.3937.
d. Penetration through steel plate.

J.3.4 IMPACTS IN NEVADA FROM INCIDENT-FREE TRANSPORTATION FOR INVENTORY MODULES 1 AND 2

This section presents the analysis of impacts to occupational and public health and safety in Nevada from incident-free transportation of spent nuclear fuel and high-level radioactive waste in Inventory Modules 1 and 2. The analysis assumed that the routes, population densities, and shipment characteristics (for example, radiation from shipping casks) for shipments under the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference was the projected number of shipments that would travel to the repository.

The following sections provide detailed information on the range of potential impacts to occupational and public safety and health from incident-free transportation of Modules 1 and 2 that result from legal-weight trucks and the 10 alternative transportation routes considered in Nevada. National impacts of incident-free transportation of Modules 1 and 2 incorporating Nevada impacts are discussed together with other cumulative impacts in Chapter 8.

J.3.4.1 Mostly Legal-Weight Truck Scenario

Tables J-52 and J-53 list estimated incident-free impacts in Nevada for the mostly legal-weight truck scenario for shipments of materials included in Inventory Modules 1 and 2.

J.3.4.2 Nevada Rail Implementing Alternatives

Table J-54 lists the range of estimated incident-free impacts in Nevada for the operation of a branch rail line to ship the materials included in Inventory Modules 1 and 2. It lists impacts that would result from operations for a branch line in each of the five possible rail corridors DOE is evaluating. These include the impacts of about 2,600 legal-weight truck shipments from commercial sites that could not use rail casks to ship spent nuclear fuel.

J.3.4.3 Nevada Heavy-Haul Truck Implementing Alternatives

Radiological Impacts

Intermodal Transfer Station Impacts. Involved worker exposures (the analysis assumed that the noninvolved workers would receive no radiation exposure and thus required no further analysis) would occur during both inbound (to the repository) and outbound (to the 77 sites) portions of the shipment campaign. DOE used the same involved worker level of effort it used in the analysis of intermodal transfer station worker industrial safety impacts to estimate collective involved worker radiological impacts (that is, 16 full-time equivalents per year). The collective worker radiation doses were adapted from a study (Smith, Daling and Faletti 1992, all) of a spent nuclear fuel transportation system, which

Table J-52. Population doses and radiological impacts from incident-free Nevada transportation for mostly legal-weight truck scenario – Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel[b]	Total[c]
Module 1			
Involved worker			
Collective dose (person-rem)	2,900	30	2,900
Estimated latent cancer fatalities	1.2	0.01	1.2
Public			
Collective dose (person-rem)	5,100	26	5,100
Estimated latent cancer fatalities	2.5	0.01	2.5
Module 2			
Involved worker			
Collective dose (person-rem)	3,000	40	3,000
Estimated latent cancer fatalities	1.2	0.02	1.2
Public			
Collective dose (person-rem)	5,300	30	5,300
Estimated latent cancer fatalities	2.6	0.02	2.6

a. Impacts are totals for shipments over 38 years.
b. Includes impacts at intermodal transfer stations.
c. Totals might differ from sums due to rounding.

Table J-53. Population health impacts from vehicle emissions during incident-free Nevada transportation for the mostly legal-weight truck scenario – Modules 1 and 2.[a]

Vehicle emission-related fatalities	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel[b]	Total[c]
Module 1	0.01	0.0004	0.01
Module 2	0.01	0.0005	0.01

a. Impacts are totals for shipments over 38 years.
b. Includes heavy-haul truck shipments in Nevada.
c. Totals might differ from sums due to rounding.

Table J-54. Radiological and nonradiological impacts from incident-free Nevada transportation for the mostly rail scenario – Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail shipments	Total[b]
Module 1			
Involved worker			
Collective dose (person-rem)	370	280 - 460	650 - 830
Estimated latent cancer fatalities	0.15	0.11 - 0.18	0.26 - 0.33
Public			
Collective dose (person-rem)	430	190 - 270	620 -700
Estimated latent cancer fatalities	0.22	0.09 - 0.14	0.31 - 0.36
Estimated vehicle emission-related fatalities	0.00019	0.004	0.0042

a. Impacts are totals for 38 years (2010 to 2048).
b. Totals might differ from sums due to rounding.

was also performed for the commercial sites. That study found that the collective worker doses that could be incurred during similar inbound and outbound transfer operations of a single loaded (with commercial spent nuclear fuel) and unloaded cask were approximately 0.027 and 0.001 person-rem per cask, respectively, as listed in Table J-55.

The analysis used these inbound and outbound collective dose factors to calculate the involved worker impacts listed in Table J-56 for Module 1 and Module 2 inventories in the same manner it used for

Table J-55. Collective worker doses (person-rem) from transportation of a single cask.[a,b]

Inbound	Inbound CD[b]	Outbound	Outbound CD
Receive transport vehicle and loaded cask. Monitor, inspect, unhook offsite drive unit, and attach onsite drive unit.	6.3×10^{-3}	Receive transport vehicle and empty cask. Monitor, inspect, unhook offsite drive unit, and attach onsite drive unit.	0.0
Move cask to parking area and wait for wash down station. Attach to carrier puller when ready.	1.4×10^{-3}	Move cask to parking area and wait for wash down station. Attach to carrier puller when ready.	5.4×10^{-4}
Move cask to receiving and handling area.	9.2×10^{-5}	Move cask to receiving and handling area.	8.0×10^{-5}
Remove cask from carrier and place on cask cart.	4.3×10^{-3}	Remove cask from carrier and place on cask cart.	2.2×10^{-4}
Connect onsite drive unit and move cask to inspection area; disconnect onsite drive unit.	7.0×10^{-4}	Connect onsite drive unit and move cask to inspection area; disconnect onsite drive unit.	3.3×10^{-5}
Hook up offsite drive unit, move to gatehouse, perform final monitoring and inspection of cask.	1.4×10^{-2}	Hook up offsite drive unit, move to gatehouse, perform final monitoring and inspection of cask.	8.3×10^{-5}
Notify appropriate organizations of the shipment’s departure.	0.0	Notify appropriate organizations of the shipment’s departure.	0.0
Total	**2.7×10^{-5}**	**Total**	**8.8×10^{-5}**

a. Adapted from Smith, Daling and Faletti (1992, Table 4.2).

b. Values are rounded to two significant figures; therefore, totals might differ from sums of values.

c. CD = collective dose (person-millirem per cask).

Table J-56. Doses and radiological health impacts to involved workers from intermodal transfer station operations – Modules 1 and 2.[a,b]

Group	Module 1		Module 2	
	Dose	Latent cancer fatality	Dose	Latent cancer fatality
Maximally exposed individual worker[c]	12	0.005	12	0.005
Involved worker population[d]	530	0.21	550	0.22

a. Includes estimated impacts from handling 300 shipments of U.S. Navy fuel that would be shipped by rail under the mostly legal-weight truck transportation scenario. DOE estimated the impacts from these shipments by adjusting the impacts from the approximately 19,300 shipments (9,650 × 2) that would pass through the intermodal transfer station under the mostly rail scenario.

b. Totals for 24 years of operations.

c. The estimated probability of a latent cancer fatality in an exposed individual.

d. The estimated number of latent cancer fatalities in an exposed involved worker population.

commercial power reactor spent nuclear fuel impacts. The number of inbound and outbound shipments for Module 1 and Module 2 inventories is from Section J.1.2. The worker impacts reflect two-way operations.

Incident-Free Transportation. Table J-57 lists the range of estimated incident-free impacts in Nevada for the use of heavy-haul trucks to ship the materials included in Inventory Modules 1 and 2. It lists impacts that would result from operations on each of the five possible highway routes in Nevada DOE is evaluating. These include impacts of about 2,600 legal-weight truck shipments from commercial sites that could not ship spent nuclear fuel using rail casks.

Table J-57. Radiological and nonradiological health impacts from incident-free transportation for the heavy-haul truck implementing alternatives – Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail and heavy-haul truck shipments[b]	Total[c]
Involved worker			
Collective dose (person-rem)	370	830 - 1,000	1,200 - 1,400
Estimated latent cancer fatalities	0.15	0.33 - 0.40	0.48 - 0.55
Public			
Collective dose (person-rem)	430	1,200 - 3,200	1,600 - 3,700
Estimated latent cancer fatalities	0.22	0.60 - 1.6	0.82 -1.8
Estimated vehicle emission-related fatalities	0.00019	0.03	0.05

a. Impacts are totals for 38 years (2010 to 2048).

b. Includes impacts to workers at an intermodal transfer station.

c. Totals might differ from sums due to rounding.

J.3.5 IMPACTS IN NEVADA FROM TRANSPORTATION ACCIDENTS FOR INVENTORY MODULES 1 AND 2

The analysis assumed that the routes, population densities, and shipment characteristics (for example, assumed radioactive material contents of shipping casks) for the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference would be the projected number of shipments that would travel to the repository. As listed in Table J-1, Module 2 would include about 3 percent more shipments than Module 1.

J.3.5.1 Mostly Legal-Weight Truck Scenario

Radiological Impacts

The analysis estimated the radiological impacts of accidents in Nevada for the mostly legal-weight truck scenario for shipments of the materials included in Inventory Modules 1 and 2. The radiological health impacts associated with Module 1 would be 0.86 person-rem and for Module 2 would be 0.88 person-rem (see Table J-58). These impacts would occur over 34 years in a population of more than 1 million people who lived within 80 kilometers (50 miles) of the Nevada routes that DOE would use. This dose risk would lead to about 1 chance in 1,000 of an additional cancer fatality in the exposed population. For comparison, about 220,000 in a population of 1 million people would suffer fatal cancers from other causes (ACS 1998, page 10).

Traffic Fatalities

The analysis estimated traffic fatalities from accidents involving the transport of spent nuclear fuel and high-level radioactive waste by legal-weight trucks in Nevada for the mostly legal-weight truck scenario for shipments of the materials included in Inventory Modules 1 and 2. It estimated that there would be 0.9 fatality over 34 years for Module 1 and 0.93 fatality for Module 2 (see Table J-58). The estimate of traffic fatalities includes the risk of fatalities from 300 shipments of naval spent nuclear fuel.

J.3.5.2 Nevada Rail Implementing Alternatives

Industrial Safety Impacts

Table J-59 lists the estimated industrial safety impacts in Nevada for the operation of a branch rail line to ship the materials included in Inventory Modules 1 and 2. The table lists impacts that would result from operations for a branch line in each of the five possible rail corridors in Nevada that DOE is evaluating.

The representative workplace loss incidence rate for each impact parameter (as compiled by the Bureau of Labor Statistics) was used as a multiplier to convert the operations crew level of effort to expected

Table J-58. Accident radiological health impacts for Modules 1 and 2 – Nevada transportation.[a]

Transportation scenario	Dose risk (person-rem)	Latent cancer fatalities	Traffic fatalities
Legal-weight truck	0.88[b]	0.0004	0.9
Legal-weight truck for the mostly rail scenario	0.1	0.00006	0.1
Mostly rail (Nevada rail implementing alternatives)			
Caliente	0.02	8.7×10^{-6}	0.13
Carlin	0.03	1.6×10^{-5}	0.17
Sloan/Jean	0.11	5.3×10^{-5}	0.10
Apex/Dry Lake	0.01	7.0×10^{-6}	0.08
Caliente-Chalk Mountain	0.01	6.9×10^{-6}	0.09
Mostly rail (Nevada heavy-haul implementing alternatives)			
Caliente	0.34	1.7×10^{-4}	1.2
Caliente-Chalk Mountain	0.28	1.4×10^{-4}	0.65
Caliente-Las Vegas	1.02	5.1×10^{-4}	0.90
Apex/Dry Lake	0.94	4.7×10^{-4}	0.46
Jean	6.5	3.2×10^{-3}	0.49

a. Impacts over 38 years.

b. Estimates of dose risk are for the transportation of the materials included in Module 2. Estimates of dose risk for transportation of the materials in Module 1 would be slightly (about 3 percent) lower.

Table J-59. Rail corridor operation worker physical trauma impacts (Modules 1 and 2).

Worker group and impact category	Corridor				
	Caliente	Carlin	Chalk Mountain	Jean	Valley Modified
Involved workers					
TRC[a]	200	200	200	150	150
LWC[b]	110	110	110	82	82
Fatalities	0.4	0.4	0.4	0.3	0.3
Noninvolved workers[c]					
TRC	9	9	9	7	7
LWC	5	5	5	3	3
Fatalities	0.01	0.01	0.01	0.01	0.01
All workers (totals)[d]					
TRC	210	210	210	160	160
LWC	120	120	120	85	85
Fatalities	0.4	0.4	0.4	0.3	0.3
Traffic fatalities[e]	1.1	1.1	1.1	0.8	0.8

a. TRC = total recordable cases (injury and illness).

b. LWC = lost workday cases.

c. Noninvolved worker impacts are based on 25 percent of the involved worker level of effort.

d. Totals might differ from sums due to rounding.

e. Fatalities from accidents during commutes to and from jobs for involved and noninvolved workers.

industrial safety losses. The involved worker full-time equivalent multiples that DOE would assign to operate each rail corridor each year was estimated to be 36 to 47 full-time equivalents, depending on the corridor for the period of operations (scaled from cost data in TRW 1996, Appendix E). Noninvolved worker full-time equivalent multiples were unavailable, so DOE assumed that the noninvolved worker level of effort would be similar to that for the repository operations work force—about 25 percent of that for involved workers. The Bureau of Labor Statistics loss incidence rate for each total recordable case, lost workday, and fatality trauma category (for example, the number of total recordable cases per full-time equivalent) was multiplied by the involved and noninvolved worker full-time equivalent multiples to project the associated trauma incidence.

The involved worker total recordable case incidence rate, 170,000 total recordable cases in a workforce of 1,620,000 workers (0.11 total recordable case per full-time equivalent) reflects losses in the Trucking and Warehousing sector during 1996. The same Bureau of Labor Statistics period of record and industry sector was used to select the involved worker lost workday case incidence rate [96,000 lost workday cases in a workforce of 1,620,000 workers (0.06 lost workday case per full-time equivalent)]. The involved worker fatality incidence rate, 22 fatalities in a workforce of 100,000 workers (0.0002 fatality per full-time equivalent) reflects losses in the Transportation and Material Moving Occupations sector during the Bureau of Labor Statistics 1994-to-1995 period of record.

The noninvolved worker incidence rate of 53,000 total recordable cases in a workforce of 2,870,000 workers (0.02 total recordable case per full-time equivalent) reflects losses in the Engineering and Management Services sector during the Bureau of Labor Statistics 1996 period of record. DOE used the same period of record and industry sector to select the noninvolved worker lost workday case incidence rate [22,000 lost workday cases in a workforce of 2,870,000 workers (0.01 lost workday case per full-time equivalent)]. The noninvolved worker fatality incidence rate, 1.5 fatalities in a workforce of 100,000 workers (0.00002 fatality per full-time equivalent) reflects losses in the Managerial and Professional Specialties sector during the 1994-to-1995 period of record.

Table J-59 lists the results of these industrial safety calculations for the five candidate corridors under Inventory Modules 1 and 2. The table also lists estimates of the number of traffic fatalities that would occur in the course of commuting by workers to and from their construction and operations jobs. These estimates used national statistics for average commute distances [18.5 kilometers (11.5 miles) one-way (ORNL 1999, all)] and fatality rates for automobile traffic [1 per 100 million kilometers (1.5 per 100 million miles) (BTS 1998, all)].

Radiological Impacts of Accidents

The analysis estimated the radiological impacts of accident scenarios in Nevada for the Nevada rail implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2. Table J-58 lists the radiological dose-risk and associated risk of latent cancer fatalities. The risks include accident risks in Nevada from approximately 2,600 legal-weight truck shipments from commercial sites that could not ship spent nuclear fuel in rail casks. The risks would occur over 34 years.

Traffic Fatalities

Traffic fatalities from accidents involving transport of spent nuclear fuel and high-level radioactive waste by rail in Nevada were estimated for the Nevada rail implementing alternatives for shipments of materials included in Inventory Modules 1 and 2. Table J-58 lists the estimated number of fatalities that would occur over 34 years for a branch rail line along each of the five possible rail corridors. These estimates include the risk of fatalities from about 2,600 legal-weight truck shipments from commercial generators that could not ship spent nuclear fuel in rail casks.

J.3.5.3 Nevada Heavy-Haul Truck Implementing Alternatives

Industrial Safety Impacts

Tables J-60 and J-61 list the estimated industrial safety impacts in Nevada for operations of heavy-haul trucks (principally highway maintenance safety impacts) and operation of an intermodal transfer station that would transfer loaded and unloaded rail casks between rail cars and heavy-haul trucks for shipments of the materials included in Inventory Modules 1 and 2. Table J-60 lists the estimated industrial safety impacts in Nevada for the operation of a heavy-haul route to the Yucca Mountain site. Table J-61 lists impacts that would result from the operation of an intermodal transfer station for any of the five possible routes DOE is evaluating that heavy-haul trucks could use in Nevada.

Table J-60. Industrial health impacts from heavy-haul truck route operations (Modules 1 and 2).

Worker group and impact category	Corridor				
	Caliente	Caliente-Chalk Mountain	Caliente-Las Vegas	Sloan/ Jean	Apex/Dry Lake
Involved workers					
TRC[a]	460	460	420	250	250
LWC[b]	250	250	230	140	140
Fatalities	0.8	0.8	0.8	0.5	0.5
Noninvolved workers[c]					
TRC	21	21	19	11	11
LWC	11	11	10	6	6
Fatalities	0.02	0.02	0.02	0.01	0.01
All workers (totals)[d]					
TRC	480	480	440	260	260
LWC	260	260	240	150	150
Fatalities	0.82	0.82	0.82	0.5	0.5
Traffic fatalities[e]	2.0	2.0	1.9	1.3	1.3

a. TRC = total recordable cases (injury and illness).
b. LWC = lost workday cases.
c. Noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
d. Totals might differ from sums due to rounding.
e. Fatalities from accidents during commutes to and from jobs for involved and noninvolved workers.

Table J-61. Annual physical trauma impacts to workers from intermodal transfer station operations (Module 1 or 2).

Involved workers			Noninvolved workers[a]			All workers		
TRC[b]	LWC[c]	Fatalities	TRC	LWC	Fatalities	TRC	LWC	Fatalities
112	60	0.2	5	2	0.0	116	62	0.2

a. The noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
b. TRC = total recordable cases of injury and illness.
c. LWC = lost workday cases.

Radiological Impacts of Accidents

The analysis estimated the radiological impacts of accidents in Nevada for the Nevada heavy-haul truck implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2.

Table J-58 lists the radiological dose-risk and associated risk of latent cancer fatalities. The risks include accident risks in Nevada from approximately 2,600 legal-weight truck shipments from commercial generating sites that could not ship spent nuclear fuel in rail casks. The risk would occur over 34 years.

Traffic Fatalities

The analysis estimated traffic fatalities from accidents involving the transport of spent nuclear fuel and high-level radioactive waste (including the rail portion of transportation to and from an intermodal transfer station) in Nevada for the heavy-haul truck implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2. Table J-58 lists the estimated number of fatalities that would occur over 34 years for a branch rail line and for each of the five possible routes for heavy-haul trucks. The estimate for traffic fatalities includes the risk of fatalities from about 2,600 legal-weight truck shipments from commercial generators that could not ship spent nuclear fuel in rail casks.

J.3.6 IMPACTS FROM TRANSPORTATION OF OTHER MATERIALS

Other types of transportation activities associated with the Proposed Action would involve shipments of materials other than the spent nuclear fuel and high-level radioactive waste discussed in previous sections. These activities would include the transportation of people. This section evaluates occupational and public health and safety and air quality impacts from the shipment of:

- Construction materials, consumables, and personnel for repository construction and operation, including disposal containers
- Waste including low-level waste, construction and demolition debris, sanitary and industrial solid waste, and hazardous waste
- Office and laboratory supplies, mail, and laboratory samples

The analysis includes potential impacts of transporting these materials for the case in which DOE would not build a rail line to the proposed repository, because the larger number of truck shipments would lead to higher impacts than those for rail shipments, as discussed above. In addition, because the construction schedule for a new rail line would coincide with the schedule for the construction of repository facilities, trucks would deliver materials for repository construction.

Rail service would benefit the delivery of 10,000 disposal containers from manufacturers. Two 33,000-kilogram (about 75,000-pound) disposal containers and their 700-kilogram (about 1,500-pound) lids (TRW 1999b, Request #027) would be delivered on a railcar—a total of 5,000 railcar deliveries over the 24-year period of the Proposed Action. These containers would be delivered to the repository along with shipments of spent nuclear fuel and high-level radioactive waste or separately on supply trains along with shipments of materials and equipment.

If rail service was not available, disposal container components that would weigh as much as 34 metric tons (37.5 tons) would be transported to Nevada by rail and transferred to overweight trucks for shipment to the repository site. In this event, 10,000 overweight truck shipments would move the containers from a railhead to the site. The State of Nevada routinely provides permits to motor carriers for overweight, overdimension loads if the gross vehicle weight does not exceed 58.5 metric tons (64.5 tons) (TRW 1999b, Request #046).

J.3.6.1 Transportation of Personnel and Materials to Repository

The following paragraphs describe impacts that would result from the transportation of construction materials, consumables, disposal containers, supplies, mail, laboratory samples, and personnel to the repository site during the construction, operation and monitoring, and closure phases.

Human Health and Safety

Most construction materials, construction equipment, and consumables would be transported to the Yucca Mountain site on legal-weight trucks. Heavy and overdimensional construction equipment would be delivered by trucks under permits issued by the Nevada Department of Transportation. DOE estimates that about 42,000 truck shipments over 5 years would be necessary to transport materials, supplies, and equipment to the site during the construction phase.

In addition to construction materials, supplies, equipment, and disposal containers, trucks would deliver consumables to the repository site. These would include diesel fuel, cement, and other materials that would be consumed in daily operations. About 13,000 semitrailer truck shipments would occur during each year of operation. Similarly, there would be an estimated 1,000 semitrailer truck shipments during each year of monitoring and 1,200 each year during closure operations.

Over the 24-year period of the Proposed Action, the repository would receive about 300,000 truck shipments of supplies, materials, equipment, disposal containers, and consumables, including cement and other materials used in underground excavation. Most of these shipments would originate in the Las Vegas metropolitan area. In addition, an estimated 54,000 shipments of office and laboratory supplies and equipment, mail, and laboratory samples would occur during the 24 years of operation. A total of about 21 million vehicle kilometers (13 million vehicle miles) of travel would be involved. Impacts would include vehicle emissions, consumption of petroleum resources, increased truck traffic on regional highways, and fatalities from accidents. Similarly, there would be about 76,000 shipments during the 76-year monitoring period after emplacement operations and 15,000 shipments during closure activities. The number of shipments during shorter or longer monitoring periods would be proportionately fewer or larger. Table J-62 summarizes these impacts.

Table J-62. Human health and safety impacts from shipments of material to the repository.[a]

Phase	Kilometers[b] traveled (millions)	Traffic fatalities	Fuel consumption (thousands of liters)[c]	Vehicle emissions-related fatalities
Construction	8.2 - 9.9	0.14 - 0.17	1,900 - 2,300	0.0006 - 0.0007
Operation and monitoring				
Emplacement and development	29 - 66	0.5 - 1.1	7,000 - 15,000	0.002 - 0.005
Monitoring				
26 years	6.5	0.1	1,500	0.0005
76 years	19	0.3	4,500	0.0014
276 years	69	1.2	16,000	0.005
Closure	4.1	0.1	1,000	0.0003

a. Impacts are totals for 24 years of operations.
b. To convert kilometers to miles, multiply by 0.62137.
c. To convert liters to gallons, multiply by 0.26418.

During the construction phase, many employees would use their personal automobiles to travel to construction areas on the repository site and to highway or rail line construction sites. The estimated peak level of direct employment during 5 years of repository construction would be 1,035 workers. Current Nevada Test Site employees can ride DOE-provided buses to and from work; similarly, buses probably would be available for repository construction workers, which would reduce the number of vehicles traveling to the site each day by approximately a factor of 8. Table J-63 summarizes the anticipated number of traffic-accident-related injuries and fatalities and the estimated consumption of gasoline that would occur from this travel activity. The greatest impact of this traffic would be added congestion at the northwestern Las Vegas Beltway interchange with U.S. Highway 95. Current estimates call for traffic at this interchange during rush hours to be as high as 1,000 vehicles an hour (Clark County 1997, Table 3-12, page 3-43). The additional traffic from repository construction, an estimated 500 vehicles per hour, would add about 50 percent to traffic volume at peak rush hour and would contribute to congestion although congestion in this area would be generally low.

The average level of employment during repository operations would be about 2,700 workers. As mentioned above, DOE provides bus service from the Las Vegas area to and from the Nevada Test Site. Table J-63 summarizes the anticipated number of traffic-accident-related fatalities and the estimated consumption of gasoline that would occur from this travel activity. The greatest impact of this traffic would be increased congestion at the northwestern Las Vegas Beltway interchange with U.S. 95. As many as 500 vehicles an hour at peak rush hour would contribute to the congestion. Approximately

Table J-63. Health impacts from transportation of construction and operations workers.[a]

Phase	Kilometers[b] traveled (in millions)	Traffic fatalities	Fuel consumption (thousands of liters)[c]	Vehicle emissions-related fatalities
Construction	36.3 - 44.4	0.5 - 0.6	400 - 500	0.0026 - 0.0032
Operation and monitoring				
Emplacement and development	240 -300	3.2 - 4.0	2,600 - 3,300	0.017 - 0.022
Monitoring (76 years)	62.2	0.8	680	0.0045
Closure	20.2 - 42.7	0.3 - 0.6	220 - 470	0.0015 - 0.0031

a. Impacts are totals for 24 years for operations.
b. To convert kilometers to miles, multiply by 0.62137.
c. To convert liters to gallons, multiply by 0.26418.

150 people would be employed during monitoring and about 500 would be employed during closure. The number of vehicles associated with these levels of employment would contribute negligibly to congestion.

Table J-64 lists the impacts associated with the delivery of fabricated disposal container components from a manufacturing site to the repository. A total of 10,000 containers would be delivered; if a rail line to Yucca Mountain was not available, the mode of transportation would be a combination of rail and overweight truck. The analysis assumes that the capacity of each railcar would be two containers and that the capacity of a truck would be one container, so there would be 5,000 railcar shipments to Nevada and 10,000 truck shipments to the Yucca Mountain site. The analysis estimated impacts for one national rail route representing a potential route from a manufacturing facility to a Nevada rail siding. The analysis estimated the impacts of transporting the containers from this siding over a single truck route—the Apex/Dry Lake route analyzed for the transportation of spent nuclear fuel and high-level radioactive waste by heavy-haul trucks. Although the actual mileage from a manufacturing facility could be shorter, DOE decided to select a distance that represents a conservative estimate [4,439 kilometers (2,758 miles)]. The impacts are split into two subcategories—health effects from vehicle emissions and fatalities from transportation accidents.

Table J-64. Impacts of disposal container shipments for Proposed Action.[a]

Type of shipment	Number of shipments	Vehicle emissions-related health effects	Traffic fatalities
Rail and truck	5,000 rail/10,000 truck	0.14	0.8

a. Impacts are totals for 24 years of operations.

Air Quality

The exhaust from vehicles involved in the transport of personnel and materials to the repository would emit carbon monoxide, nitrogen dioxide, and particulate matter (PM_{10}). Because carbon monoxide is the principal pollutant of interest for evaluating impacts caused by motor vehicle emissions, the analysis focused on it.

The analysis assumed that most of the personnel who would commute to the repository would reside in the Las Vegas area and that most of the materials would travel to the repository from the Las Vegas area. To estimate maximum potential emissions to the Las Vegas Valley airshed, which is in nonattainment for carbon monoxide (FHWA 1996, pages 3-53 and 3-54), the analysis assumed that all personnel and material would travel from the center of Las Vegas to the repository. Table J-65 lists the estimated annual amount of carbon monoxide that would be emitted to the valley airshed during the phases of the repository project and the percent of the corresponding threshold level.

As listed in Table J-65, the annual amount of carbon monoxide emitted to the nonattainment area would be below the threshold level during all phases of the repository. In the operation phase, the estimated annual amount of carbon monoxide emitted would be close (93 percent) to the threshold level. So, a more

Table J-65. Annual amount of carbon monoxide emitted to Las Vegas Valley airshed from transport of personnel and material to repository (kilograms per year)[a] for the Proposed Action.

Phase	Annual emission rate	GCR threshold level[b]
Construction	47,000	51
Operation and monitoring		
Operation period	85,000	93
Monitoring period	6,700	7.4
Closure	17,000	19

a. To convert kilograms to tons, multiply by 0.0011023.

b. GCR = General Conformity Rule emission threshold level for carbon monoxide is 91,000 kilograms (100 tons) per year.

detailed analysis and conformity analysis might be required to determine if mitigation would be needed to ensure that the additional emissions did not impede efforts in Nevada to bring the Las Vegas area into attainment for carbon monoxide.

For areas that are in attainment, pollutant concentrations in the ambient air probably would increase due to the additional traffic but, given the relatively small amount of traffic that passes through these areas, the additional traffic would be unlikely to cause the ambient air quality standards to be exceeded.

Noise

Traffic-related noise on major transportation routes used by the workforce would likely increase. The analysis of impacts from traffic noise assumed that the workforce would come from Nye County (20 percent) and Clark County (80 percent). During the period of maximum employment in 2015, an estimated daily maximum of 576 vehicles would pass through the Gate 100 entrance at Mercury during rush hour (DOE 1996c, page 4-45), compared to a baseline of 232 vehicles per hour. This would result in an increase in rush hour noise from 65.5 dBA to 69.5 dBA for the communities of Mercury and Indian Springs. The 4.4-dBA increase could be perceptible to the communities but, because of the short duration, would be unlikely to result in an adverse response.

J.3.6.2 Impacts of Transporting Wastes from the Repository

During repository construction and operations, DOE would ship waste and sample material from the repository. The waste would include hazardous, mixed, and low-level radioactive waste. Samples would include radioactive and nonradioactive hazardous materials shipped to laboratories for analysis. In addition, nonhazardous solid waste could be shipped from the repository site to the Nevada Test Site for disposal. However, as noted in Chapter 2, DOE proposes to include an industrial landfill on the repository site. Table J-66 summarizes the maximum quantities of waste (generally from the uncanistered packaging scenario and the low thermal load scenario) that DOE would ship from the repository and the number of truck shipments.

Occupational and Public Health and Safety

The quantities of hazardous waste that DOE would ship to approved facilities off the Nevada Test Site would be relatively small and would present little risk to public health and safety. This waste could be shipped by rail (if DOE built a rail line to the repository site) or by legal-weight truck to permitted disposal facilities. The principal risks associated with shipments of these materials would be related to traffic accidents. These risks would include 0.01 fatality for the combined construction, operation and monitoring, and closure phases for hazardous wastes.

DOE probably would ship low-level radioactive waste by truck to existing disposal facilities on the Nevada Test Site. Although these shipments would not use public highways, DOE estimated their risks. As with shipments of hazardous waste, the principal risk in transporting low-level radioactive waste would be related to traffic accidents. Because traffic on the Nevada Test Site is regulated by the Nye County Sheriffs Department, DOE assumed that accident rates on the site are similar to those of secondary highways in Nevada. Low-level radioactive waste would not be present during the construction of the repository. Therefore, accidents involving such waste could occur only during the

Table J-66. Shipments of waste from the Yucca Mountain Repository.[a]

Waste	Construction		Operation and monitoring		Closure	
	Volume (cubic meters)[b]	Number of shipments	Volume (cubic meters)	Number of shipments	Volume (cubic meters)	Number of shipments
Hazardous[c]	990	60	6,100	340	630	8
Low-level radioactive[d]	0	0	68,000	1,800	3,500	2
Dual-purpose canisters[e]	0	0	30,000	6,600	0	0
Mixed[c]	0	0	23	2	0	0
Nonhazardous solid[f,g]	13,000	120	90,000	810	160,000	1,400

a. Source: Chapter 4, Section 4.1.12.
b. To convert cubic meters to cubic yards, multiply by 1.3079.
c. Shipment numbers based on 16.64 cubic meters per shipment.
d. Shipment numbers based on 38 cubic meters per shipment.
e. Shipment numbers based on 23 metric tons per shipment.
f. Shipment numbers based on cubic meters per shipment.
g. Includes construction and demolition debris and sanitary and industrial solid waste.

operation and monitoring and the closure phases, although most of this waste would be generated during the operation and monitoring phase. DOE estimates 0.05 traffic fatality from the transportation of low-level radioactive waste during the repository operation and monitoring and closure phases.

Air Quality

The quantities of hazardous waste that DOE would ship to approved facilities off the Nevada Test Site would be relatively small. Vehicle emissions due to these shipments would present little risk to public health and safety.

Biological Resources and Soils

The transportation of people, materials, and wastes during the construction, operation and monitoring, and closure phases of the repository would involve more than 1.6 billion vehicle-kilometers (1 billion vehicle-miles) of travel on highways in southern Nevada. This travel would use existing highways that pass through desert tortoise habitat. Individual desert tortoises probably would be killed. However, because populations of the species are low in the vicinity of the routes (Bury and Germano 1994, pages 57 to 72), few would be lost. Thus, the loss of individual desert tortoises due to repository traffic would not be likely to be a threat to the conservation of this species. In accordance with requirements of Section 7 of the Endangered Species Act, DOE would consult with the Fish and Wildlife Service and would comply with mitigation measures resulting from that consultation to limit losses of desert tortoises from repository traffic.

J.3.6.3 Impacts from Transporting Other Materials and People in Nevada for Inventory Modules 1 and 2

The analysis evaluated impacts to occupational and public health and safety in Nevada from the transport of materials, wastes, and workers (including repository-related commuter travel) for construction, operation and monitoring, and closure of the repository that would occur for the receipt and emplacement of materials in Inventory Modules 1 and 2. The analysis assumed that the routes and transportation characteristics (for example, accident rates) for transportation associated with the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference would be the projected number of trips for materials, wastes, and workers traveling to the repository.

Table J-67 lists estimated incident-free (vehicle emissions) impacts and traffic (accident) fatality impacts in Nevada for the transportation of materials, wastes, and workers (including repository-related commuter travel) for the construction, operation and monitoring, and closure of the repository that would occur for the receipt and emplacement of the materials in Inventory Modules 1 and 2.

Table J-67. Impacts from transportation of materials, consumables, personnel, and waste for Modules 1 and 2.[a]

Category	Kilometers traveled[b]	Fatalities	Emission-related health effects
Materials	90 - 160	1.7 - 2.9	0.07 - 0.01
Personnel	490 - 650	4.9 - 6.5	0.04 - 0.05
Waste material (Module 1/Module 2)			
Hazardous	0.17/0.20	0.018/0.021	0.00001/0.00001
Low-level radioactive	0.75/0.86	0.10/0.12	0.001
Nonhazardous solid	0.66	0.066	0.00005
Dual-purpose canisters	35	1.5	0.24

a. Numbers are rounded.

b. To convert kilometers to miles, multiply by 0.62137.

Even with the increased transportation of the other materials included in Module 1 or 2, DOE expects that the transportation of materials, consumables, personnel, and waste to and from the repository would be minor contributors to all transportation on a local, state, and national level. Public and worker health impacts would be small from transportation accidents involving nonradioactive hazardous materials. On average, in the United States there is about 1 fatality caused by the hazardous material being transported for each 30 million shipments by all modes (DOT 1998a, page 1; DOT undated, Exhibit 2b).

J.3.6.4 Environmental Justice

The impacts of transporting people and materials other than spent nuclear fuel and high-level radioactive waste would be small and random. Because the number of shipments and commuter trips would be small in comparison to other commercial and commuter travel in southern Nevada and would use existing transportation facilities in the area, impacts to land use; air quality; hydrology; biological resources and soils; occupational and public health and safety; cultural resources; socioeconomics; noise; aesthetics; utilities, energy, and materials; and waste management would be small. In addition, due to the nearly random nature of accidents that would involve the transportation of materials and people, the probability of such an accident would be small in any location, minimizing the risk at a specific location. Furthermore, because potential accidents would be nearly random, impacts to minority or low-income populations and to Native Americans along the routes in Nevada would be unlikely to be disproportionately high and adverse.

Because there would be no adverse or disproportionate impacts from transportation of people and materials, a detailed environmental justice study is not required.

J.3.6.5 Summary of Impacts of Transporting Other Materials

Table J-68 summarizes the impacts of transporting other materials to the repository site for the Proposed Action.

Table J-68. Health impacts from transportation of materials, consumables, personnel, and waste for the Proposed Action.[a]

Category	Distance traveled (kilometers)[b]	Impact
Human health and safety		
Construction		
Materials	8,200,000 - 9,900,000	0.14 - 0.17 fatality
Personnel	36,300,000 - 44,400,000	0.5 - 0.6 fatality
Waste		
Hazardous	14,500	0.002 fatality
Low-level waste	--[c]	--
Nonhazardous	29,000	0.003 fatality
Canisters	--	--
Operation and monitoring		
Materials	57,000,000 - 94,000,000	1.0 - 1.6 fatalities
Personnel	300,000,000 - 360,000,000	4.0 - 4.8 fatalities[d]
Waste		
Hazardous	90,000	0.002 fatality
Low-level waste	435,000	0.008 fatality
Nonhazardous	196,000	0.003 fatality
Canisters	1,590,000	0.028 fatality
Closure		
Materials	4,400,000	0.1 fatality
Personnel	20,200,000 - 42,700,000	0.3 - 0.6 fatality
Waste		
Hazardous	9,200	0.001 fatality
Low-level waste	22,200	0.002 fatality
Nonhazardous	338,000	0.04 fatality
Canisters	0	--
Air quality		
Construction traffic	74,000,000	75 percent of Air Quality General Conformity Rule threshold for PM_{10}
Operation and monitoring traffic		
Operations	860,000,000	170 percent of carbon monoxide threshold
Monitoring	170,000,000	9 percent of carbon monoxide threshold
Closure traffic	1,000,000,000	30 percent of carbon monoxide threshold
Biological resources	1,000,000,000	Individual desert tortoises would be killed but kills would not be likely to be a threat to conservation of species
Noise	--	Small impacts unlikely to affect communities
Environmental justice	--	Traffic impacts unlikely to be high and disproportionate for minority or low income populations or populations of Native Americans

a. Numbers are rounded.
b. To convert kilometers to miles, multiply by 0.62137.
c. -- = none.
d. Monitoring for 76 years.

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Appendix K

Long-Term Radiological Impact Analysis for the No-Action Alternative

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APPENDIX K. LONG-TERM RADIOLOGICAL IMPACT ANALYSIS FOR THE NO-ACTION ALTERNATIVE

K.1 Introduction

This appendix provides detailed information related to the radiological impact analysis for No-Action Alternative Scenario 2, including descriptions of the conceptual models used for facility degradation, spent nuclear fuel and high-level radioactive waste material degradation, and data input parameters. In addition, this appendix discusses the computer programs and exposure calculations used. The methods described include summaries of models and programs used for radioactive material release, environmental transport, radiation dose, and radiological human health impact assessment. Although the appendix describes No-Action Scenario 1, it focuses primarily on the long-term (100 to 10,000 years) radiological impacts associated with Scenario 2.

NO-ACTION ALTERNATIVE SCENARIOS 1 AND 2

Under the Nuclear Waste Policy Act, the Federal Government has the responsibility to provide permanent disposal of spent nuclear fuel and high-level radioactive waste to protect the public's health and safety and the environment. DOE intends to comply with the terms of existing consent orders and compliance agreements on the management of spent nuclear fuel and high-level radioactive waste. However, the course that Congress, DOE, and the commercial nuclear utilities would take if there was no recommendation to use Yucca Mountain as a repository is highly uncertain.

In light of these uncertainties, it would be speculative to attempt to predict precise consequences. To illustrate one set of possibilities, however, DOE decided to focus the analysis of the No-Action Alternative on the potential impacts of two scenarios:

Scenario 1: Long-term storage of spent nuclear fuel and high-level radioactive waste at the current storage sites, with effective institutional control for at least 10,000 years.

Scenario 2: Long-term storage of spent nuclear fuel and high-level radioactive waste, with the assumption of no effective institutional control after approximately 100 years.

DOE recognizes that neither of these scenarios is likely to occur if there was a decision to not develop a repository at Yucca Mountain. However, the Department selected these two scenarios for analysis because they provide a baseline for comparison to the impacts from the Proposed Action and because they reflect a range of the potential impacts that could occur.

To permit a comparison of the impacts between the construction, operation and monitoring, and eventual closure of a proposed repository at Yucca Mountain and No-Action Scenario 2, the U.S. Department of Energy (DOE) took care to maintain consistency, where possible, with the modeling techniques used to conduct the *Viability Assessment of a Repository at Yucca Mountain* (DOE 1998, all) and in the *Total System Performance Assessment – Viability Assessment (TSPA-VA) Analyses Technical Basis Document* (TRW 1998a,b,c,d,e,f,g,h,i,j,k, all) for the proposed repository (see Appendix I, Section I.1, for details). In pursuit of this goal, DOE structured this analysis to facilitate an impact comparison with the repository impact analysis. Important consistencies include the following:

- Identical evaluation periods (100 years and 10,000 years)

- Identical spent nuclear fuel and high-level radioactive waste inventories at the reference repository:
  - Proposed Action: 63,000 metric tons of heavy metal (MTHM) of commercial spent nuclear fuel; 2,333 MTHM of DOE spent nuclear fuel; 8,315 canisters of high-level radioactive waste; and 50 MTHM of surplus weapons-usable plutonium
  - Module 1: All Proposed Action materials, plus an additional 42,000 MTHM of commercial spent nuclear fuel; 167 MTHM of DOE spent nuclear fuel; and 13,965 canisters of high-level radioactive waste. This would result in a total of approximately 105,000 MTHM of commercial spent nuclear fuel; 2,500 MTHM of DOE spent nuclear fuel; and 22,280 canisters of high-level radioactive waste, plus 50 MTHM of surplus weapons-usable plutonium (see Appendix A, Figure A-2).

DEFINITION OF METRIC TONS OF HEAVY METAL

Quantities of spent nuclear fuel are traditionally expressed in terms of *metric tons of heavy metal* (typically uranium), without the inclusion of other materials such as cladding (the tubes containing the fuel) and structural materials. A metric ton is 1,000 kilograms (1.1 tons or 2,200 pounds). Uranium and other metals in spent nuclear fuel (such as thorium and plutonium) are called *heavy metals* because they are extremely dense; that is, they have high weights per unit volume. One metric ton of heavy metal disposed of as spent nuclear fuel would fill a space approximately the size of a typical household refrigerator.

- Consistent spent nuclear fuel and high-level radioactive waste corrosion and dissolution models
- Identical radiation dose and risk conversion factors
- Similar assumptions regarding the future habits and behaviors of population groups (that is, that they will not be much different from those of populations today)

For commercial facilities, the No-Action analysis estimated short- and long-term radiological impacts for Scenario 1 and short-term impacts for Scenario 2 during the first 100 years for facility workers and the public based on values provided by the U.S. Nuclear Regulatory Commission (NRC 1991a, page 21). For DOE facilities, radiological impacts for these periods under Scenarios 1 and 2 were estimated based on analysis by Orthen (1999, all). To ensure consistency with the repository impact analysis, the long-term facility degradation and environmental releases of radioactive materials were estimated by adapting Total System Performance Assessment process models developed to predict the behavior of spent nuclear fuel and high-level radioactive waste in the repository (Battelle 1998, pages 2.4 to 2.9).

Because DOE did not want to unduly influence the results to favor the repository, it used assumptions were that generally resulted in lower predicted impacts (rather than applying the bounding assumptions used in many of the repository impact analyses) if Total System Performance Assessment models were not available or not appropriate for this continuous storage analysis. For example, the No-Action Scenario 2 analysis took into account the protectiveness of the stainless-steel waste canister when estimating releases of radioactive material from the vitrified high-level radioactive waste; the Total System Performance Assessment assumed no credit for material protection or radionuclide retardation by the intact canister. This approach dramatically reduced the release rate of high-level radioactive waste materials to the environment, thereby resulting in lower estimated total doses and dose rates to the exposed populations. Conversely, in many instances the Total System Performance Assessment selected values for input parameters that defined ranges to ensure that there would be no underestimation of the associated impacts. Section K.4 discusses other consistencies and inconsistencies between the Total System Performance Assessment and the No-Action analysis.

The long-term impact analysis used recent climate and meteorological data, assuming they would remain constant throughout the evaluation period (Poe and Wise 1998, all). DOE recognizes that there could be considerable changes in the climate over 10,000 years (precipitation patterns, ice ages, global warming, etc.) but, to simplify the analysis, did not attempt to quantify climate changes. Section K.4.1.2 discusses the difficulties of modeling these changes and the potential effect on outcomes resulting from uncertainties associated with predicting potential future climatic conditions.

Although the repository Total System Performance Assessment used probabilistic process models to evaluate the transport of radioactive materials within Yucca Mountain and underlying groundwater aquifers, DOE used the deterministic computer program Multimedia Environmental Pollutant Assessment System (MEPAS; Buck et al. 1995, all) for the No-Action Scenario 2 analysis because of the need to model the transport of radioactive material. In addition, it discusses environmental pathways not present at the repository (for example, the movement of contaminants through surface water). The MEPAS program has been accepted and used by DOE and the Environmental Protection Agency for long-term performance assessments (Rollins 1998a, pages 1, 10, and 19).

PROBABILISTIC AND DETERMINISTIC ANALYSES

A *probabilistic* analysis represents data input to a model as a range of values that represents the uncertainty associated with the actual or true value. The probabilistic model randomly samples these input parameter distributions many times to develop a possible range of results. The range of results provides a quantitative estimate of the uncertainty of the results.

A *deterministic* analysis uses a best estimate single value for each model input and produces a single result. The deterministic analysis will usually include a separate analysis that addresses the uncertainty associated with each input and provides an assessment of impact these uncertainties could have on the model results.

Analyses can use both approaches to provide similar information regarding the uncertainty of the results.

K.2 Analytical Methods

This section describes the methodology used to evaluate the long-term degradation of the concrete facilities, steel storage containers, and spent nuclear fuel and high-level radioactive waste materials. In addition, it discusses the eventual release and transport of radioactive materials under Scenario 2. The institutional control assumed under Scenario 1 would ensure ongoing maintenance, repair and replacement of storage facilities, and containment of spent nuclear fuel and high-level radioactive waste. For this reason, assuming the degradation of engineered barriers and the release and transport of radioactive materials is not appropriate for Scenario 1. The Scenario 2 analysis assumed that the degradation process would begin at the time when there was no effective institutional control (that is, after approximately 100 years) and the facilities would no longer be maintained. This section also describes the models and assumptions used to evaluate human exposures and potential health effects, and cost impacts.

K.2.1 GENERAL METHODOLOGY

For the No-Action analysis, the facilities, dry storage canisters, cladding, spent nuclear fuel, and high-level radioactive waste material, collectively known as the *engineered barrier system*, were modeled using an approach consistent (to the extent possible) with that developed for the Viability Assessment (DOE 1998, Volume 3). These process models were developed to evaluate, among other things, the performance of the repository engineered barrier system in the underground repository environment. In this analysis, the process models were adapted whenever feasible to evaluate surface environmental conditions at commercial and DOE sites. These models are described below.

Figure K-1 shows the modeling of the degradation of spent nuclear fuel and high-level radioactive waste and the release of radioactive materials over long periods. Five steps describe the process of spent nuclear fuel and high-level radioactive waste degradation; a sixth step, facility radioactive material release, describes the amount and rate of precipitation that would transport the radioactive material or *dissolution products* to the environment. This section describes each process and the results. Additional details are provided in reference documents (Poe 1998a, all; Battelle 1998, all).

Environmental parameters important to the degradation processes include temperature, relative humidity, precipitation chemistry (pH and chemical composition), precipitation rates, number of rain-days, and freeze/thaw cycles. Other parameters considered in the degradation process describe the characteristics and behavior of the engineered barrier system, including barrier material composition and thickness. To simplify the analysis, the United States was divided into five regions (as shown in Figure K-2) for the purposes of estimating degradation rates and human health impacts (see Section K.2.1.6 for additional details).

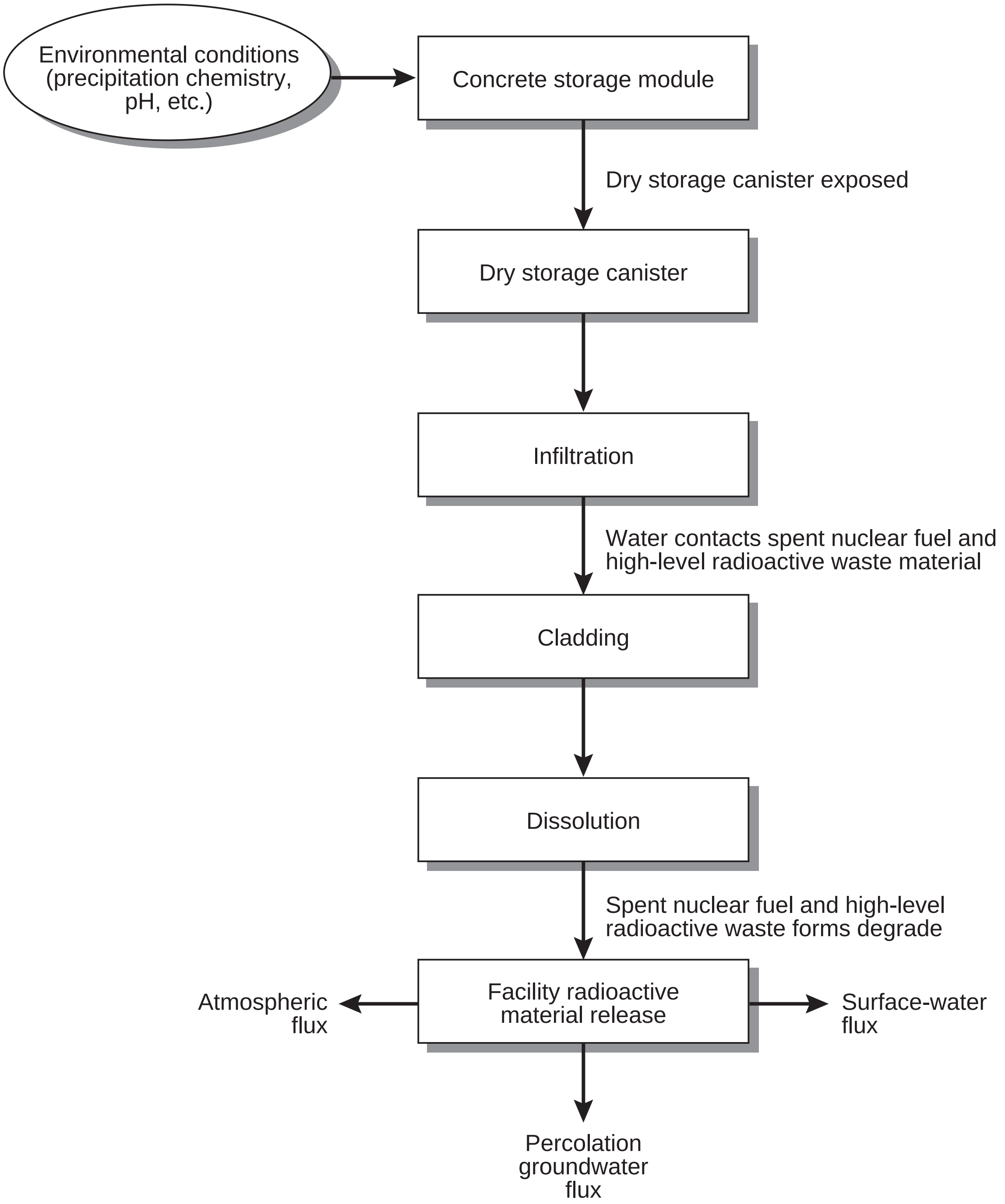
Under the No-Action Alternative, commercial utilities would manage their spent nuclear fuel at 72 nuclear power generating facilities. DOE would manage its spent nuclear fuel and high-level radioactive waste at five DOE facilities [the Hanford Site (Region 5), the Idaho National Engineering and Environmental Laboratory (Region 5), Fort St. Vrain (Region 5), the West Valley Demonstration Project (Region 1), and the Savannah River Site (Region 2)]. The No-Action analysis evaluated DOE spent nuclear fuel and high-level radioactive waste at the commercial and DOE sites or at locations where Records of Decision have placed or will place these materials (for example, West Valley Demonstration Project spent nuclear fuel was evaluated at the Idaho National Engineering and Environmental Laboratory (60 *FR* 28680, June 1, 1995). Therefore, the No-Action analysis evaluated DOE aluminum-clad spent nuclear fuel at the Savannah River Site and DOE non-aluminum-clad fuel at the Idaho National Engineering and Environmental Laboratory. DOE evaluated most of the Fort St. Vrain spent nuclear fuel at the Colorado site. In addition, the analysis evaluated high-level radioactive waste at the West Valley Demonstration Project, the Idaho National Engineering and Environmental Laboratory, the Hanford Site, and the Savannah River Site.

K.2.1.1 Concrete Storage Module Degradation

The first process model analyzed degradation mechanisms related to failure of the concrete storage module. *Failure* is defined as the time when precipitation would infiltrate the concrete and reach the spent nuclear fuel or high-level radioactive waste storage canister. The analysis (Poe 1998a, Section 2.0) considered degradation due to exposure to the surrounding environment.

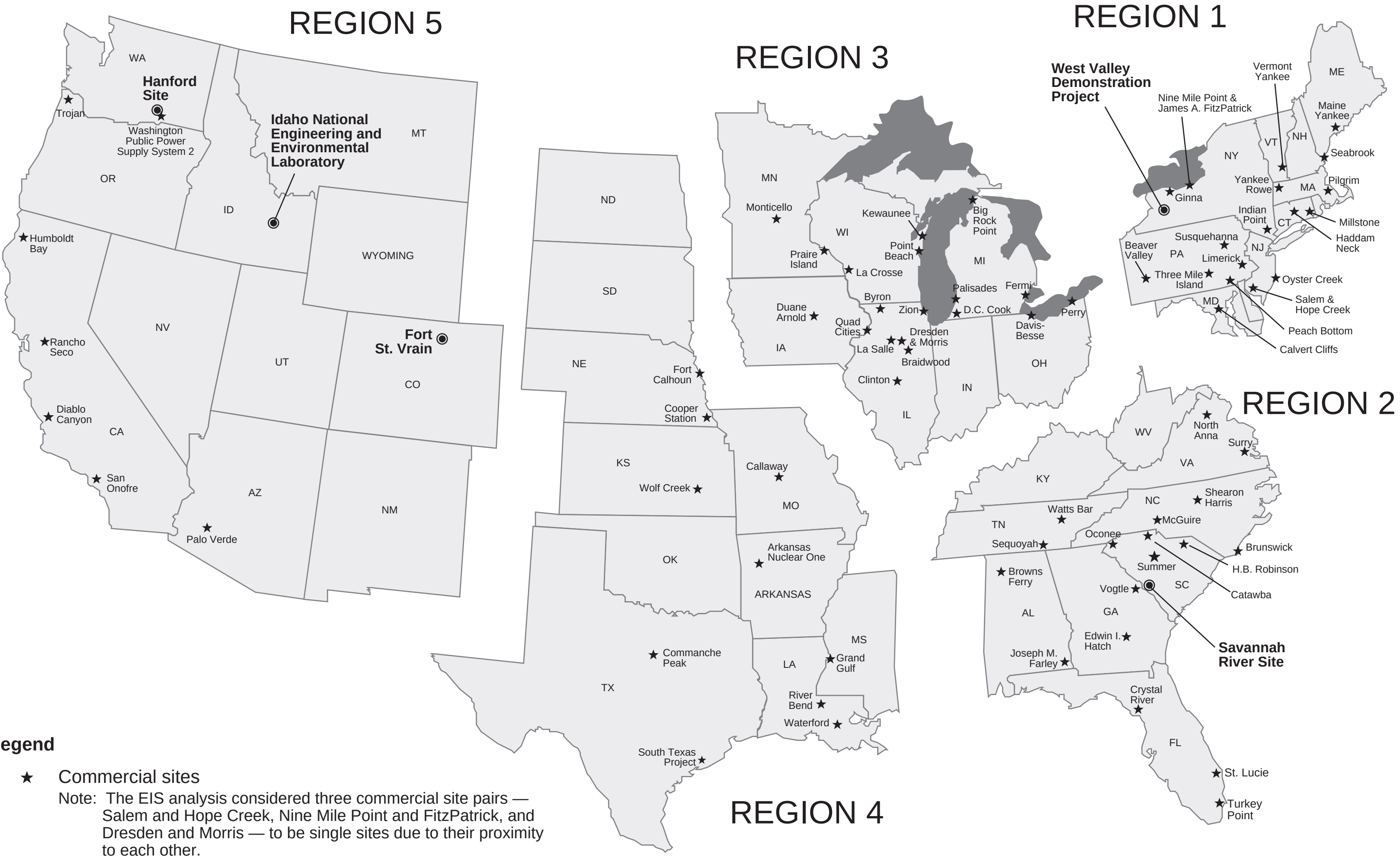
The primary cause of failure of surface-mounted concrete structures is freeze/thaw cycles that cause the concrete to crack and spall (break off in layers), which allows precipitation to enter the concrete, causing more freeze damage. *Freeze/thaw failure* is defined as the time when half of the thickness of the concrete is cracked and spalled. Some regions (coastal California, Texas, Florida, etc.) are essentially without the freeze/thaw cycle. In these locations the primary failure mechanism is chlorides in precipitation, which decompose the chemical constituents of the concrete into sand-like materials. This process progresses more slowly than the freeze/thaw process. Figure K-3 shows estimated concrete storage module failure times.

Below-grade concrete structures, such as those used to store some of the DOE spent nuclear fuel and most of the high-level radioactive waste, would be affected by the same concrete degradation mechanisms as surface facilities. Below grade, the freeze/thaw degradation would not be as great because the soil would moderate temperature fluctuations. The primary failure mechanism for below-grade facilities would be the loss of the above-grade roof, which would result in precipitation seeping around shield plugs. The



Source: Adapted from Battelle (1998, page 2.4).

Figure K-1. Primary steps and processes involved in the degradation of the engineered barrier system.



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

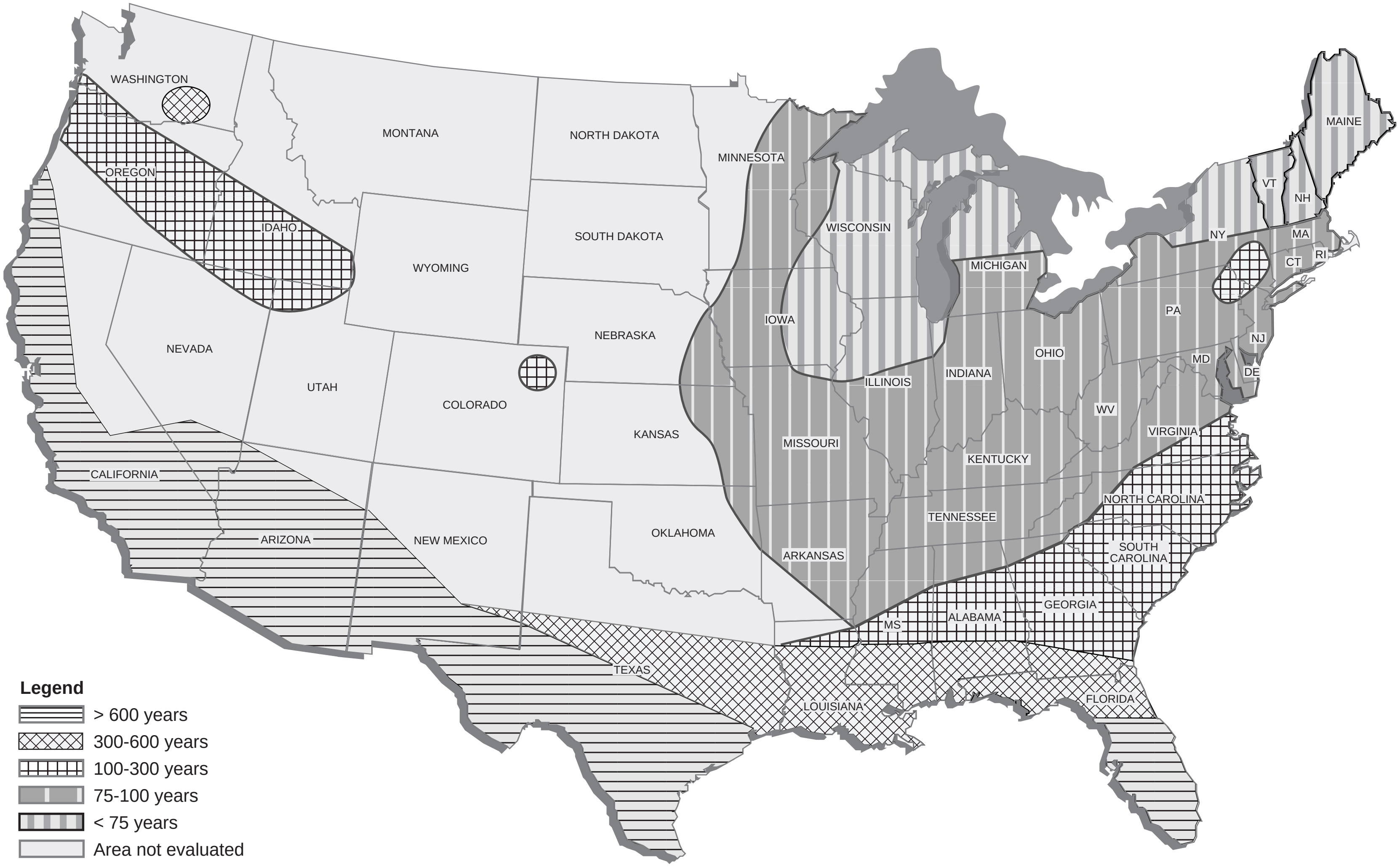
Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

Symbols do not reflect precise locations.

Note: None of the facilities evaluated are located in Alaska or Hawaii.

Source: Modified from Poe (1998b, page 2).

Figure K-2. No-Action Alternative analysis regions.



Climate was evaluated only in regions with existing spent nuclear fuel or high-level radioactive waste storage facilities.

Source: Modified from Poe (1998b, page A-7).

Figure K-3. Failure times for above-ground concrete storage modules.

analysis assumed that this would occur 50 years after the end of facility maintenance, and that this would be the reasonable life expectancy of a facility without maintenance and periodic repair (Poe 1998a, pages 4-6 to 4-19).

K.2.1.2 Storage Canister Degradation

The second process analyzed was spent nuclear fuel and high-level radioactive waste storage canister degradation. For commercial and DOE spent nuclear fuel, the analysis defined failure of the stainless-steel dry storage canister as the time at which precipitation penetrated the canister and wet the spent nuclear fuel. The analysis defined failure for the high-level radioactive waste as the time at which precipitation penetrated the canister. This is consistent with the repository definition that failure of the waste package would occur when water penetrated the package and came in contact with the contents. The stainless-steel model used for the No-Action analysis was consistent with the waste package inner layer corrosion model used for the repository Total System Performance Assessment (DOE 1998, Volume 3, Section 3.4) with the functional parameters modified to incorporate stainless-steel corrosion data (Section K.4.3.1 discusses the sensitivity of outcome to carbon-steel dry storage containers). In addition, the analysis used parameters appropriate for above-ground conditions, including temperature, meteorological data, and chemical constituents in the atmosphere and precipitation. Although inconsistent with the assumptions used for the Total System Performance Assessment, the analysis took credit for the protectiveness of the high-level radioactive waste canister because (1) it is the only container between the waste material and the environment and, (2) to ignore the protectiveness of this barrier would have resulted in a considerable overestimation of impacts. This approach is consistent with the decision, in the case of the No-Action Scenario 2 analysis, to provide a realistic radionuclide release rate where possible and to preclude the overestimation of the associated radiological human health impacts.

The primary determinants of stainless-steel corrosion for the different regions are the amount, the acidity, and the chloride concentration of the precipitation. The storage canisters degrade faster in the below-grade storage configuration than on the surface due to the higher humidity in the below-grade environment. The storage canisters degrade faster in the below-grade storage configuration than on the surface due to the higher humidity in the below-grade environment. The high-level radioactive waste canisters degrade faster than the spent nuclear fuel canisters because they are not as thick. The analysis evaluated three corrosion mechanisms—general corrosion, pitting corrosion, and crevice corrosion (Battelle 1998, Appendix A). Of the three, crevice corrosion would be the dominant failure mechanism for the regions analyzed. Corrosion rates and penetration times vary among the different regions of the country. The analysis calculated regional penetration times from the time at which it assumed that precipitation first would come in contact with the stainless steel. Table K-1 lists the results.

K.2.1.3 Infiltration

The third process analyzes infiltration of water to the spent nuclear fuel and high-level radioactive waste. The amount of water in contact with these materials would be directly related to the size of the dry storage canister footprint and the mean (average) annual precipitation at each storage site. The rate of precipitation varies throughout the Unites States from extremely low (less than 25 centimeters [10 inches] per year) in the arid portions of the west to high (more than 150 centimeters [60 inches] per year) along the Gulf Coast in the southeast (Table K-2, Figure K-4). Local precipitation rates were used to determine the amount of water available that could cause dry storage canister and cladding failure, and spent nuclear fuel and high-level radioactive waste material dissolution.

Table K-1. Time (years) after the assumed loss of effective institutional control at which first failures would occur and radioactive materials could reach the accessible environment.

Material	Region	Storage facility	Weather[a] protection lost	Canister[b] breached (initial material release)
Commercial spent nuclear fuel	1	Surface	100	1,400
	2	Surface	700	1,500
	3	Surface	170	1,100
	4	Surface	750	1,600
	5	Surface	3,500	5,400
DOE spent nuclear fuel	2	Surface	700	1,400
	5	Surface	50	1,400
	5	Below grade	50	800
High-level radioactive waste	1	Surface	100	1,200
	2	Below grade	50	500
	5	Below grade	50	700

a. Source: Adapted from Poe (1998b, Appendix A).
b. Source: Battelle (1998, data files, all); spent nuclear fuel dry storage or high-level radioactive waste canister.

Table K-2. Average regional precipitation.[a]

Region	Annual precipitation (centimeters)[b]	Percent of days with precipitation
1	110	30
2	130	29
3	80	33
4	110	31
5	30	24

a. Source: Adapted from Poe (1998b, Appendix A, pages A-13 to A-16).
b. To convert centimeters to inches, multiply by 0.3937.

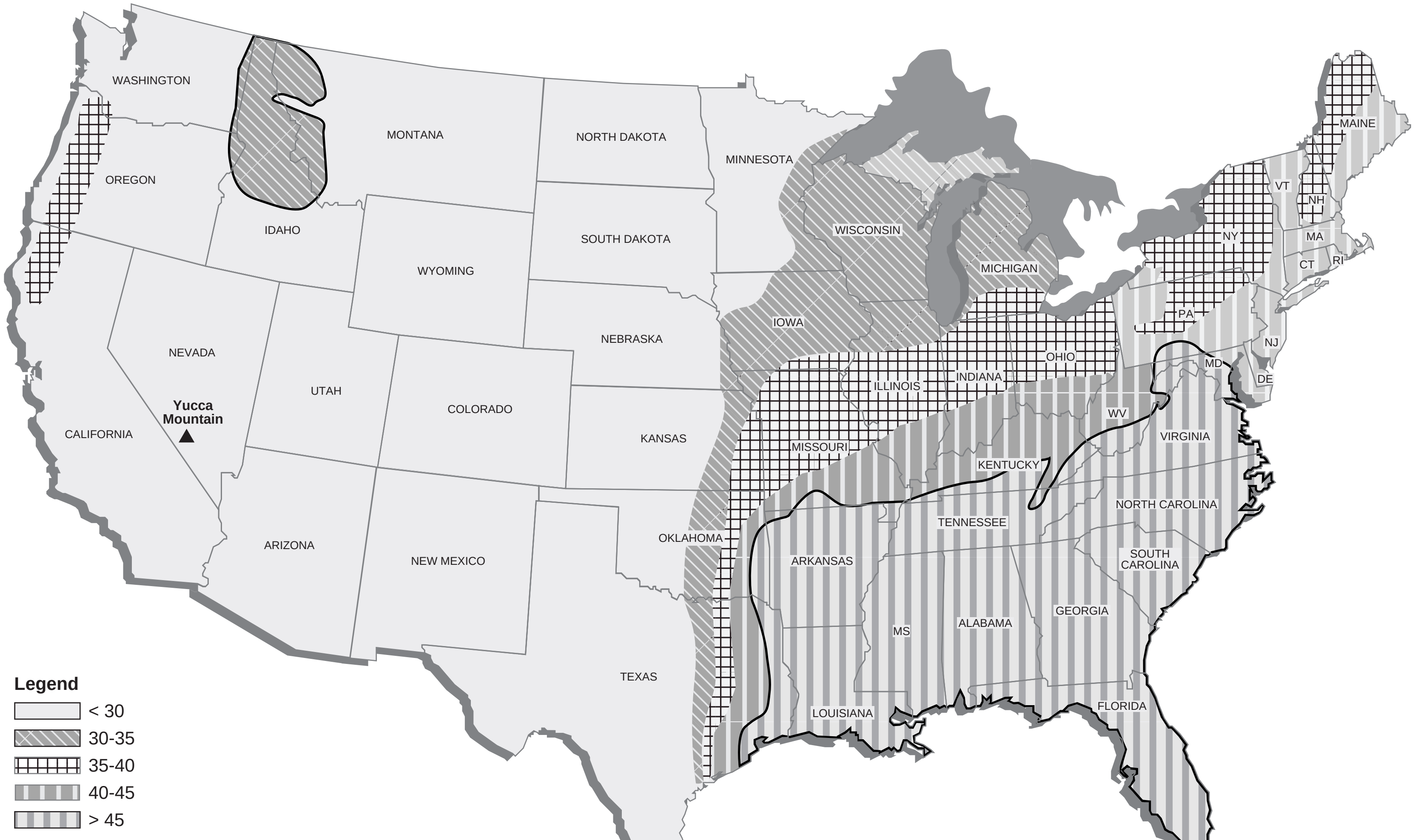
K.2.1.4 Cladding

The fourth process analyzed was failure of the cladding, which is a protective barrier, usually metal (aluminum, zirconium alloy, stainless steel, nickel-chromium, Hastalloy, tantalum, or graphite), surrounding the spent nuclear fuel material to contain radioactive materials. For spent nuclear fuel, cladding is the last engineered barrier to be breached before the radioactive material can begin to be released to the environment.

K.2.1.4.1 *Commercial Spent Nuclear Fuel Cladding*

The principal cladding material used on commercial spent nuclear fuel is zirconium alloy. About 1.2 percent (of MTHM) of commercial spent nuclear fuel is stainless-steel clad (Appendix A, Section A.2.1.5.3). To be consistent with the Total System Performance Assessment, this analysis evaluated two cladding failure mechanisms: (1) so-called *juvenile failures* (failures existing at the start of the analysis period), and (2) *new failures* (failures that occur during the analysis period due to conditions in the storage container). The analysis assumed that juvenile failures existed in 0.1 percent of the zirconium alloy-clad spent nuclear fuel and in all of the stainless-steel-clad fuel at the beginning of the analysis period, and that after failure the cladding would offer no further protection to the radioactive material [this is consistent with the Viability Assessment assumption (DOE 1998, Volume 3, page 3-97)].

Figure K-5 shows new failures (expressed as percent of commercial spent nuclear fuel over time) of zirconium alloy cladding, which were modeled using the median value assumed in the Total System Performance Assessment–Viability Assessment cladding abstraction (TRW 1998f, pages 6-19 to 6-54)



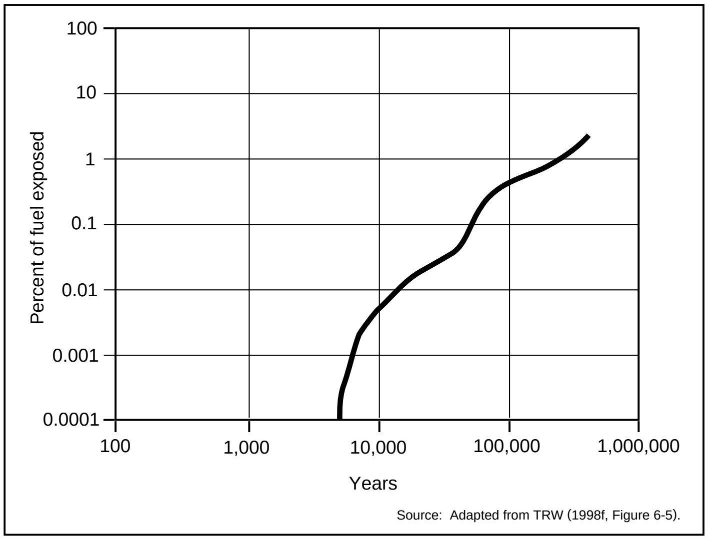
Inches per year
1 inch = 2.54 centimeters

Precipitation ranges (30-year average values)

Yucca Mountain receives less than 12 inches of precipitation each year.

Source: Modified from Poe (1998b, page A-9).

Figure K-4. Precipitation ranges for regions with existing spent nuclear fuel and high-level radioactive waste storage facilities.



Source: Adapted from TRW (1998f, Figure 6-5).

Figure K-5. Percent of commercial spent nuclear fuel exposed over time due to new failures.

for zirconium alloy corrosion. The Viability Assessment (DOE 1998, Volume 3, all) defines this information as a "fractional multiplier," which is calculated from the fraction of the failed fuel pin surface area. In the No-Action analysis, this corrosion is assumed to commence when weather protection afforded by the waste package is lost and the cladding is exposed to environmental precipitation. The Total System Performance Assessment-Viability Assessment also considers cladding failure from creep strain, delayed hydride cracking, and mechanical failure from rock falls. These additional mechanisms normally occur after the 10,000-year analysis period and are therefore not considered in the No-Action analysis. As shown in Figure K-5, during the 10,000-year analysis period, less than 0.01 percent of the zirconium alloy-clad spent nuclear fuel would be expected to fail. If the upper limit curve from Figure 4 of the Total System Performance Assessment-Viability Assessment cladding abstraction (TRW 1998f, pages 6-19 to 6-54) was used, the value could be as high as 0.5 percent of the zirconium alloy-clad spent nuclear fuel. The lower limit value from the Total System Performance Assessment-Viability Assessment cladding abstraction curve would be much less than 0.001 percent.

K.2.1.4.2 *DOE Spent Nuclear Fuel Cladding*

The composition and cladding materials of DOE spent nuclear fuel vary widely. The cladding assumption for the surrogate material used in this analysis is identical (no cladding credit) to the assumption used in the Total System Performance Assessment analysis (see Section K.4.3.2 for the discussion of uncertainty in relation to cladding).

K.2.1.5 Dissolution of Spent Nuclear Fuel and High-Level Radioactive Waste

The fifth process analyzed was the dissolution of the spent nuclear fuel and high-level radioactive waste. The rate of release of radionuclides from these materials would be related directly to the amount of surface area exposed to moisture, the quantity and chemistry of available water, and temperature. The Total System Performance Assessment process model, modified to reflect surface environmental conditions (temperature, relative humidity, etc.), was used to estimate release rates from the exposed spent nuclear fuel and high-level radioactive waste. The model and application to surface conditions is described in detail in Battelle (1998, pages 2.9 to 2.11).

K.2.1.5.1 *Commercial Spent Nuclear Fuel Dissolution*

Consistent with the repository impact analysis, this analysis estimated that new zirconium alloy failures would begin late in the 10,000-year period (see Figure K-5). As discussed in Section K.2.1.4.1, only 0.01 percent of the zirconium alloy-clad spent nuclear fuel would be likely to fail during the 10,000-year analysis period. Therefore, most of the exposed material considered in this analysis would result from juvenile failures of zirconium alloy- and stainless-steel-clad spent nuclear fuel.

K.2.1.5.2 *DOE Spent Nuclear Fuel Dissolution*

The analysis assumed that DOE spent nuclear fuel would be a metallic uranium fuel with zirconium alloy cladding (a representative or surrogate fuel that consisted primarily of N-Reactor fuel). Consistent with the repository input analysis, the No-Action Scenario 2 analysis takes no credit for the cladding. The analysis used the Total System Performance Assessment model for metallic uranium fuel, modified for surface environmental conditions, to predict releases of the DOE spent nuclear fuel.

K.2.1.5.3 *High-Level Radioactive Waste Dissolution*

Most high-level radioactive waste would be stored in below-grade concrete vaults. As discussed in Section K.2.1.1, these vaults would be exposed to precipitation as soon as weather protection was lost (the model assumed this would occur 50 years after loss of institutional control). After the loss of weather protection and failure of the stainless-steel canisters, the high-level radioactive waste would be exposed to precipitation. The environment in the underground vault would be humid and deterioration would occur. Thus, the material would be exposed to either standing water or humid conditions in the degrading vaults after the canister failed. The borosilicate glass deterioration model used in this analysis was the same as the Total System Performance Assessment model modified to reflect surface conditions (temperature and precipitation chemistry).

K.2.1.6 Regionalization of Sites for Analysis

The climate of the contiguous United States varies considerably across the country. The release rate of the radionuclide inventory would depend primarily on the interactions between environmental conditions (rainfall, freeze-thaw cycles) and engineered barriers. To simplify the analysis, DOE divided the country into five regions (see Figure K-2) (Poe 1998b, page 2).

The analysis assumed that a single hypothetical site in each region would store all the spent nuclear fuel and high-level radioactive waste existing in that region. Such a site does not exist but is a mathematical construct for analytical purposes. To ensure that the calculated results for the regional analyses reflect appropriate inventory, facility and material degradation, and radionuclide transport, the spent nuclear fuel and high-level radioactive waste inventories, engineered barriers, and environmental conditions for the hypothetical sites were developed from data for each of the existing sites in the given region. Weighting criteria to account for the amount and types of spent nuclear fuel and high-level radioactive waste at each site were used in the development of the environmental data for the regional site, such that the results of the analyses for the hypothetical site were representative of the sum of the results of each actual site if they had been modeled independently (Poe 1998b, page 1). If there are no storage facilities in a particular area of the country, the environmental parameters of that area were not evaluated.

Table K-3 lists the Proposed Action and Module 1 quantities of commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste in each of the five regions. The values in Table K-1 are the calculated results of failures of the various components of the protective engineered barriers and release of radioactive material in each region.

K.2.2 RADIONUCLIDE RELEASE

The sixth and final step in the process is the release of radioactive materials to the environment. The anticipated release rates (fluxes) were estimated in terms of grams per 70-year period (typical human life expectancy in the United States) of uranium dioxide, uranium metal, or borosilicate glass for commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste, respectively. To assess potential lifetime impacts on human receptors, the amount of fission products and transuranics associated

Table K-3. Proposed Action and Module 1 quantities of spent nuclear fuel (metric tons of heavy metal) and canisters of high-level radioactive waste in each geographic region.[a,b]

	Commercial spent nuclear fuel[c]								
	Region total[d]		With juvenile cladding failure		Stainless-steel cladding	DOE spent nuclear fuel[e]		High-level radioactive waste[f]	
Region	Proposed Action (MTHM)	Module 1 (MTHM)	Proposed Action (MTHM)	Module 1 (MTHM)	Proposed Action and Module 1[g] (MTHM)	Proposed Action (MTHM)	Module 1 (MTHM)	Proposed Action (canisters)	Module 1 (canisters)
1	17,000	27,000	16	27	410			300	300
2	19,000	32,000	19	32	0	30	45	6,000	6,200
3	15,000	23,000	15	23	170				
4	7,200	14,000	7	14	0				
5	5,400	10,000	5	9	140	2,300	2,455	2,000	15,500
Totals	**63,600**	**106,000**	**62**	**105**	**720**	**2,300**	**2,500**	**8,300**	**22,000**

a. Source: Appendix A.
b. Totals might differ from sums due to rounding.
c. All analyzed as stored on surface as shown on Chapter 2, Figures 2-36, 2-37, and 2-38.
d. Includes plutonium in mixed-oxide spent nuclear fuel, which is assumed to behave like other commercial spent nuclear fuel.
e. A representative or surrogate fuel that consisted primarily of N-reactor fuel.
f. Includes plutonium in can-in-canister.
g. Assumes failure of 100 percent of stainless-steel-clad when placed into dry storage.

with gram quantities of uranium dioxide, uranium metal, and borosilicate glass were calculated for approximately 140 consecutive 70-year average human lifetimes to determine releases from the 10,000-year analysis period. Weighting criteria were used to ensure appropriate contributions by the different types of spent nuclear fuel and the high-level radioactive waste in each region, as appropriate. The result was a single release rate for each region that accounted for the different materials (uranium dioxide, uranium metal, and borosilicate glass).

The radionuclide distributions in the spent nuclear fuel and high-level radioactive waste (Appendix A) were used for these analyses. These were expressed as radionuclide-specific curies for storage packages (assembly or canister). The curies per storage package were converted to curies per gram of uranium dioxide, uranium metal, or borosilicate glass (as described above for each spent nuclear fuel and high-level radioactive waste material). This radionuclide distribution was multiplied by release flux (curies of spent nuclear fuel and high-level radioactive waste material per 70-year period) after being corrected for decay and the ingrowth of decay products for various times after disposal. These corrections were determined using the ORIGEN computer program (ORNL 1991, all) for each of the approximately 140 consecutive 70-year human lifetimes to determine the release over the 10,000-year period. The results of the ORIGEN runs were used as input to the environmental transport program.

DEFINITIONS

Fission products: Elements produced when uranium atoms split in a nuclear reactor, some of which are radioactive. Examples are cesium, iodine, and strontium.

Transuranics: Radioactive elements, heavier than uranium, that are produced in a nuclear reactor when uranium atoms absorb neutrons rather than splitting. Examples of transuranics include plutonium, americium, and neptunium.

Curie: The basic unit of radioactivity. It is equal to the quantity of any radionuclide in which 37 billion atoms are decaying per second.

Specific activity: An expression of the number of curies of activity per gram of a given radionuclide. It is dependent on the half life and molecular weight of the nuclide.

In addition to the 53 isotopes important to the repository long-term impact analysis specified in Appendix A, the No-Action Scenario 2 analysis considered 167 other isotopes in the light-water reactor radiological database (DOE 1992, Page 1.1-1). Of the 220 isotopes evaluated, six would contribute more than 99.5 percent of the total dose. Table K-4 lists these six isotopes along with technetium-99, which individually would contribute less than 0.003 percent of the total dose. Plutonium-239 and -240 would contribute more than 96 percent of the radiological impacts during the 10,000-year analysis period because of their very large dose conversion factors. Americium-241 and -243 would be minor contributors to the dose. Neptunium-237 and technetium-99 were of tertiary importance (Table K-4).

Table K-4. Radionuclides and relative contributions over 10,000 years to Scenario 2 impacts.[a]

Isotope	Percent of total dose
Americium-241	3.2
Americium-243	0.86
Neptunium-237	0.29
Plutonium-238	0.2
Plutonium-239	49.0
Plutonium-240	47.0
Technetium-99	< 0.003

a. Source: Toblin (1998a, page 6).

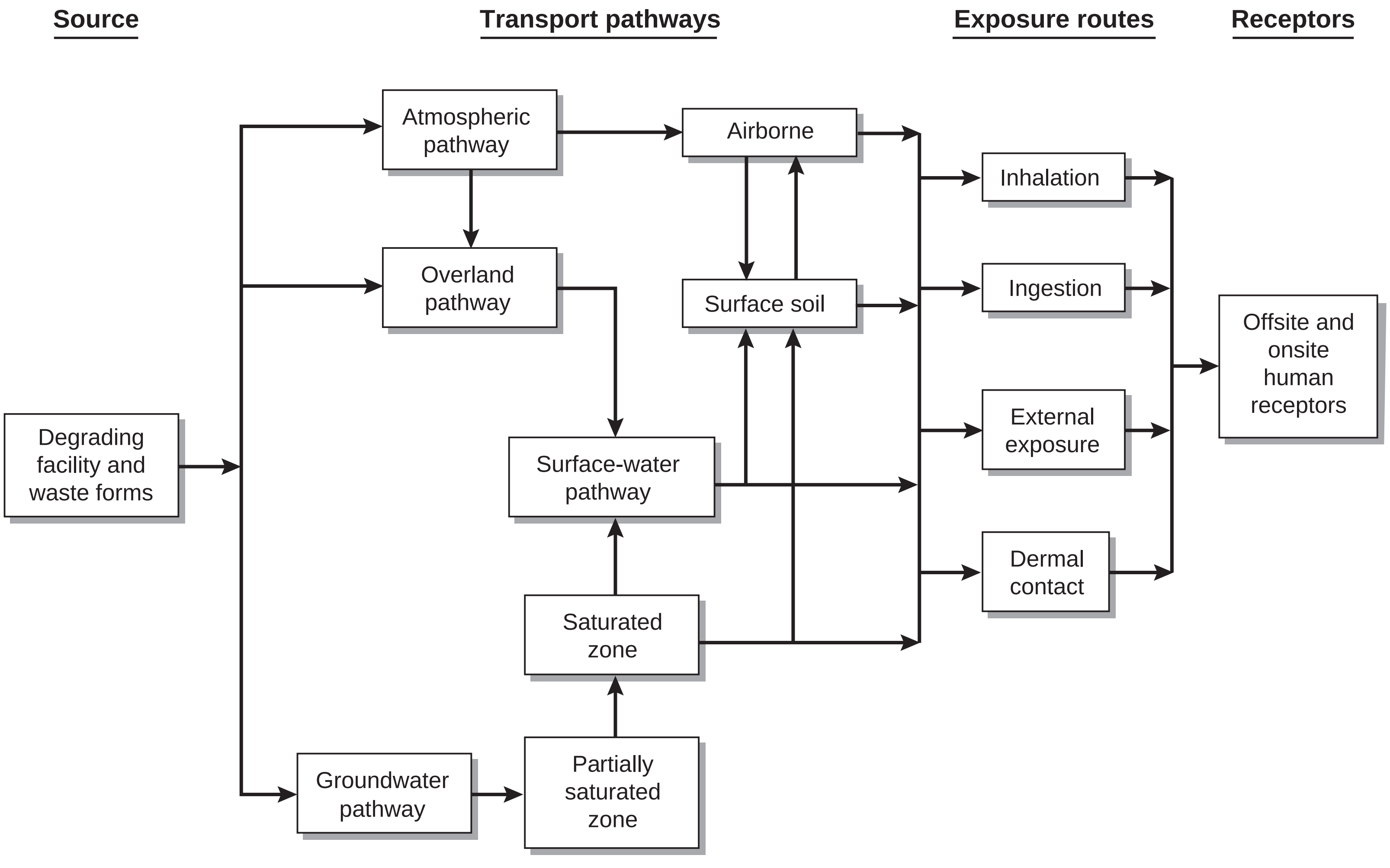
K.2.3 ENVIRONMENTAL TRANSPORT OF RADIOACTIVE MATERIALS

Radioactive materials in degraded spent nuclear fuel and high-level radioactive waste could be transported to the environment surrounding each storage facility by three pathways: groundwater, surface-water runoff, and atmosphere. Figure K-6 shows the potential exposure pathways. The analysis assumed that existing local climates would persist throughout the time of exposure of the spent nuclear fuel and high-level radioactive waste to the environment. The assumed configuration for the degraded storage facilities would have debris covering the radioactive material, which would remain inside the dry storage canisters. While the dry storage canisters could fail sufficiently to permit water to enter, they probably would retain their structural characteristics, thereby minimizing the dispersion of radioactive particulate material to the atmosphere (Mishima 1998, page 4). Based on this analysis, the airborne particulate pathway generally would not be an important source of human exposure. The assumption is that after radionuclides dissolved in the precipitation they would reach the environment either through groundwater or surface-water transport.

The analysis performed environmental fate and transport pathway modeling using the Multimedia Environmental Pollutant Assessment System program (Buck et al. 1995, all). The Multimedia Environmental Pollutant Assessment System is an integrated system of analytical, semianalytical, and empirically based mathematical models that simulate the transport and fate of radioactive materials through various environmental media and calculate concentrations, doses, and health effects at designated receptor locations.

The Multimedia Environmental Pollutant Assessment System was originally developed by Pacific Northwest National Laboratory to enable DOE to prioritize the investigation and remediation of the Department's hazardous, radioactive, and mixed waste sites in a scientific and objective manner based on readily available site information. The Multimedia Environmental Pollutant Assessment System has evolved into a widely accepted (by Federal and international agencies) computational tool for calculating the magnitude of environmental concentrations and public health impacts caused by releases of radioactive material from various sources.

The following sections discuss the assumptions and methods used to determine radioactive material transport for groundwater and surface-water pathways. Environmental parameters defined for input to the



Source: Adapted from Buck et al. (1995, all).

Figure K-6. Potential exposure pathways associated with degradation of spent nuclear fuel and high-level radioactive waste.

Multimedia Environmental Pollutant Assessment System program were collected from various sources for specific sites (Sinkowski 1998, page 2) and regionalized parameters were developed (Poe and Wise 1998, all). The analysis used long-term averages to represent environmental conditions, and assumed that these parameters would remain constant over the 10,000-year analysis period. The following sections discuss the method for each pathway.

K.2.3.1 Groundwater Transport

Precipitation falling on degrading spent nuclear fuel and high-level radioactive waste material would form a radioactive solution (leachate) that could migrate through the vadose zone (the unsaturated upper layer of soil) to the underlying water table, which would dilute, disperse, and transport the material downgradient through the local aquifer system. As a result, there is a potential for human exposure through the groundwater pathway to downgradient well users and to populations along surface-water bodies where groundwater feeds into surface water.

The groundwater component of the radioactive material fluxes (infiltration) averaged over 70-year (lifetime) increments was entered in the Multimedia Environmental Pollutant Assessment System program. The infiltration would carry the contaminated leachate down through the vadose zone to the saturated zone (aquifer). The contaminants would be diluted and dispersed as they traveled through the aquifer. Radioactive material retardation would occur in both the unsaturated (above the water table) and saturated (below the water table) zones. A distribution adsorption (that is, surface retention) coefficient, K_d, (the amount of material adsorbed to soil particles relative to that in the water) modeled this retardation (Toblin 1998a, page 2). This coefficient is radioactive material-specific and varies for each material based on such factors as soil pH and clay content.

Table K-5 lists the adsorption coefficients, K_d, for the elements explicitly modeled for groundwater transport. The coefficients are expressed as a function of the clay content of the soil through which the elements are being transported; the analyses assumed a soil pH between 5 and 9. Note that the K_d values of all isotopes of a given element (for example, plutonium-238, -239, and -240) are the same, because adsorption is a chemical rather than nuclear process.

The time required to traverse the groundwater was determined for each radionuclide and 70-year period (Toblin 1998a, page 4). Tables K-6 and K-7 list the range of nuclide groundwater transport times, from source to receptor, for each of the five regions. Times are listed for the important nuclides (see Table K-4). The analysis assumed that the vadose/aquifer flow fields were steady-state, so that the nuclide travel times at a particular site would be constant over the 10,000-year analysis period, although the nuclide release rates were not. Table K-6 lists parameters describing the total (over the analysis period) and maximum nuclide release rates for the same important nuclides. Region 5, dominated by two large DOE sites, is seen to result in the largest nuclide releases of all of the regions.

Table K-7 also lists the number of water systems and people that would obtain water from the affected waterways. Many of these people would be subject to impacts from more than one site because they would obtain their water from affected waterways downstream from multiple sites.

When the groundwater reached the point where it outcropped to surface water, radioactive material transport would be subject to further dilution and dispersion. For most of the regions analyzed, the distance between the storage location and the downgradient surface-water body would be inside the site boundary; therefore, offsite wells generally would not be affected. However, the analysis calculated groundwater concentrations for hypothetical onsite and offsite receptors. The Multimedia Environmental Pollutant Assessment System program calculated groundwater and surface-water concentrations at each receptor location for consecutive 70-year lifetimes in the 10,000-year analysis period.

Table K-5. Multimedia Environmental Pollutant Assessment System default elemental equilibrium adsorption coefficients (K_d) for soil pH between 5 and 9.[a]

	Clay content by weight		
Element	< 10 percent	10 to 30 percent	$\geq$ 30 percent
Actinium	228	538	4,600
Americium	82	200	1,000
Californium	0	0	0
Carbon	0	0	0
Cesium	51	249	270
Chlorine	0	0	0
Cobalt	2	9	200
Curium	82	200	1,000
Iodine	0	0	0
Krypton	0	0	0
Lead	234	597	1,830
Neptunium	3	3	3
Nickel	12	59	650
Niobium	50	100	100
Palladium	0	4	40
Plutonium	10	100	250
Protactinium	0	50	500
Radium	24	100	124
Ruthenium	274	351	690
Samarium	228	538	4,600
Selenium	6	15	15
Strontium	24	100	124
Technetium	3	20	20
Thorium	100	500	2,700
Tin	5	10	10
Tritium	0	0	0
Uranium	0	50	500
Zirconium	50	500	1,000

a. Source: Toblin (1998a, page 2).

The parameters necessary for the spent nuclear fuel and high-level radioactive waste storage sites for the Multimedia Environmental Pollutant Assessment System were defined. Pertinent hydrologic and hydrogeologic information was derived from the site-specific Updated Final Safety Analysis Reports for commercial nuclear sites and site-specific data provided by the various DOE sites (Jenkins 1998, page 1).

Table K-8 lists the range (over the individual sites) in each region of the important hydrogeologic parameters that would affect the transport of the radionuclides through the groundwater. These parameters form the basis for the nuclide transport times listed in Table K-7.

A simplifying analytical assumption was that radioactive material transport would occur only through the shallowest aquifer beneath the site. Because this assumption limits the interchange of groundwater with underlying aquifers, less radioactive material dilution would occur, and groundwater pathway impacts could be slightly overestimated. However, because impacts from the groundwater pathway would be minor in comparison to surface-water pathways, the total estimated impacts would not be affected by this assumption.

Table K-6. Regional source terms and environmental transport data for important isotopes used for collective drinking water radiological impact analysis.[a]

Parameter	Plutonium-239/240	Plutonium-238	Americium-241	Americium-243	Neptunium-237	Technetium-99
Nuclide released in 10,000 years (curies)						
Region 1	4,200	20	660	115	8.9	98
Region 2	17,000	97	1,500	240	32	1,200
Region 3	130,000	660	31,000	3,300	260	2,600
Region 4	4,300	17	450	110	9.0	89
Region 5	570,000	180	42,000	1,700	720	6,500
Maximum annual nuclide release (curies per year)						
Region 1	19	0.020	1.2	0.053	0.0031	0.034
Region 2	53	0.035	2.2	0.11	0.0083	0.19
Region 3	60	0.71	56	1.6	0.092	1.0
Region 4	0.20	0.016	0.78	0.054	0.0034	0.035
Region 5	140	0.22	66	0.47	0.14	1.4
Years (from 2016) of maximum annual nuclide release						
Region 1	1,435	1,435	1,435	1,435	1,435	1,435
Region 2	1,575	1,575	1,575	1,575	1,575	1,575
Region 3	1,155	1,155	1,155	1,155	1,155	1,155
Region 4	1,715	1,715	1,715	1,715	1,715	1,715
Region 5	875	875	875	875	875	875
Nuclide reaching receptors in 10,000 year (curies)						
Region 1	3,600	11	130	43	8.8	95
Region 2	13,000	10	1.4	39	31	1,100
Region 3	110,000	250	380	510	250	2,500
Region 4	2,000	3.6	0.66	24	6.0	59
Region 5	180,000	2.6	0.020	1.2	630	5,600
Nuclide transport time[b] (years)						
Region 1	10-5,500	10-5,500	10-45,000	10-45,000	10-1,700	10-1,700
Region 2	460-9,000	460-9,000	2,000-36,000	2,000-36,000	43-860	140-1,500
Region 3	65-45,000	65-45,000	410-260,000	410-260,000	31-9,800	31-9,800
Region 4	850-520,000	850-520,000	3,000-1,000,000	3,000-1,000,000	59-16,000	130-100,000
Region 5	1,400-26,000	1,400-26,000	2,700-220,000	2,700-220,000	44-8,000	280-8,000

a. Source: Toblin (1998a, page 4).

b. Time from source to receptor.

Table K-7. Transport and population data for drinking water pathway impact analysis.

Parameter	Region 1	Region 2	Region 3	Region 4	Region 5
Groundwater flow time (years)[a]	2.0 to 59	4.6 to 37	1.8 to 420	4.6 to 960	2.9 to 190
Number of people that would obtain domestic water supply from affected waterways (millions)[b]	6.7	5.3	13.1	5.3	0.16
Affected drinking water systems[c]	112	147	137	64	23

a. From source to outcrop; source: adapted from Jenkins (1998, Table 2).

b. Source: Poe (1998b, page 12).

c. Source: Adapted from Sinkowski (1998, all).

K.2.3.2 Surface-Water Transport

The amount of leachate from degraded spent nuclear fuel and high-level radioactive waste in the surface-water pathway would depend on soil characteristics and the local climate. The Multimedia Environmental Pollutant Assessment System considers precipitation rates (Table K-2), soil infiltration, evapotranspiration, and erosion management practices to determine the amount of leachate that would run

Table K-8. Multimedia Environmental Pollutant Assessment System regional groundwater input parameters.[a]

Parameter	Region 1	Region 2	Region 3	Region 4	Region 5
Vadose zone					
Contaminated liquid infiltration rate (vertical Darcy velocity) (feet per year)[b]	3.1 - 3.5	4.4	2.7 - 3.1	2.7 - 4.4	0.88 - 3.1
Clay content (percent)	0 - 15	1 - 47	1 - 47	3 - 15	1 - 15
pH of pore water	5 - 9	5 - 9	5 - 9	5 - 9	5 - 9
Thickness (feet)	6 - 50	10 - 50	4 - 160	2 - 80	23 - 250
Bulk density (grams per cubic centimeter)	1.4 - 1.9	1.4 - 1.6	1.4 - 1.6	1.4 - 1.6	1.4 - 1.7
Total porosity (percent)	5 - 46	38 - 49	38 - 49	38 - 46	38 - 49
Field capacity (percent)	2.5 - 28	9 - 42	9 - 42	9 - 28	9 - 28
Saturated hydraulic conductivity (feet per year)	210 - 6,800	27 - 6,800	27 - 6,800	210 - 6,800	72 - 6,800
Aquifer					
Clay content (percent)	0 - 3	0 - 47	0 - 15	0 - 15	0 - 10
pH of pore water	5 - 9	5 - 9	5 - 9	5 - 9	5 - 9
Thickness (feet)	7 - 100	10 - 85	7 - 160	20 - 150	25 - 250
Bulk density (grams per cubic centimeter)	1.6 - 2.1	1.4 - 2.0	1.5 - 1.7	1.4 - 1.7	1.5 - 1.9
Total porosity (percent)	5 - 38	5 - 49	5 - 44	5 - 46	23 - 44
Effective porosity (percent)	2.9 - 22	2.9 - 28	2.9 - 25	22 - 27	13 - 25
Saturated hydraulic conductivity (feet per year)	210 - 6,800	27 - 6,800	27 - 6,800	210 - 6,800	72 - 6,800
Darcy velocity (feet per year)	6.8 - 1,400	12 - 170	3.9 - 430	0.58 - 270	33 - 560
Travel distance (feet)	1,900 - 5,600	2,000 - 4,700	1,900 - 23,000	1,600 - 12,000	1,900 - 37,000

a. Source: Adapted from Jenkins (1998, Table 2).

b. Annual precipitation rate (through degraded structure).

off rather than percolate into the soil. The contaminated runoff would travel overland and eventually enter nearby rivers and streams that would dilute it further.

To determine the impacts of the contaminated discharge to surface water on the downstream populations using that water (affected populations), DOE calculated the surface water flow rate and the release rate of contaminants (as curies per year) contributed by each storage location draining to the surface water. Using these values, DOE determined surface-water radionuclide concentrations for each receptor location. DOE applied these concentrations to the respective affected populations to estimate impacts for each region.

K.2.3.3 Atmospheric Transport

If degraded spent nuclear fuel or high-level radioactive waste was exposed to the environment, small particles could become suspended in the air and transported by wind. The Multimedia Environmental Pollutant Assessment System methodology includes formulations for radioactive material (particulate) suspension by wind, vehicular traffic, and other physical disturbances of the ground surface. The impacts from the atmospheric pathways would be small in comparison to surface-water pathways because the cover provided by the degraded structures and the relatively large particle size and density of the materials (see Section K.2.3) would preclude suspension by wind. Therefore, impacts from the transport of radioactive particulate materials were not included in the analysis.

K.2.4 HUMAN EXPOSURE, DOSE, AND RISK CALCULATIONS

This section describes methods used in the No-Action Scenario 2 analysis to estimate dose rates and potential impacts (latent cancer fatalities) to individuals and population groups from exposures to radionuclide contaminants in groundwater and surface water and in the atmosphere. As discussed above, these contaminated environmental media would result from the degradation of storage facilities (Sections K.2.1.1), corroding dry storage canisters (Section K.2.1.2), cladding failure (Section K.2.1.4), spent nuclear fuel and high-level radioactive waste dissolution (Section K.2.1.5), leachate percolation and groundwater transport (Section K.2.3.1), surface-water runoff (Section K.2.3.2), and atmospheric suspension and transport (Section K.2.3.3).

For Scenario 1 and the first 100 years of Scenario 2, the presence of effective institutional control would ensure that radiological releases to the environment and radiation doses to workers and the public remained within Federal limits and DOE Order requirements and were maintained as low as reasonably achievable. As a result, impacts to members of the public would be very small. Potential radiological human health impacts that could occur would be due primarily to occupational radiation exposure of onsite workers. The analysts estimated these impacts based on actual operational data from commercial nuclear powerplant sites (NRC 1991a, pages 22 - 25) and projected these impacts for the 100- and 10,000-year analysis periods for Scenario 1.

For Scenario 2, impacts to onsite workers and the public during institutional control (approximately 100 years) would be the same as those for Scenario 1. However, because the assumption for Scenario 2 is that there would be no effective institutional control after approximately 100 years, engineered barriers would begin to degrade and eventually would not prevent radioactive materials from the spent nuclear fuel and high-level radioactive waste from entering the environment. During the period of no effective institutional control, there would be no workers at the site. Thus, impacts were calculated only for the public.

For Scenario 2, the potential highest exposures and dose rates over a 70-year lifetime period were evaluated for individuals and exposed populations. In addition, the total integrated dose to the exposed population for the 10,000-year analysis period was estimated. Human exposure parameters (exposure times, ingestion and inhalation rates, agricultural activities, food consumption rates, etc.) were developed based on recommendations from Federal agencies (EPA 1988, pages 113 to 131; EPA 1991, Attachment B; NRC 1977, pages 1.109-1 to 1.109-2; Shipers and Harlan 1989, all; NRC 1991b, Chapter 6) and are reflected as Multimedia Environmental Pollutant Assessment System default values (Buck et al. 1995, Section 1.0). Other parameters chosen for this analysis are summarized in supporting documentation (Sinkowski 1998, all; Toblin 1998a,b,c, all). Table K-9 lists the exposure and usage parameters for all of the pathways considered in the analysis (see Section K.3.1).

The Scenario 2 analysis evaluated long-term radiation doses and impacts to populations exposed through the surface-water and groundwater pathways. This analysis estimated population impacts only for the drinking water pathway using regionalized effective populations and surface-water dilution factors discussed in Section K.2.3.2. Other pathways were evaluated to determine their potential contribution in relation to drinking water doses. These analyses are discussed in Section K.3.1.

K.2.4.1 Gardener Impacts

To reasonably bound human health impacts resulting from human intrusion, two types of gardener were evaluated—the onsite gardener (10 meters [33 feet]) from the degrading storage facility) and the near-site gardener (5 kilometers [3 miles] from the degrading facility). The analysis had both of these hypothetical gardeners residing on the flow path for groundwater. The gardeners would obtain all their drinking water from contaminated groundwater, grow their subsistence gardens in contaminated soils, and irrigate them with the contaminated groundwater. The contaminated garden soils, suspended by the wind, would contaminate the surfaces of the vegetables consumed by the gardeners. The hypothetical onsite gardener would be the maximally exposed individual.

Table K-9. Multimedia Environmental Pollutant Assessment System human exposure input parameters for determination of all pathways radiological impacts sensitivity analysis (page 1 of 2).[a]

Water source[b]	Surface water
Domestic water supply treatment[c]	Yes
Fraction of plutonium removed by water treatment[d]	0.3
Drinking water rate (liters per day per person)[e]	2
Irrigation rate (liters per square meter per month)[f]	100
Leafy vegetable consumption rate (kilograms per day per person)[g]	0.021
Other vegetable consumption rate (kilograms per day per person)	0.13
Meat consumption rate (kilograms per day per person)	0.065
Milk consumption rate (kilograms per day per person)	0.075
Finfish consumption rate (kilograms per day per person)	0.0065
Shellfish consumption rate (kilograms per day per person)	0.0027
Shoreline contact (hours per day per person)	0.033
Americium ingestion dose conversion factor (rem per picocurie)[h]	3.6×10^{-6}
Americium finfish bioaccumulation factor	250
Americium shellfish bioaccumulation factor	1,000
Americium meat transfer factor (days per kilogram)	3.5×10^{-6}
Americium milk transfer factor (days per liter)	4.0×10^{-7}
Neptunium ingestion dose conversion factor (rem per picocurie)	4.4×10^{-6}
Neptunium finfish bioaccumulation factor	250
Neptunium shellfish bioaccumulation factor	400
Neptunium meat transfer factor (days per kilogram)	5.5×10^{-5}
Neptunium milk transfer factor (days per liter)	5.0×10^{-6}
Technetium ingestion dose conversion factor (rem per picocurie)	1.5×10^{-9}
Technetium finfish bioaccumulation factor	15
Technetium shellfish bioaccumulation factor	5
Technetium meat transfer factor (days per kilogram)	8.5×10^{-3}
Technetium milk transfer factor (days per liter)	1.2×10^{-2}
Plutonium ingestion dose conversion factor (rem per picocurie)[i]	3.5×10^{-6}
Plutonium finfish bioaccumulation factor	250
Plutonium shellfish bioaccumulation factor	100
Plutonium meat transfer factor (days per kilogram)	5.0×10^{-7}
Plutonium milk transfer factor (days per liter)	1×10^{-7}
Yield of leafy vegetables [kilograms (wet) per square meter]	2.0
Yield of vegetables [kilograms (wet) per square meter]	2.0
Yield of meat feed crops [kilograms (wet) per square meter]	0.7
Yield of milk animal feed crops [kilograms (wet) per square meter]	0.7
Meat animal intake rate for feed (liters per day)	68
Milk animal intake rate for feed (liters per day)	55
Meat animal intake rate for water (liters per day)	50
Milk animal intake rate for water (liters per day)	60
Agricultural areal soil density (kilograms per square meter)	240
Retention fraction of activity on plants	0.25
Translocation factor for leafy vegetables	1.0
Translocation factor for other vegetables	0.1
Translocation factor for meat animal	0.1
Translocation factor for milk animal	1.0
Fraction of meat feed contaminated	1.0
Fraction of milk feed contaminated	1.0
Fraction of meat water contaminated	1.0
Fraction of milk water contaminated	1.0
Meat animal soil intake rate (kilograms per day)	0.5

Table K-9. Multimedia Environmental Pollutant Assessment System human exposure input parameters for determination of all pathways radiological impacts sensitivity analysis (page 2 of 2).[a]

Water source[b]	Surface water
Milk animal soil intake rate (kilograms per day)	0.5
Leafy vegetable growing period (days)	60
Other vegetable growing period (days)	60
Beef animal feed growing period (days)	30
Milk animal feed growing period (days)	30
Water intake rate while showering (liters per hour)	0.06
Duration of shower exposure (hours per shower)	0.167
Shower frequency (per day)	1.0
Thickness of shoreline sediment (meters)	0.04
Density of shoreline sediments (grams per cubic meter)	1.5
Shore width factor for shoreline external exposure	0.2

a. Source: Buck et al. (1995, MEPAS default settings).
b. Groundwater for gardener.
c. No for gardener.
d. Zero for gardener.
e. To convert liters to gallons, multiply by 0.26418.
f. To convert liters per square meter to gallons per square foot, multiply by 0.00025.
g. To covert kilograms to pounds, multiply by 2.2046.
h. Sediment ingestion = 0.1 grams per hour (0.000022 pounds per hour) during contact.
i. For plutonium-239/240.

HUMAN INTRUSION

Spent nuclear fuel and high-level radioactive waste in surface or below-grade storage facilities would be readily accessible in the absence of institutional control. For this reason, DOE anticipates that both planned and inadvertent intrusions could occur. An example of the former would be the scavenger who searches through the area seeking articles of value; an example of the latter would be the farmer who settles on the site and grows agricultural crops with no knowledge of the storage structure beneath the soil. Intrusions into contaminated areas also could occur through activities such as building excavations, road construction, and pipeline or utility replacement.

Under the conditions of Scenario 2, intruders could receive external exposures from stored spent nuclear fuel and high-level radioactive waste that would grossly exceed current regulatory limits and, in some cases, could be sufficiently high to cause prompt fatalities. In addition, long-term and repeated intrusions, such as those caused by residential construction or agricultural activities near storage sites, could result in long-term chronic exposures that could produce increased numbers of latent cancer fatalities. These intrusions could also result in the spread of contamination to remote locations, which could increase the total number of individuals potentially exposed.

Calculations were performed using transport models described by Buck et al. (1995, all) for gardeners in each of the five analysis regions using regionalized source terms and environmental parameters. Therefore, calculated impacts to the regional gardener (maximally exposed individual) would not represent the highest impacts possible from a single site in a given region, but rather would reflect an average impact for the region. Details of the analysis are provided in Toblin (1998c, all). The regional hydrogeologic parameters listed in Table K-10, together with transient nuclide release rates (the maximum of which is indicated in the table), were used to determine the radiological impacts to the regional gardener as a result of groundwater transport. The regional parameters were based on a curie-weighting of the individual site parameters for plutonium and americium. The exposure parameters in

Table K-10. Multimedia Environmental Pollutant Assessment System groundwater transport input parameters for estimating radiological impacts to the onsite and near-site gardener.[a]

Parameter	Region 1	Region 2	Region 3	Region 4	Region 5
Vadose zone					
Contaminated liquid infiltration rate (vertical Darcy velocity) (feet per year)[b,c]	3.5	4.4	2.7	3.5	0.88
Clay content (percent)	1	10	12	11	2
pH of pore water	5 - 9	5 - 9	5 - 9	5 - 9	5-9
Thickness (feet)	11	44	7.1	43	180
Longitudinal dispersivity (feet)	0.11	0.44	0.071	0.43	1.8
Bulk density (grams per cubic meter)[d]	1.6	1.5	1.5	1.5	1.6
Total porosity (percent)	38	42	44	45	41
Field capacity (percent)	9.3	15	23	21	12
Saturated hydraulic conductivity (feet per year)	6,500	660	1,700	1,000	5,900
Aquifer					
Clay content (percent)	1.8	6.5	1.2	4.4	0.69
pH of pore water	5 - 9	5 - 9	5 - 9	5 - 9	5 - 9
Thickness (feet)	45	50	37	64	210
Bulk density (grams per cubic meter)	1.6	1.8	1.6	1.6	1.7
Total porosity (percent)	38	40	38	35	30
Effective porosity (percent)	22	23	22	20	17
Darcy velocity (feet per year)	340	62	69	51	300
Longitudinal dispersivity (feet)	f(x)[e]	f(x)	f(x)	f(x)	f(x)
Lateral dispersivity (feet)	f(x) ÷ 3	f(x) ÷ 3	f(x) ÷ 3	f(x) ÷ 3	f(x) ÷ 3
Vertical dispersivity (feet)	f(x) ÷ 400	f(x) ÷ 400	f(x) ÷ 400	f(x) ÷ 400	f(x) ÷ 400
Maximum annual plutonium-239 and -240 release (curies per year)	4.9	0.24	3.8	0.32	2.1
Years (from 2016) of maximum annual plutonium release	1,365	1,575	1,155	1,715	875

a. Source: Toblin (1998c, page 2-4).

b. Annual precipitation rate (through degraded structure).

c. To convert feet to meters, multiply by 0.3048.

d. To convert grams per cubic meter to pounds per cubic foot, multiply by 0.0000624.

e. $f(x) = 2.72 \times (\log_{10} 0.3048 \times x)^{2.414}$, where x = downgradient distance.

Table K-9 describe the radionuclide exposure to the gardener where applicable (for example, exposure parameters related to the fish are not applicable to the gardener).

K.2.4.2 Direct Exposure

The analysis evaluated potential external radiation dose rates to the maximally exposed individual for a commercial independent spent fuel storage installation because this type of facility would provide the highest external exposures of all the facilities analyzed in this appendix. Maximum dose rates over the 10,000-year analysis period were evaluated for each region. The maximally exposed individual was assumed to be 10 meters (about 33 feet) from an array of concrete storage modules containing 1,000 MTHM of commercial spent nuclear fuel. The maximum dose rate varied between regions depending on how long the concrete shielding would remain intact (Table K-1).

The direct gamma radiation levels were calculated (Davis 1998, page 1). To ensure consistency between this analysis and the Total System Performance Assessment, the same radionuclides were used for the design of the Yucca Mountain Repository surface facility shielding (TRW 1995, Attachment 9.5). Radionuclide decay and radioactive decay product ingrowth over the 10,000-year analysis period were calculated using the ORIGEN computer program (ORNL 1991, all).

Neutron emissions were not included because worst-case impacts (death within a short period of exposure) would be the same with or without the neutron component. Details of these calculations and analyses are provided in supporting documentation (Rollins 1998b, all).

K.2.5 ACCIDENT METHODOLOGY

Spent nuclear fuel and high-level radioactive waste stored in above-ground dry storage facilities would be protected initially by the robust surrounding structure (either metal or concrete) and by a steel storage container that contained the material. Normal storage facility operations would be primarily passive because the facilities would be designed for cooling via natural convection. DOE evaluated potential accident and criticality impacts for both Scenario 1 (institutional control for 10,000 years) and Scenario 2 (assumption of no effective institutional control after approximately 100 years with deterioration of the engineered barriers initially protecting the spent nuclear fuel or high-level radioactive waste).

For Scenario 1, human activities at each facility would include surveillance, inspection, maintenance, and equipment replacement when required. The facilities and the associated systems, which would be licensed by the Nuclear Regulatory Commission, would have certain required features. License requirements would include isolation of the stored material from the environment and its protection from severe accident conditions (10 CFR 50.34). The Nuclear Regulatory Commission requires an extensive safety analysis that considers the impacts of plausible accident-initiating events such as earthquakes, fires, high winds, and tornadoes. No plausible accident scenarios have been identified that result in the release of radioactive material from the storage facilities (PGE 1996, all; CP&L 1989, all). In addition, the license would specify that facility design requirements include features to provide protection from the impacts of severe natural events. This analysis assumed maintenance of these features indefinitely for the storage facilities.

DOE performed a scoping analysis to identify the kinds of events that could lead to releases of radioactive material to the environment prior to degradation of concrete storage modules and found none. The two events determined to be the most challenging to the integrity of the concrete storage modules would be the crash of an aircraft into the storage facility and a severe seismic event.

- Davis, Strenge, and Mishima (1998, all) concluded that the postulated aircraft crash would be potentially more severe than a postulated seismic event because storage facility damage from an aircraft crash probably would be accompanied by a fire that could heat the spent nuclear fuel or high-level radioactive waste and increase the quantity of material released to the environment. The analysis showed that hurtling aircraft components produced by such an event would not penetrate the storage facility and that a subsequent fire would not result in a release of radioactive materials.

- For the seismic event, meaningful damage would be unlikely because storage facilities would be designed to withstand severe earthquakes. Even if such an event caused damage, no immediate release would occur because no mechanism has been identified that would cause meaningful fuel pellet damage to create respirable airborne particles. If this damage did not occur, the source term would be limited to gaseous fission products, carbon-14, and a very small amount of preexisting fuel pellet dust. Subsequent repairs to damaged facilities or concrete storage modules would preclude the long-term release of radionuclides.

Criticality events are not plausible for Scenario 1 because water, which is required for criticality, could not enter the dry storage canister. The water would have to penetrate several independent barriers, all of which would be maintained and replaced as necessary under Scenario 1.

Under Scenario 2, facilities would degrade over time and the structures would gradually deteriorate and lose their integrity. The analysis determined that two events, an aircraft crash and inadvertent criticality, would be likely to dominate the impacts from accidents, as described in the following paragraphs.

K.2.5.1 Aircraft Crash

DOE determined that an aircraft crash into a degraded concrete storage module would be the largest plausible accident-initiating event that could occur at the storage sites. This event would provide the potential for the airborne dispersion of radioactive material to the environment and, as a result, the potential for exposure of individuals who lived in the vicinity of the site. The aircraft crash could result in mechanical damage to the storage casks and the fuel assemblies they contained, and a fire could result. The fire would provide an additional mechanism for dispersion of the radioactive material. The frequency and consequences of this event are described in detail in Davis, Strenge and Mishima (1998, all).

The aircraft assumed for the analysis is a midsize twin-engine commercial jet (Davis, Strenge, and Mishima 1998, page 2). The area affected by a crash was computed using the DOE standard formula (DOE 1996, Chapter 6) in which the aircraft could crash directly into the side or top of the concrete storage modules, or could strike the ground in the immediate vicinity of the facility and skid into the concrete storage modules. Using this formula, the dimensions of a typical storage facility as shown in Chapter 2, Figure 2-37, and the aircraft configuration would result in an estimated aircraft crash frequency of 0.0000032 (3 in 1 million) crashes per year (Davis, Strenge, and Mishima 1998, page 5). This frequency is within the range that DOE typically considers the design basis, which is defined by DOE as 0.000001 or greater per year (DOE 1993, page 28).

The analysis estimated the consequences of the aircraft crash on degraded concrete storage modules. The twin-engine jet was assumed to crash into an independent spent fuel storage installation that contained 100 concrete storage modules, each containing 24 pressurized-water reactor fuel assemblies. Using the penetration methodology from DOE (1996, Chapter 6), an aircraft crash onto these concrete storage modules could penetrate 0.8 meter (2.6 feet). Because the concrete storage modules have 1.2-meter (3.9-foot) thick walls, the crash projectiles would not penetrate the reinforced concrete in the as-constructed form. Thus, DOE determined that the aircraft crash would not cause meaningful consequences until the concrete storage modules were considerably degraded, when an aircraft projectile could penetrate a concrete storage module and damage a storage cask (Davis, Strenge, and Mishima 1998, page 7). The degradation process is highly location-dependent, as noted in Section K.2.1.1. For sites in northern climates, the degradation would be relatively rapid due to the freeze/thaw cycling that would expedite concrete breakup; considerable degradation could occur in 200 to 300 years. For southern climates, the degradation would be much slower. Thus, an aircraft crash probably would not result in meaningful consequences for a few hundred to a few thousand years, depending on location. The timing is of some importance because the radioactive materials in the fuel would decay over time, and the potential for radiation exposure would decline with the decay.

The analysis assumed that the aircraft crash occurred 1,000 years after the termination of institutional control at a facility where the concrete had degraded sufficiently to allow breach of the dry storage canister. Computing public impacts from the air crash event requires estimating the population to a distance of 80 kilometers (50 miles) from a hypothetical site (the distance beyond which impacts from an airborne release would be very small). This analysis considered two such sites, one in an area of a high population site and one in an area of low population. The average population around all of the sites in each of the five regions defined in Figure K-2 was computed based on 1990 census data. The average ranged from a high of 330 persons per square mile in region 1 (high population) to a low of 77 persons per square mile in region 4 (low population). Both of these population densities (assumed to be uniform around the hypothetical sites) were used in the consequence calculation.

Estimating the amount of airborne respirable particles that would result from a crash requires assumptions about the impact and resulting fire. The impact of the jet engines probably would cause extensive damage to the fuel assemblies in the degraded concrete storage module, and would scatter fuel pins around the immediate area. The fuel tanks in the aircraft would rupture, and fuel would disperse around the site and collect in pools. These pools would ignite, and an intense fire [hotter than 500°C (approximately 930°F)] (Davis, Strenge, and Mishima 1998, page 8) would result. The fire would heat the fuel pins to the point of cladding rupture. The ruptured fuel pins would cause fuel pellets to be exposed to the fire. As the fire burned, the fuel pools would recede, exposing additional fuel pellets to the air. This would cause oxidation of the hot uranium dioxide fuel pellets, converting them to U_3O_8 (another form of uranium oxide), which would produce a large amount of fuel pellet dust, including small particles that could become airborne and inhaled into the lungs. The estimated fraction of the fuel converted to respirable airborne dust would be 0.12 percent (Davis, Strenge and Mishima 1998, page 9). The fire would cause a thermal updraft that could loft the fuel pellet dust into the atmosphere.

The consequences from the event were computed with the MACCS2 program (Rollstin, Chanin, and Jow 1990, all). This model has been used extensively by the Nuclear Regulatory Commission and DOE to estimate impacts from accident scenarios involving releases of radioactive materials. The model computes dose to the public from the direct radiation by the cloud of radioactive particles released during the accident, from inhaling particles, and from consuming food produced from crops and grazing land that could be contaminated as the particles are deposited on the ground from the passing cloud. The food production and consumption rates are based on generic U.S. values (Kennedy and Strenge 1992, pages 6.19 to 6.28; Chanin and Young 1998, all). The program computes the dispersion of the particles as the cloud moves downwind. The dispersion would depend on the weather conditions (primarily wind speed, stability, and direction) that existed at the time of the accident. This calculation assumed median weather conditions and used annual weather data from airports near the centers of the regions.

K.2.5.2 Criticality

DOE evaluated the potential for nuclear criticality accidents involving stored spent nuclear fuel. A criticality accident is not possible in high-level radioactive waste because most of the fissionable atoms were removed or the density of fissionable atoms was reduced by the addition of glass matrix. Nuclear criticality is the generation of energy by the fissioning (splitting) of atoms as a result of collisions with neutrons. The energy release rate from the criticality event can be very low or very high, depending on several factors, including the concentration of fissionable atoms, the availability of moderating materials to slow the neutrons to a speed that enables them to collide with the fissionable atoms, and the presence of materials that can absorb neutrons, thus reducing the number of fission events.

Criticality events are of concern because under some conditions they could result in an abrupt release of radioactive material to the environment. If the event were energetic enough, the dry storage canister could split open, fuel cladding failure could occur, and fragmentation of the uranium dioxide fuel pellets could occur.

The designs of existing dry storage systems for spent nuclear fuel, in accordance with Nuclear Regulatory Commission regulations (10 CFR Part 72) preclude criticality events by various measures, including primarily the prevention of water entering the dry storage canister. If water is excluded, a criticality cannot occur.

If institutional control was maintained at the dry storage facilities (Scenario 1), a criticality is not plausible because the casks would be monitored and maintained such that introduction of water into the canister would not be possible. However, under Scenario 2, eventual degradation (corrosion) of the dry storage canisters could lead to the entry of water from precipitation, at which point criticality could be possible if other conditions were met simultaneously.

The analysis considered three separate criticality events:

- A low-energy event that involved a criticality lasting over an intermediate period (minutes or more). This event would not produce high temperatures or generate large additional quantities of radionuclides. Thus, no fuel cladding failures and no meaningful increase in consequences would be likely.

- An event in which a system went critical but at a slow enough rate so the energy release would not be large enough to produce steam, which would terminate the event. This event could continue over a relatively long period (minutes to hours), and would differ from the low-energy event in that the total number of fissions could be very large, and a large increase in radionuclide inventory could result. This increase could double the fission product content of the spent nuclear fuel. No fuel cladding failures would be likely in this event, so no abrupt release of radionuclides would occur.

- An energetic event in which a system went critical and produced considerable fission energy. This event could occur if seriously degraded fuel elements collapsed abruptly to the bottom of the canister in the presence of water that had penetrated the canister. This event would produce high fuel temperatures that could lead to cladding rupture and fuel pellet oxidation. The radiotoxicity of the radionuclide inventory produced by the fission process would be comparable to the inventory in the fuel before the event.

The probability of a criticality occurring as described in these scenarios is highly uncertain. However, DOE expects the probability would be higher for the first two events, and much lower for the third (energetic energy release). Several conditions would have to be met for any of the three events to occur. The concrete storage module and dry storage canister must have degraded such that water could enter but not drain out. The fuel would have to contain sufficient fissionable atoms (uranium-235, plutonium 239) to allow criticality. This would depend on initial enrichment (initial concentration of uranium-235) and burnup of the fuel in the reactor before storage (which would reduce the uranium-235 concentration). Because a small amount of spent nuclear fuel would be likely to have appropriate enrichment burnup combinations that could enable criticality to occur, none of the criticality events can be completely ruled out. The energetic criticality event is the only one with the potential to produce large impacts. Such an event would be possible, but would be highly unlikely; its consequences would be uncertain. The event could cause a prompt release of radionuclides. However, the amount released would not be likely to exceed that released by the aircraft crash event evaluated above. Thus, this analysis did not evaluate specific consequences of a criticality event.

K.3 Results

K.3.1 RADIOLOGICAL IMPACTS

Impacts to human health from long-term environmental releases and human intrusion were estimated using the methods described in Section K.2 and in supporting technical documents (Sinkowski 1998, all; Jenkins 1998, all; Battelle 1998, all; Poe 1998a,b, all; Poe and Wise 1998, all; Toblin 1998a,b,c, all). The radiological impacts on human health would include internal exposures due to the intake of radioactive materials released to surface water and groundwater.

Six of the seven radionuclides listed in Table K-4 would contribute more than 99 percent of the total dose. Table K-11 lists the estimated radiological impacts by region during the last 9,900 years under Scenario 2 for the Proposed Action and Module 1 inventories of spent nuclear fuel and high-level radioactive waste. As noted above, these impacts would be to the public from drinking water from the major waterways contaminated by surface-water runoff of radioactive materials from degraded spent nuclear fuel and high-level radioactive waste storage facilities (Toblin 1998a,b, all). Figure K-7 shows the locations of all commercial nuclear and DOE waste storage sites in the United States and more than 20 potentially affected major waterways. At present, 30.5 million people are served by municipal water systems with intakes along the potentially affected portions of these waterways. Over the 9,900-year analysis period, about 140 generations would be potentially affected. However, because releases are not estimated to occur during about the first 1,000 years for most regions, the potential affected population could be as high as 3.9 billion.

SCENARIO 2 IMPACTS

The principal long-term human health consequences from the storage of spent nuclear fuel and high-level radioactive waste would result from rainwater flowing through degraded storage facilities where it would dissolve the material. The dissolved material would travel through groundwater and surface-water runoff to rivers and streams where people could use it for domestic purposes such as drinking water and crop irrigation. The Scenario 2 analysis estimated population impacts resulting only from the consumption of contaminated drinking water and exposures resulting from land contamination due to periodic flooding, although other pathways, such as eating contaminated fish, could contribute additional impacts larger than those from drinking water for selected individuals in the exposed population.

Table K-11. Estimated collective radiological impacts to the public from continued storage of Proposed Action and Module 1 inventories of spent nuclear fuel and high-level radioactive waste at commercial and DOE storage facilities – Scenario 2.[a]

	9,900-year population dose[b] (person-rem)		9,900-year LCFs[c]		Years until peak impact[d]	
Region	Proposed Action	Module 1	Proposed Action	Module 1	Proposed Action	Module 1
1	1,800,000	1,820,000	900	900	1,400	1,400
2	760,000	1,260,000	380	630	5,100	8,300
3	3,500,000	3,650,000	1,800	1,830	3,400[d]	3,400[d]
4	70,000	138,000	30	69	3,900	3,900
5	460,000	461,000	230	230	7,100	7,000
Totals	**6,590,000**	**7,330,000**	**3,340**	**3,700**		

a. Total population (collective) dose from drinking water pathway over 9,900 years.

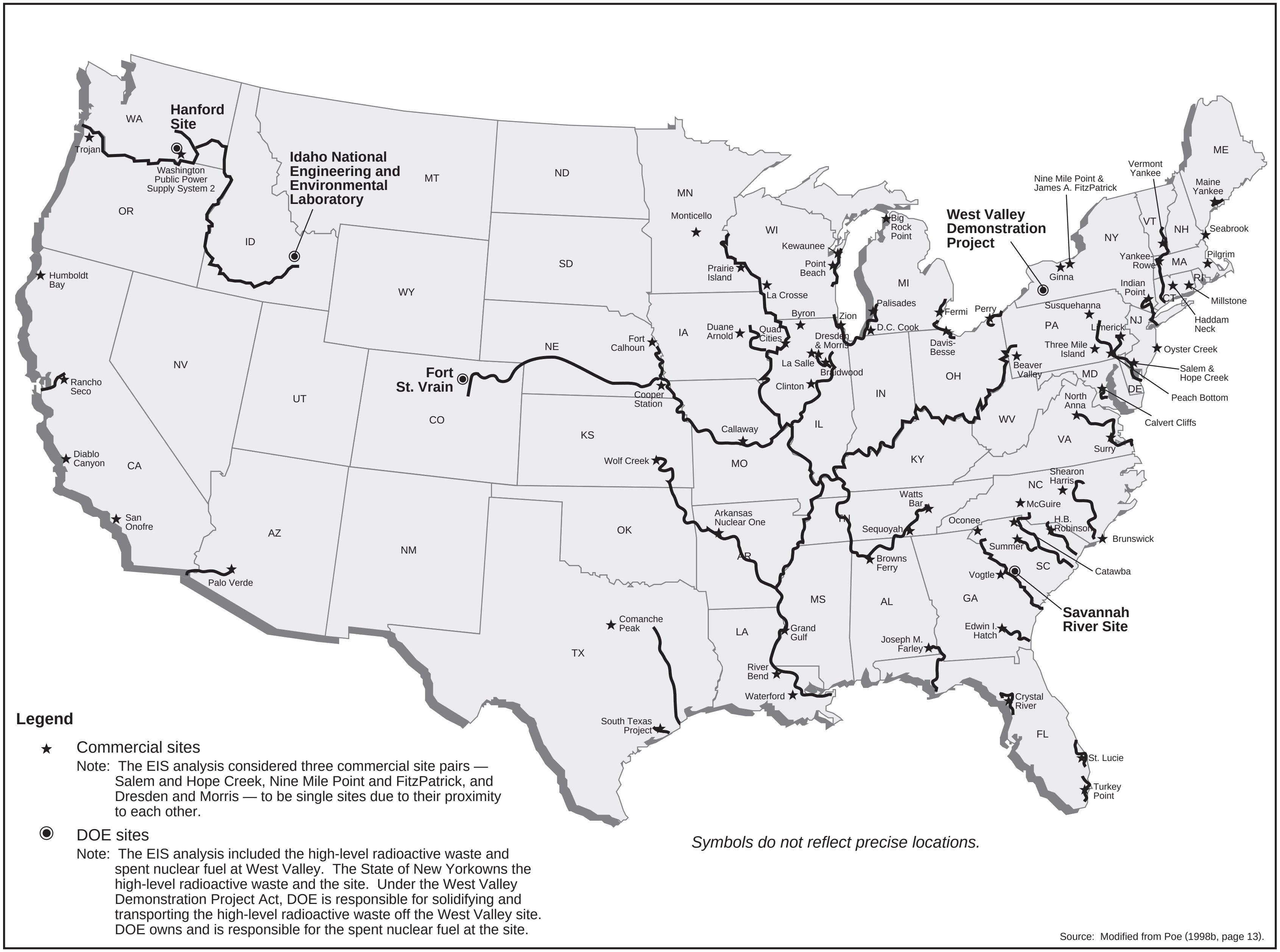
b. LCF = latent cancer fatality; additional number of latent cancer fatalities for the exposed population group based on an assumed risk of 0.0005 latent cancer fatality per person-rem of collective dose (NCRP 1993a, page 112).

c. Years after 2116 when the maximum doses would occur.

d. Year of combined U.S. peak impact would be the same as for Region 3 peak impact, because the predominant impact would be in Region 3.

Table K-11 indicates the variability of individual doses and potential impacts in the five regions analyzed (see Section K.2.1.6). The variability among regions is due to differences in types and quantities of spent nuclear fuel and high-level radioactive waste, annual precipitation, size of affected populations, and surface-water bodies available to transport the radioactive material.

Table K-11 also indicates that the Proposed Action inventory would produce a collective drinking water dose of 6.6 million person-rem over 9,900 years, which could result in an additional 3,300 latent cancer



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste and spent nuclear fuel at West Valley. The State of New Yorkowns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste off the West Valley site. DOE owns and is responsible for the spent nuclear fuel at the site.

Source: Modified from Poe (1998b, page 13).

Figure K-7. Major waterways near commercial and DOE sites.

fatalities in the total potentially exposed population of 3.9 billion, in which about 900 million fatal cancers [using the lifetime fatal cancer risk of 24 percent (NCHS 1993, page 5)] would be likely to occur from all other causes. Figures K-8 and K-9 show the Proposed Action inventory regional collective doses and potential latent cancer fatalities, respectively, for approximately 140 consecutive 70-year lifetimes that would occur during the 9,900-year analysis period. The peaks shown in Figures K-8 and K-9 would result from the combination of the sites that drain to the Mississippi River and the relatively large populations potentially affected along these waterways. These values include impacts for the Proposed Action inventory only. Similar curves for the Module 1 inventory are not shown because of their similarity to those for the Proposed Action inventory. As listed in Table K-11, the impacts from the Module 1 inventory would be approximately 20 percent greater than for the Proposed Action inventory.

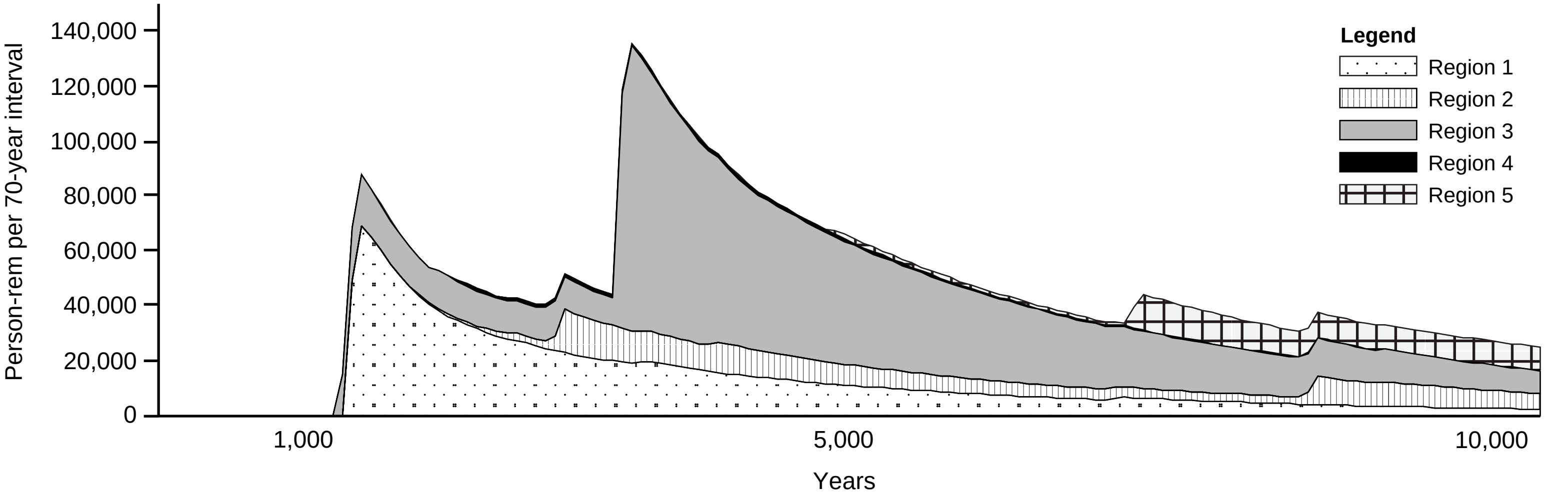
The additional 3,300 Proposed Action latent cancer fatalities (or 3,700 Module 1 latent cancer fatalities) over the 10,000-year analysis period would not be the only negative impact. Under Scenario 2, more than 20 major waterways of the United States (for example, the Great Lakes, the Mississippi, Ohio, and Columbia rivers, and many smaller rivers along the Eastern Seaboard) that currently supply domestic water to 30.5 million people would be contaminated with radioactive material. The shorelines of these waterways would be contaminated with long-lived radioactive materials (plutonium, uranium, americium, etc.) that would result in exposures to individuals who came into contact with the sediments, potentially increasing the number of latent cancer fatalities. Each of the 72 commercial and 5 DOE sites throughout the United States would have potentially hundreds of acres of land and underlying groundwater systems contaminated with radioactive materials at concentrations that would be potentially lethal to anyone who settled near the degraded storage facilities. The radioactive materials at the degraded facilities and in the floodplains and sediments would persist for hundreds of thousands of years.

As mentioned above, DOE only estimated potential collective impacts resulting from the consumption of contaminated surface water. However, other pathways (food consumption, contaminated floodplains, etc.) that could contribute to collective dose were evaluated (Toblin 1998b, all; Rollins 1998c, all) to determine their relative importance to the drinking water pathway. These pathways included the following:

- Consumption of vegetables irrigated with contaminated water
- Consumption of meat and milk from animals that drank contaminated water or were fed with contaminated feed
- Consumption of contaminated finfish and shellfish
- Direct exposure to contaminated shoreline sediments
- Exposures resulting from contamination of floodplains during periods of high stream (river) flow

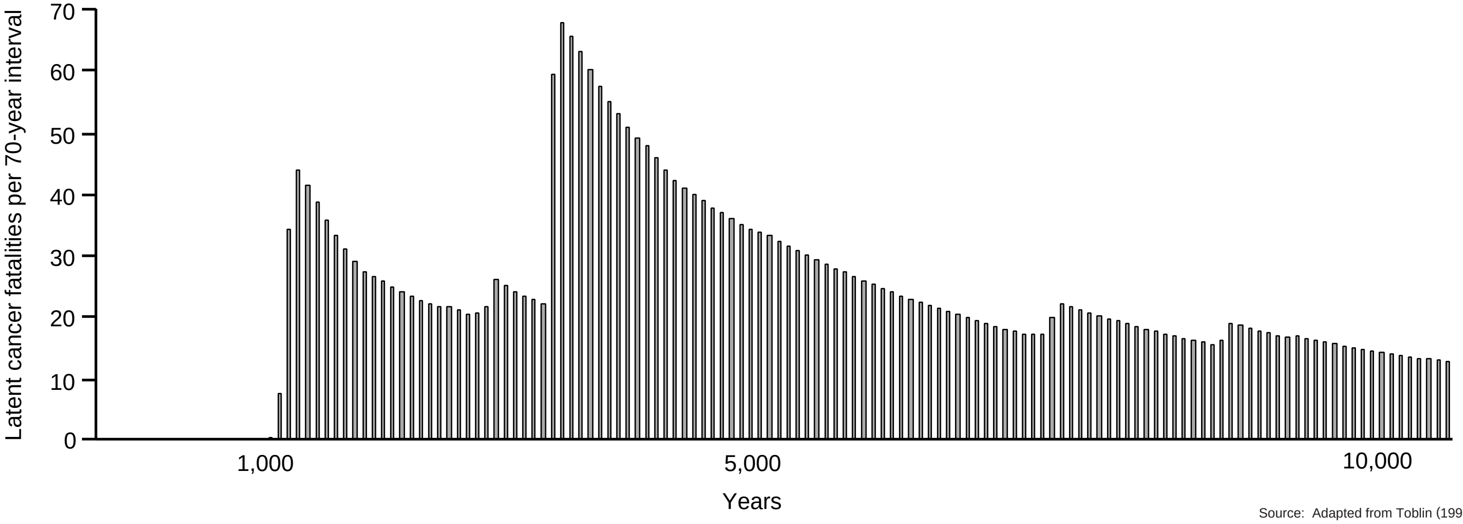
These analyses determined that an individual living in a contaminated floodplain and consuming vegetables irrigated with contaminated surface water could receive a radiation exposure dose three times higher than that from the consumption of contaminated surface water only (Toblin 1998b, page 3). In addition, the analysis determined that impacts to 30 million individuals potentially living in contaminated floodplains would be less than 10 percent of the collective impacts shown in Figure K-9 and, therefore, did not include them in the estimates because DOE did not want to overestimate the impacts from Scenario 2.

DOE evaluated airborne pathways (Mishima 1998, all) and judged that potential impacts from those pathways would be very small in comparison to impacts from liquid pathways because the degraded facility structures would protect the radioactive material from winds. To simplify the analysis, impacts to



Source: Adapted from Toblin (1998a, pages 5, 9, and 10).

Figure K-8. Regional collective dose from the Proposed Action inventory under No-Action Scenario 2.



Source: Adapted from Toblin (1998a, page 9).

Figure K-9. Total potential latent cancer fatalities throughout the United States from the Proposed Action inventory under No-Action Scenario 2.

the public from radiation emanating from the degraded storage facilities were not included. Those impacts were judged to represent a small fraction of the impacts calculated for the liquid pathways (Table K-11).

Estimates of localized impacts (Toblin 1998c, page 1) assumed that individuals (onsite and near-site gardeners) would take up residence near the degraded storage facilities and would consume vegetables from their gardens irrigated with groundwater withdrawn from the contaminated aquifer directly below their locations. In addition, the onsite gardener would be exposed to external radiation emanating from the exposed dry storage canisters; therefore, the onsite gardener would be the maximally exposed individual.

Table K-12 lists the internal estimated dose rates (see Section K.2.4.1 for details) and the times for peak exposure for each of the five regions.

Table K-12. Estimated internal dose rates (rem per year) and year of peak exposure[a] (in parentheses) for the onsite and near-site gardeners – Scenario 2.[b]

	Maximally exposed individual distances (meters)[c] from storage facilities			
Region	10[d]	150	1,000	5,000
1	3,100 (1,800)	670 (2,200)	51 (2,000)	12 (2,600)
2	100 (2,700)	96 (2,000)	12 (2,900)	2 (7,100)
3	3,100 (1,800)	1,800 (2,000)	150 (2,600)	31 (6,000)
4	140 (3,200)	130 (3,900)	14 (4,800)	2 (9,300)
5	3,300 (4,600)	180 (5,300)	59 (5,300)	2 (6,100)

a. Years after facility maintenance ended.
b. Source: Adapted from Toblin (1998c, Table 4, page 5).
c. To convert meters to feet, multiply by 3.2808.
d. The maximally exposed individual would be the onsite gardener.

The regional dose rates listed in Table K-12 would depend on the concentration of contaminants (primarily plutonium) in the underlying aquifer from which water was extracted and used by the gardener for consumption and crop irrigation. These aquifer concentrations, in turn, would be affected by the type and location of stored materials (spent nuclear fuel and high-level radioactive waste) in each region, the rate at which the contaminants were leached from the stored material, the amount of water (precipitation) available for dilution, and the thickness of the aquifer. For example, releases in Region 5 would probably be smaller and would occur later than those in other regions because of the region’s lack of precipitation. This is indeed the case for commercial fuel, which is stored in above-grade concrete storage modules, stainless-steel dry storage canisters, and mostly intact corrosion-resistant zirconium alloy cladding. However, early releases would occur in Region 5 because most DOE spent nuclear fuel is stored in below-grade vaults (see Appendix A, page A-25) that would stop providing rain protection after 50 years (see Section K.2.1.1 for details). In addition, the analysis assumed no credit for the protectiveness of the DOE spent nuclear fuel cladding (see Section K.2.1.4.2 for details), which would result in releases that began early (about 800 years after weather protection was lost) and persist at a nearly constant rate for more that 6,000 years (Toblin 1998c, page 3).

The 10-meter (33-foot) doses listed in Table K-12 would be due to leachate concentrations from the storage area with no groundwater dilution. Downgradient doses decrease more rapidly in Regions 1 and 5 than in other regions because of greater groundwater dilution. The downgradient decrease in Region 5 would also be due to the relatively thick aquifer, which results in greater vertical plume spread and increases plume attenuation (Toblin 1998c, pages 4-6).

As shown in Table K-12, an onsite gardener in Region 5 could receive an internal committed dose as high as 3,300 rem for each year of ingestion of plutonium-239 and -240. However, the individual actually would receive only about 70 rem the first year, 140 rem the second year, 210 rem the third year, and so on until reaching an equilibrium annual dose (in approximately 50 years) of 3,300 rem per year. The individual would continue to receive this equilibrium dose as long as the radioactive material uptake remained constant.

If the annual doses are added, in less than 10 years the individual would have received more than 2,000 rem. If the International Commission on Radiological Protection risk conversion factor were applied to this dose, a probability of fatal cancer induction of 1 could be calculated. In other words, the use of this risk conversion would predict that the individual would contract a fatal cancer after 10 years of exposure. This calculated risk is approximately 4 times greater than the lifetime risk of contracting a fatal cancer from all other causes (24 percent).

Table K-13 shows that the direct radiation dose rate to the onsite gardener could be as high as 7,300 rem per year. Unlike internal dose, this dose would actually be delivered during the year of exposure. This maximum value assumes a complete loss of shielding normally provided by the concrete storage module at the same time as the loss of weather protection (see Table K-1). Assuming a dose of 7,300 rem per year, the individual probably would die from acute radiation exposure. This dose would probably cause extensive cell damage in the individual that would result in severe acute adverse health conditions and death within weeks or months (NRC 1996, page 8.29-5). However, these higher radiation dose rates are based on an early estimated time to structural failure of the concrete storage module. If these failure times were extended by as little as 100 years, the associated dose rates would decrease by a factor of 10 because the levels of radiation emanating from the degraded facilities would have decreased by about a factor of 10 due to radioactive decay (Rollins 1998c, page 12).

Table K-13. Estimated external peak dose rates (rem per year) for the onsite and near-site gardeners – Scenario 2.

		Maximally exposed individual distances (meters)[a] from storage facilities			
Region	Year of peak exposure[b]	10[c]	150	1,000	5,000
1	190	7,200	4	0.001	0.0
2	800	28	0.04	0.0	0.0
3	170	7,300	4	0.001	0.0
4	850	31	0.04	0.0	0.0
5	3,600	32	0.05	0.0	0.0

a. To convert meters to feet, multiply by 3.2808.

b. Years after 2116; source: adapted from Poe (1998a, all).

c. Source: Adapted from Davis (1998, all); the maximally exposed individual would be the onsite gardener.

The internal and external dose rates are presented separately because they would occur at different times and are therefore not additive.

K.3.2 UNUSUAL EVENTS

This section includes a quantitative assessment of potential accident impacts and a qualitative discussion of the impacts of sabotage.

K.3.2.1 Accident Scenarios

The analysis examined the impacts of accident scenarios that could occur during the above-ground storage of spent nuclear fuel and high-level radioactive waste and concluded that the most severe accident scenarios would be an aircraft crash into concrete storage modules or a severe seismic event. In Scenario 1, where storage would be in strong rigid concrete storage modules that had not degraded, the accident would not be expected to release radioactive material.

In Scenario 2, the concrete storage modules would deteriorate with time. DOE concluded that an aircraft crash into degraded concrete storage modules would dominate the consequences. The analysis evaluated the potential for criticality accidents and concluded that an event severe enough to produce meaningful consequences would be extremely unlikely, and that the consequences would be bounded by the aircraft crash consequences. Table K-14 lists the consequences of an aircraft crash on a degraded spent fuel concrete storage module.

Table K-14. Consequences of aircraft crash onto degraded spent nuclear fuel concrete storage module.[a]

Impact	High-population site[b]	Low-population site[c]
Collective population dose (person-rem)	26,000	6,000
Latent cancer fatalities	13	3

a. Source: Davis, Strenge, and Mishima (1998, page 11).
b. 330 persons per square mile.
c. 77 persons per square mile.

K.3.2.2 Sabotage

Storage of spent nuclear fuel and high-level radioactive waste over 10,000 years would entail a continued risk of intruder access at each of the 77 sites. Sabotage could result in a release of radionuclides to the environment around the facility. In addition, intruders could attempt to remove fissile material, which could result in releases of radioactive material to the environment. For Scenario 1, the analysis assumed that safeguards and security measures currently in place would remain in effect during the 10,000-year analysis period at the 77 sites. Therefore, the risk of sabotage would continue to be low. However, the difficulty of maintaining absolute control over 77 sites for 10,000 years would suggest that the cumulative risk of intruder attempts would increase.

For Scenario 2, the analysis assumed that safeguards and security measures would not be maintained at the 77 sites after approximately the first 100 years. For the remaining 9,900 years of the analysis period, the cumulative risk of intruder attempts would increase. Therefore, the risk of sabotage would increase substantially under this scenario.

K.4 Uncertainties

Section K.3 contains estimates of the radiological impacts of the No-Action Alternative, which assumes continued above-ground storage of spent nuclear fuel and high-level radioactive waste at sites across the United States. Associated with the impact estimates are uncertainties typical of predictions of the outcome of complex physical and biological phenomena and of the future state of society and societal institutions over long periods. DOE recognized this fact from the onset of the analysis; however, the predictions will be valuable in the decisionmaking process because they provide insight based on the best information and scientific judgments available.

This analysis considered five aspects of uncertainty:

- Uncertainties about the nature of changes in society and its institutions and values, in the physical environment, and of technology as technology progresses

- Uncertainties associated with future human activities and lifestyles

- Uncertainties associated with the mathematical representation of the physical processes and with the data in the computer models

- Uncertainties associated with the mathematical representation of the biological processes involving the uptake and metabolism of radionuclides and the data in the computer models
- Uncertainties associated with accident scenario analysis

The following sections discuss these uncertainties in the context of possible effects on the impact estimates reported in Chapter 7 and Section K.3.

K.4.1 SOCIETAL VALUES, NATURAL EVENTS, AND IMPROVEMENTS IN TECHNOLOGY

K.4.1.1 Societal Values

History is marked by periods of great social upheaval and anarchy followed by periods of relative political stability and peace. Throughout history, governments have ended abruptly, resulting in social instability, including some level of lawlessness and anarchy. The Scenario 1 assumption is that political stability would exist to the extent necessary to ensure adequate institutional control to monitor and maintain the spent nuclear fuel and high-level radioactive waste to protect the workers and the public for 10,000 years. The Scenario 2 assumption is that in the United States political stability would exist for 100 years into the future and that the spent nuclear fuel and high-level radioactive waste would be properly monitored and maintained and the public would be protected for this length of time. If a political upheaval, such as the one that recently occurred in the former Soviet Union, were to occur in the United States, the government could have difficulty protecting and maintaining the storage facilities, and the degradation processes could begin earlier than postulated in Scenario 2. If institutional control were not maintained for at least 100 years, radioactive materials from the spent nuclear fuel and high-level radioactive waste could enter the environment earlier, which would result in higher estimated impacts due to the higher radiotoxicity of the materials. However, this scenario would probably increase overall impacts by no more than a factor of 2.

K.4.1.2 Changes in Natural Events

Because of the difficulty of predicting impacts of climate change (glaciation, precipitation, global warming), DOE decided to evaluate facility degradation and environmental transport mechanisms based on current climate conditions. For example, glaciation, which many scientists agree will occur again within 10,000 years, probably would cover the northeastern United States with a sheet of ice. The ice would crush all structures including spent nuclear fuel and high-level radioactive waste storage facilities and could either disperse the radioactive materials in the accessible environment or trap the materials in the ice sheet. In addition, large populations would migrate from the northeastern United States to warmer climates, thus changing the population distribution and densities throughout the United States (the coastline could move 100 miles out from its current position due to the reduced water in the oceans). Other scientists predict that global warming could lead to extensive flooding of low-lying coastal areas throughout the world. Such changes would have to be known with some degree of certainty to make accurate estimates of potential impacts associated with the release of spent nuclear fuel and high-level radioactive waste materials to the environment. To simplify the analysis, DOE has chosen not to attempt to quantify the impacts resulting from the almost certain climate changes that will occur during the analysis period.

K.4.1.3 Improvements in Technology

We are living in a time of unparalleled technical advancement. It is possible that cures for many common cancers will be found in the coming decades. In this regard, the National Council on Radiation Protection and Measurements (NCRP 1995, page 51) states that:

> *One of the most important factors likely to affect the significance of radiation dose in the centuries and millennia to come is the effect of progress in medical technology. At some future time, it is possible that a greater proportion of somatic [cancer] diseases caused by radiation will be treated successfully. If, in fact, an increased proportion of the adverse health effects of radiation prove to be either preventable or curable by advances in medical science, the estimates of long-term detriments may need to be revised as the consequences (risks) of doses to future populations could be very different.*

Effective cures for cancer would affect the fundamental premise on which the No-Action Alternative impact analysis is based. However, this technology change was not included in the impact analyses.

Other advancements in technology could include advancements in water purification that could reduce the concentration of contaminants in drinking water supplies. Improved corrosion-resistant materials could reduce package degradation rates, which could reduce the release of contaminants and the resultant impacts. In addition, future technology could enable the detoxification of the spent nuclear fuel and high-level radioactive waste materials, thereby removing the risks associated with human exposure.

K.4.2 CHANGES IN HUMAN BEHAVIOR

General guidance for the prediction of the evolution of society has been provided by the National Research Council in *Technical Bases for Yucca Mountain Standards* (National Research Council 1995, pages 28 and 70), in which the Committee on Technical Bases for Yucca Mountain Standards concluded that there is no scientific basis for predicting future human behavior. The study recommends policy decisions that specify the use of default (or reference) scenarios to incorporate future human behaviors into compliance assessment calculations. This No-Action Alternative analysis followed this approach, based on societal conditions as they exist today. In doing so, the analysis assumed that populations would remain at their present locations and that population densities would remain at the current levels. This assumption is appropriate when estimating impacts for comparison with other proposed actions; however, it does not reflect reality. Populations are constantly moving and changing in size. If, for example, populations were to move closer to and increase in size in areas near the storage facilities, the radiation dose and resultant adverse impacts could increase substantially. However, DOE has no way to predict such changes accurately and, therefore, did not attempt to quantify the resultant effects on overall impacts.

Another lifestyle change that could affect the overall impacts would involve food consumption patterns. For example, people might curtail their use of public water supplies derived from rivers if they learned that the river water carried carcinogens. Widespread adoption of such practices could reduce the impacts associated with the drinking water pathway.

K.4.3 MATHEMATICAL REPRESENTATIONS OF PHYSICAL PROCESSES AND OF THE DATA INPUT

The DOE approach for the No-Action Alternative was to be as comparable as possible to the approach used for the predictions of impacts from the proposed Yucca Mountain Repository to enable direct comparisons of the impact estimates for the two cases. Therefore, the analysis either used the process models developed for the Total System Performance Assessment directly or adapted them for the

No-Action Alternative impact calculations. For processes that were different from those treated in the Total System Performance Assessment, DOE developed analytical approaches.

In a general sense, the Total System Performance Assessment calculations used a stochastic (random) approach to develop radiological impact estimates. Existing process models were used to generate a set of responses for a particular process. In the Total System Performance Assessment process, the impact calculations sample each set of process responses and calculate a particular impact result. A large number of calculations were performed. From the set of variable results, an expected value can be identified, as can a distribution of results that is an indication of the uncertainties in the calculated expected values.

For the No-Action Alternative analysis, the calculations were based on only a single set of best estimate parameters. No statistical distribution of results was generated as a basis for the quantification of uncertainties. This section describes the uncertainties associated with the input data and modeling used to evaluate the rates of degradation of the materials considered in this document and to estimate the impacts of the resulting releases. It describes the key assumptions, shows where the assumptions are consistent with Total System Performance Assessment assumptions, and qualitatively assesses the magnitude of the uncertainties caused by the assumptions.

Calculating the radiological impacts to human receptors required a mathematical representation of physical processes (for example, water movement) and data input (for example, material porosity). There are uncertainties in both the mathematical representations and in the values of data. The Total System Performance Assessment accommodates these uncertainties by using a probabilistic approach to incorporate the uncertainties, whereas the No-Action analysis uses a deterministic approach in combination with an uncertainty analysis. When done correctly, both approaches yield the same information, although, as in the case of the Total System Performance Assessment, the probabilistic approach provides quantitative information.

K.4.3.1 Waste Package and Material Degradation

The major approaches and assumptions used for the No-Action Scenario 2 analysis are listed in Table K-15. The table indicates where the continued storage calculations followed the basic methods developed for the Total System Performance Assessment. It also indicates the processes for which models other than those used in the Total System Performance Assessment were applied.

DOE analyzed surface storage of commercial spent nuclear fuel in horizontal stainless-steel canisters inside concrete storage modules. There are other probable forms of storage, including horizontal and vertical casks made of materials ranging from stainless steel to carbon steel. Degradation and releases from vertical carbon-steel casks were evaluated qualitatively. Such storage units would be likely to fail from corrosion earlier than concrete and stainless steel. The concrete and stainless-steel units were calculated to fail and begin releasing their contents at about 1,000 years after the assumed loss of institutional control. The less-resistant carbon-steel units could begin releasing their contents earlier and their use would result in a longer period of release and increased impacts. This difference is likely to be an increase of 10 to 30 percent in population dose commitment and resultant latent cancer fatalities.

K.4.3.2 Consequences of Radionuclide Release

The dose-to-risk conversion factors typically used to estimate adverse human health impacts resulting from radiation exposures contain considerable uncertainty. The risk conversion factor of 0.0005 latent cancer fatality per person-rem of collective dose for the general public typically used in DOE National Environmental Policy Act documents is based on recommendations of the International Commission on Radiological Protection (ICRP 1991, page 22) and the National Council on Radiation Protection and Measurements (NCRP 1993a, page 112). The factor is based on health effects observed in the high dose

Table K-15. Review of approaches, assumptions, and related uncertainties[a] (page 1 of 2).

Approach or assumption	Consistent with repository analysis assumptions	Sensitivity of impacts to approach or assumption[b]
Period of analysis – 10,000 years	Yes	None
Commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste quantities equivalent to NWPA specified 70,000 MTHM and Module 1	Yes	None
No credit for stainless-steel cladding on commercial spent nuclear fuel	Yes	If credit were taken for stainless-steel cladding, LCFs[a] could decrease by as much as a factor of 10.
0.1 percent of zirconium alloy cladding is initially failed	Yes	If energetic events (that is, concrete collapse) had been considered in the No-Action analysis, impacts could have been slightly smaller (additional protection from winds) to a factor of 100 higher.
Concrete storage module weather protection	This is a primary protective barrier for the No-Action analysis and is not applicable to TSPA	If weather protection from the concrete storage module had not been assumed in the No-Action analysis, LCFs could be higher by less than a factor of 10.
Concrete base pad degradation	Not applicable	Used NRC recommended values (probably overestimated degradation and reduced consequences in the No-Action analysis); increase in LCFs by several factors but less than a factor of 10
Credit for stainless-steel canister on high-level radioactive waste	No; TSPA does not take credit for stainless-steel container	If the No-Action analysis had not taken credit for the stainless-steel canister, LCFs would change very little (slight increase) because of the intrinsic stability of the borosilicate glass.
DOE spent nuclear fuel evaluated by a representative surrogate that is based mostly on DOE N-Reactor spent nuclear fuel (other spent nuclear fuel types not evaluated)	Yes	If actual fuel types were evaluated, LCFs could either increase or decrease by less than a factor of 2.
No credit given for zirconium alloy cladding on N-Reactor spent nuclear fuel	Yes	If credit was given for the N-Reactor zirconium alloy cladding, the LCFs would decrease by less than a factor of 2.
Stainless steel deterioration	Model paralleled TSPA approach for Alloy-22	Model based on best information; if incorrect and corrosion proceeds more rapidly and stainless steel offers no protection, LCFs could increase by as much as a factor of 100
Zirconium alloy cladding deterioration	Yes, very slow corrosion rate.	If the No-Action analysis had assumed larger or smaller deterioration rates, LCFs could have increased by several orders of magnitude or decreased by less than a factor of 2.
Zirconium alloy cladding credit	Yes	If the No-Action analysis had not taken credit for zirconium alloy cladding, LCFs could have increased by as much as 2 orders of magnitude.
Deterioration of spent nuclear fuel and high-level radioactive waste core materials	Yes	None

Table K-15. Review of approaches, assumptions, and related uncertainties[a] (page 2 of 2).

Approach or assumption	Consistent with repository analysis assumptions	Sensitivity of impacts to approach or assumption[b]
Use of recent regional climate conditions to determine deterioration (temperature, precipitation, etc.)	No; No-Action analysis used constant "effective" regional weather parameters weighted for material inventories and potentially affected downstream populations; TSPA used actual weather patterns measured at Yucca Mountain. The TSPA also assumed long-term climate changes would occur in the form of increased precipitation.	If actual site climate data and projected future potential climate changes had been considered in the No-Action analysis, LCFs could have increased or decreased by as much as a factor of 10. Climate change assumptions such as a glacier covering most of the northeastern seaboard of the United States would have made estimating impacts from continued storage virtually impossible.
Surface transport by precipitation	Not applicable; TSPA only considered groundwater transport because there is no surface-water transport pathway possible for the repository.	If the No-Action analysis had not considered the groundwater transport pathway, LCFs could have been as much as a factor of 10 higher.
Regional binning of sites – not specific site parameters	Not applicable; TSPA considered only a single site; the No-Action analysis evaluated potential impacts from 77 sites on a regional basis.	None, the No-Action analysis binned sites into categories and developed "effective" regional climate conditions such that calculated impacts would be comparable to those which could be calculated by a site-specific analysis.
Atmospheric dose consequences judged to be small when compared to liquid pathways.	Yes	Small impact on LCFs.
Drinking water doses	Yes; primary pathway evaluated	Use of drinking-water-only pathway underestimates total collective LCFs by less than a factor of 3.
Used the Multimedia Environmental Pollutant Assessment System[c] (Buck et al. 1995, all (Leigh et al. 1993, all) modeling approach for calculating population uptake/ingestion	No; TSPA uses GENII-S.[d] GENII-S uses local survey data; the Multimedia Environmental Pollutant Assessment System uses EPA/NRC exposure/uptake default and actual population data	No impact. The two programs yield comparable results as used in these analyses.
ICRP[e] approach to calculate dose commitment from ingested radionuclides	Yes	No impact.
Human health impacts calculated as LCFs with NCRP[f] conversion factors	NA; TSPA does not estimate LCFs.	Use of other than the linear no-threshold model could result in a change in estimated LCFs from 0.25 to 2 times the nominal value.[g]

a. Abbreviations: NWPA = Nuclear Waste Policy Act; MTHM = metric tons of heavy metal; LCF = latent cancer fatality; TSPA = Total System Performance Assessment; NRC = Nuclear Regulatory Commission; ICRP = International Commission on Radiological Protection; EPA = Environmental Protection Agency.

b. Sensitivity of impacts to approach/assumption is based on professional judgement and, if applicable, the effects of the approaches/assumptions on calculations.

c. Buck et al. (1995, all).

d. Leigh et al. (1993, al).

e. ICRP (1979, all).

f. NCRP (1993a, page 112).

g. NCRP (1997, page 75).

and high dose rate region (20 to 50 rem per year). Health effects were extrapolated to the low-dose region (less than 10 rem per year) using the linear no-threshold model. This model is generally recommended by the International Commission on Radiological Protection and the National Council of Radiation Protection and Measurements, and most radiation protection professionals believe this model produces a conservative estimate (that is, an overestimate) of health effects in the low-dose region, which is the exposure region associated with continued storage of spent nuclear fuel and high-level radioactive waste. This report summarizes estimates of the impacts associated with very small chronic population doses to enable comparison of alternatives in this EIS. These impact estimates should be viewed as conservatively high; in fact, the uncertainties are such that the actual level of impact could be zero.

According to the National Council on Radiation Protection and Measurements, the results of an analysis of the uncertainties in the risk coefficients “show a range (90 percent confidence intervals) of uncertainty values for the lifetime risk for both a population of all ages and an adult worker population from about a factor of 2.5 to 3 below and above the 50th percentile value” (NCRP 1997, page 74).

The National Council on Radiation Protection and Measurements states, “This work indicates that given the sources of uncertainties considered here, together with an allowance for unspecified uncertainties, the values of the lifetime risk can range from about one-fourth or so to about twice the nominal values” (NCRP 1997, page 75).

Because of the large uncertainties that exist in the dose/effect relationship, the Health Physics Society has recommended “…against quantitative estimation of health risks due to radiation exposure below a lifetime dose of 10 rem …” (HPS 1996, page 1). In essence, the Society has recommended against the quantification of risks due to individual radiation exposures comparable to those estimated in the No-Action analysis. These uncertainties are due, in part, to the fact that epidemiological studies have been unable to demonstrate that adverse health effects have occurred in individuals exposed to small doses (less than 10 rem per year) over a period of many years (chronic exposures) and to the fact that the extent to which cellular repair mechanisms reduce the likelihood of cancers is unknown.

Other areas of uncertainty in estimation of dose and risk include the following:

- *Uncertainties Related to Plant and Human Uptake of Radionuclides.* There are large uncertainties related to the uptake (absorption) of radionuclides by agricultural plants, particularly in the case where “regionalized,” versus “site-specific” data are used. Also of importance are variations in the absorption of specific radionuclides through the human gastrointestinal tract. Factors that influence the absorption of radionuclides include their chemical or physical form, their concentrations, and the presence of stable elements having similar chemical properties. In the case of agricultural crops, many of these factors are site-specific.

- *Uncertainties in Dose and Risk Conversion Factors.* The magnitudes and sources of the uncertainties in the various input parameters for the analytical models need to be recognized. In addition to the factors cited above, these include those required for converting absorbed doses into equivalent doses, for calculating committed doses, and for converting organ doses into effective (whole body) doses. Although these various factors are commonly assigned point values for purposes of dose and risk estimates, each of these factors has associated uncertainties.

- *Conservatisms in Various Models and Parameters.* In addition to recognizing uncertainties, one must take into account the magnitudes and sources of the conservatisms in the parameters and models being used. These include the fact that the values of the tissue weighting factors and the methods for calculating committed and collective doses are based on the assumption of a linear no-threshold relationship between dose and effect. As the International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements have stated, the use of the linear no-threshold hypothesis provides an upper bound on the associated risk (ICRP 1966, page 56). Also to be considered is that the concept of committed dose could overestimate the actual dose by a factor of 2 or more (NCRP 1993b, page 25).

K.4.3.3 Accidents and Their Uncertainty

The accident methodology used in this analysis is described in Section K.2.5 for Scenarios 1 and 2. It states that for Scenario 1 an aircraft crash into the storage array would provide the most severe accident scenario and its consequences would not cause a release from the rugged concrete storage module. The analysis placed considerable weight on the quality and strength of the concrete storage module and dry storage canister. For an analysis extending 10,000 years, more severe natural events can be postulated than those used as the design basis for the dry storage canister, and they could cause failure of the canister. This could exceed the consequences estimated for Scenario 1, but it would be unlikely to exceed the consequences for the aircraft accident scenario evaluated for Scenario 2.

Section K.2.5.1 concludes that the aircraft crash on the degraded concrete storage modules would be the largest credible event that could occur. The best estimate impacts from this event ranged from 3 latent cancer fatalities for a low-population site to 13 for a high-population site. The uncertainties in these estimates are very large. As discussed above, the aircraft crash could cause a minimum of no latent cancer fatalities given the uncertainty in the model that converts doses to cancers. The maximum impact could be 50 times greater than the estimated values if an aircraft crash involving the largest commercial jet occurred at the time of initial concrete storage module degradation at a northern site under adverse weather conditions (conditions that would maximize the offsite doses) involving spent fuel with the maximum expected inventory of radionuclides.

K.4.4 UNCERTAINTY SUMMARY

The sections above discuss qualitatively and semiquantitatively the uncertainties associated with impact estimates resulting from the long-term storage of spent nuclear fuel and high-level radioactive waste at multiple sites across the United States. As stated above, DOE has not attempted to quantify the variability of estimated impacts related to possible changes in climate, societal values, technology, or future lifestyles. Although uncertainties with these changes could undoubtedly affect the total consequences reported in Section K.3 by several orders of magnitude, DOE did not attempt to quantify these uncertainties to simplify the analysis.

DOE attempted to quantify a range of uncertainties associated with mathematical models and input data, and estimated the potential effect these uncertainties could have on collective human health impacts. By summing the uncertainties discussed in Sections K.4.1, K.4.2, and K.4.3 where appropriate, DOE estimates that total collective impacts over 10,000 years could have been underestimated by as much as 3 or 4 orders of magnitude. However, because there are large uncertainties in the models used for quantifying the relationship between low doses (that is, less than 10 rem) and the accompanying health impacts, especially under conditions in which the majority of the populations would be exposed at a very low dose rate, the actual collective impact could be zero.

On the other hand, impacts to individuals (human intruders) who could move to the storage sites and live close to the degraded facilities could be severe. During the early period (200 to 400 years after the assumed loss of institutional control), acute exposures to external radiation from the spent nuclear fuel and high-level radioactive waste material could result in prompt fatalities. In addition, after a few thousand years onsite shallow aquifers could be contaminated to such a degree that consumption of water from these aquifers could result in severe adverse health effects, including premature death. Uncertainties related to these localized impacts are related primarily to the inability to predict accurately how many individuals could be affected at each of the 77 sites over the 10,000-year analysis period. In addition, the uncertainties associated with localized impacts would exist for potential consequences resulting from unusual events, both manmade and natural.

Therefore, as listed in Table K-15, uncertainties resulting from future changes in natural phenomena and human behavior that cannot be predicted, process model uncertainties, and dose-effect relationships, taken together, could produce the results presented in Section K.3, overestimating or underestimating the impacts by as much as several orders of magnitude. Uncertainties of this magnitude are typical of predictions of the outcome of complex physical and biological phenomena over long periods. However, these predictions (with their uncertainties) are valuable to the decisionmaking process because they provide insight based on the best information available.

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Appendix L

Floodplain/Wetlands Assessment for the Proposed Yucca Mountain Geologic Repository

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APPENDIX L. FLOODPLAIN/WETLANDS ASSESSMENT FOR THE PROPOSED YUCCA MOUNTAIN GEOLOGIC REPOSITORY

L.1 Introduction

Pursuant to Executive Order 11988, *Floodplain Management*, each Federal agency is required, when conducting activities in a floodplain, to take actions to reduce the risk of flood damage; minimize the impact of floods on human safety, health, and welfare; and restore and preserve the natural and beneficial values served by floodplains. Pursuant to Executive Order 11990, *Protection of Wetlands,* each Federal agency is to avoid, to the extent practicable, the destruction or modification of wetlands, and to avoid direct or indirect support of new construction in wetlands if a practicable alternative exists. Regulations issued by the U.S. Department of Energy (DOE) that implement these Executive Orders are contained in Title 10 of the Code of Federal Regulations (CFR) Part 1022, *Compliance with Floodplain/Wetlands Environmental Review Requirements*.

In 1982, Congress enacted the *Nuclear Waste Policy Act* in recognition of the national problem created by the accumulation of spent nuclear fuel and high-level radioactive waste at many commercial and DOE sites throughout the country. The Act recognized the Federal government's responsibility to permanently dispose of the Nation's spent nuclear fuel and high-level radioactive waste. By 1986, DOE narrowed the number of potentially acceptable geologic repository sites to three. Then in 1987, Congress amended the Act by redirecting DOE to determine the suitability of only Yucca Mountain in southern Nevada.

If, after a possible recommendation by the Secretary of Energy, the President considers the site qualified for an application to the U.S. Nuclear Regulatory Commission for a construction authorization, the President will submit a recommendation of the site to Congress. If the site designation becomes effective, the Secretary of Energy will submit to the Nuclear Regulatory Commission a License Application for a construction authorization. DOE could then select a rail corridor or a site for an intermodal transfer station, along with its associated route for heavy-haul trucks, among those considered for Nevada in the EIS. Following such a decision, additional field surveys, environmental and engineering analyses, and National Environmental Policy Act reviews would likely be needed regarding a specific rail alignment for the selected corridor or the site for the intermodal transfer station and its associated route. When more specific information becomes available about activities proposed to take place within floodplains and wetlands, DOE will conduct further environmental review in accordance with 10 CFR 1022.

In 1989, DOE published a Notice of Floodplain/Wetlands Involvement (54 *FR* 6318, February 9, 1989) for site characterization studies at Yucca Mountain. These studies are designed to determine the suitability of Yucca Mountain to isolate nuclear waste. A floodplain assessment was prepared (DOE 1991, all) and a Statement of Findings was issued by DOE (56 *FR* 49765, October 1, 1991). In 1992, DOE prepared a second floodplain assessment on locating part of the entry point to the subsurface Exploratory Studies Facility in the 100-year floodplain of a wash at Yucca Mountain (DOE 1992, all). The Statement of Findings for this assessment was published in the Federal Register (57 *FR* 48363, October 23, 1992). Both Statements of Findings concluded that the benefits of locating activities and structures in the floodplains outweigh the potential adverse impacts to the floodplains and that alternatives to these actions were not reasonable.

The Nuclear Waste Policy Act, as amended, requires that a recommendation by the Secretary to the President to construct a repository must be accompanied by a Final EIS. As part of the EIS process, and following the requirements of 10 CFR Part 1022, DOE issued a *Notice of Floodplain and Wetlands Involvement* in the *Federal Register* (64 *FR* 31554, June 11, 1999). The Notice requested comments from the public regarding potential impacts on floodplains and wetlands associated with construction of a potential rail line or a potential intermodal transfer station with its associated route for heavy-haul trucks to and in the vicinity of Yucca Mountain, depending on the rail or intermodal alternative selected (Figure L-1). As of July 2,1999, DOE had received no comments from the public. This floodplain/wetlands assessment has been prepared in conjunction with the *Notice of Floodplain and Wetlands Involvement*, and in accordance with 10 CFR Part 1022.

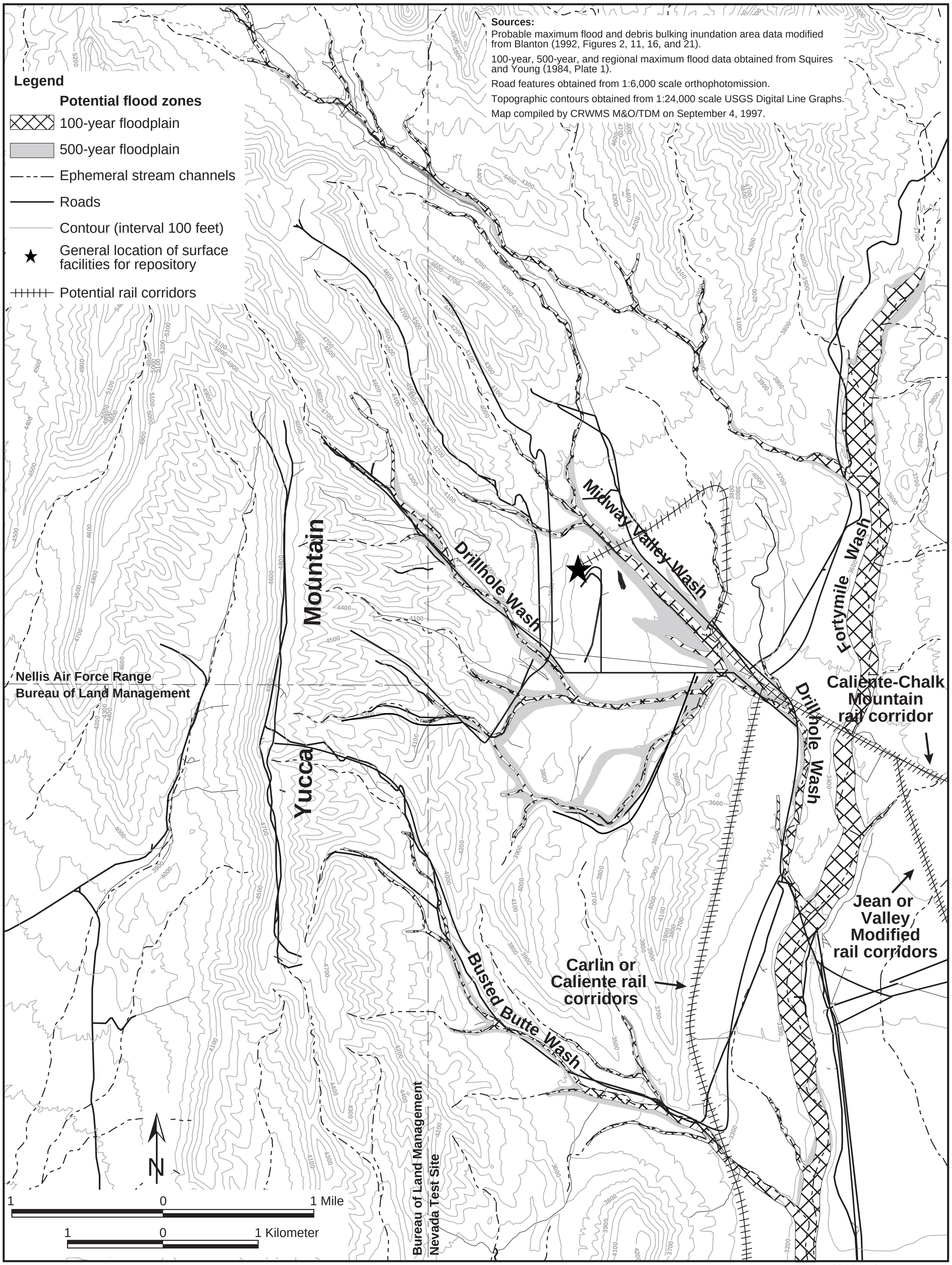
This assessment examines the effects of proposed repository construction and operation and potential construction of a rail line or intermodal transfer station on:

1. Floodplains near the Yucca Mountain site (Fortymile Wash, Busted Butte Wash, Drillhole Wash, and Midway Valley Wash; there are no delineated wetlands near the Yucca Mountain site), and

2. Floodplains and areas that may have wetlands (for example, springs and riparian areas) along potential rail corridors in Nevada and at intermodal transfer station locations associated with routes for heavy-haul trucks. If DOE selects rail as the mode of spent nuclear fuel and high-level radioactive waste transport in Nevada to the Yucca Mountain site, one of five rail corridors would be selected (Figure L-2). If DOE selects heavy-haul as the mode of transport for spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site, one of five corridors and one of three intermodal transfer station locations would be selected (Figure L-3). A more detailed floodplain/wetlands assessment of the selected rail corridor or route for heavy-haul trucks would then be prepared. This assessment compares what is known about the floodplains, springs, and riparian areas along the five possible rail corridors and at the three intermodal transfer station locations. This assessment does not evaluate potential floodplain or wetlands effects along routes because these existing roads should already be designed to meet 100-year floodplain design specifications. If upgrades to existing roads are deemed necessary, a more detailed floodplain/wetlands assessment would be prepared at that time.

Title 10 CFR Part 1022.4 defines a flood or flooding as "…*a temporary condition of partial or complete inundation of normally dry land areas from....the unusual and rapid accumulation of runoff of surface waters...*" Title 10 CFR Part 1022.4 identifies floodplains that must be considered in a floodplain assessment as the *base floodplain* and the *critical-action floodplain*. The base floodplain is the area inundated by a flood having a 1.0 percent chance of occurrence in any given year (referred to as the 100-year floodplain). The critical-action floodplain is the area inundated by a flood having a 0.2 percent chance of occurrence in any given year (referred to as the 500-year floodplain). C*ritical action* is defined as any activity for which even a slight chance of flooding would be too great. Such actions could include the storage of highly volatile, toxic, or water-reactive materials. The critical-action floodplain was considered because petroleum, oil, lubricants, and other hazardous materials could be used during the construction of a rail line or road upgrades and because spent nuclear fuel and high-level radioactive waste would be transported across the washes.

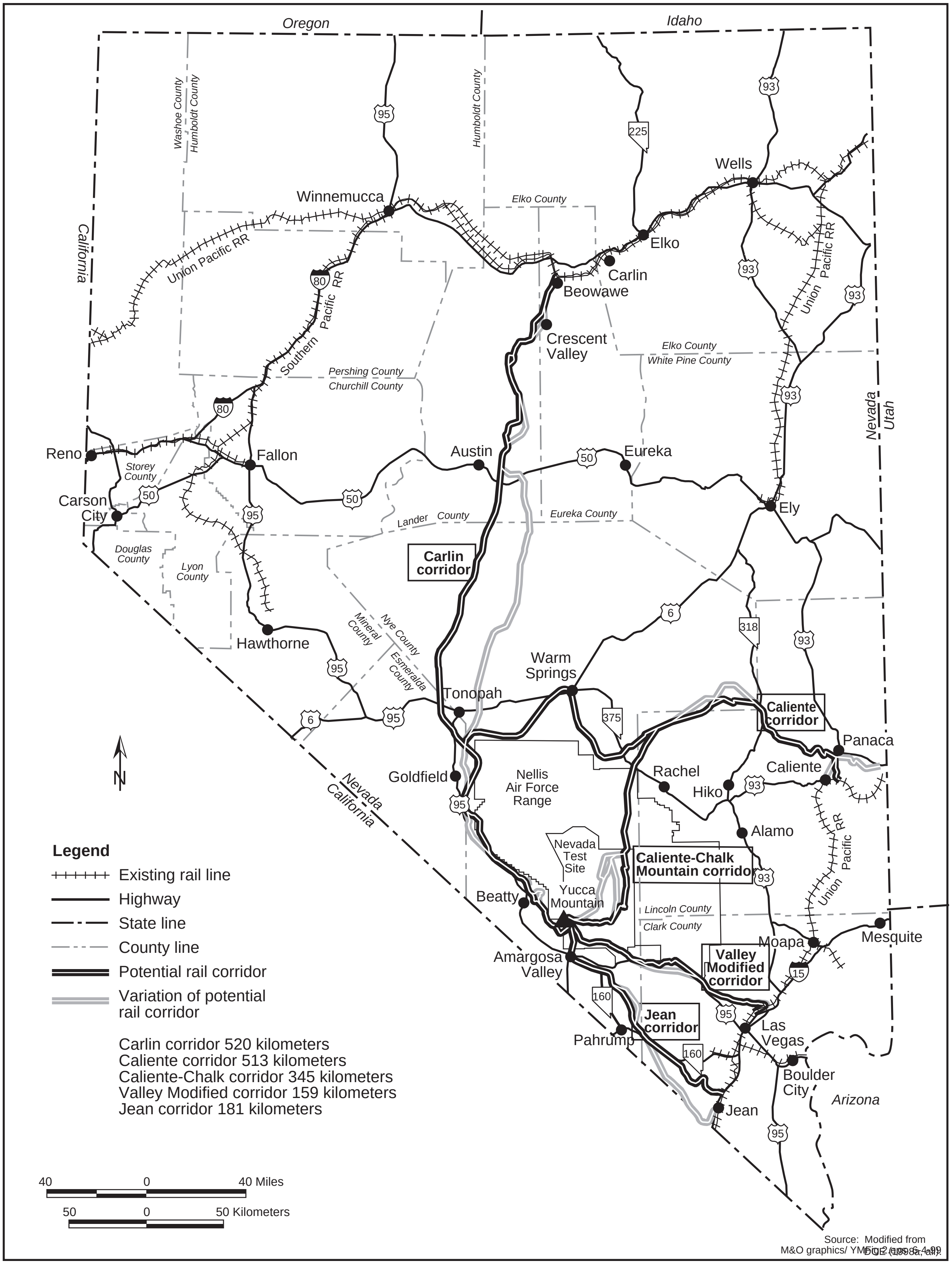
Title 10 CFR Part 1022.11 requires DOE to use Flood Insurance Rate Maps or Flood Hazard Boundary Maps to determine if a proposed action would be located in the base or critical-action floodplain. On Federal or state lands where Flood Insurance Rate Maps or Flood Hazard Boundary Maps are not available, DOE is required to seek flood information from the appropriate land-management agency or from agencies with expertise in floodplain analysis. The U.S. Geological Survey was therefore asked by DOE to complete a flood study of Fortymile Wash and its principal tributaries (which include Busted Butte, Drillhole, and Midway Valley washes) and outline areas of inundation from 100-year and 500-year floods (Squires and Young 1984, Plate 1).



Sources:
Probable maximum flood and debris bulking inundation area data modified from Blanton (1992, Figures 2, 11, 16, and 21).
100-year, 500-year, and regional maximum flood data obtained from Squires and Young (1984, Plate 1).
Road features obtained from 1:6,000 scale orthophotomission.
Topographic contours obtained from 1:24,000 scale USGS Digital Line Graphs.
Map compiled by CRWMS M&O/TDM on September 4, 1997.

M&O graphics/YMFig 1.eps 6-8-99

Figure L-1. Yucca Mountain site topography, floodplains, and potentialrail corridors.



Source: Modified from DOE (1998a, all).

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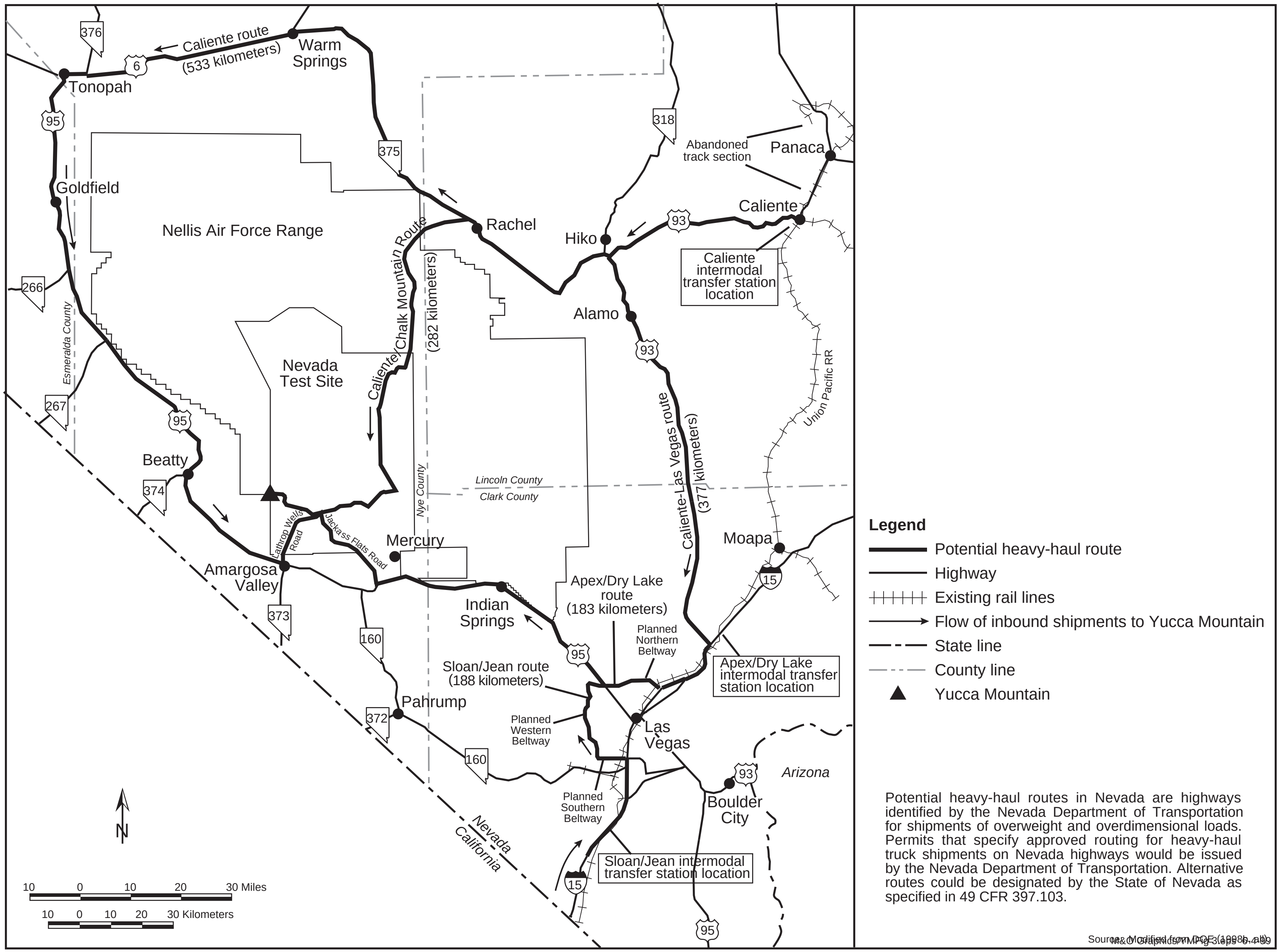
Figure L-2. Potential Nevada rail corridors to Yucca Mountain.



Potential heavy-haul routes in Nevada are highways identified by the Nevada Department of Transportation for shipments of overweight and overdimensional loads. Permits that specify approved routing for heavy-haul truck shipments on Nevada highways would be issued by the Nevada Department of Transportation. Alternative routes could be designated by the State of Nevada as specified in 49 CFR 397.103.

Source: Modified from DOE (1998b, all)

M&O Graphics/TM/Fig 3.eps 6-4-99

Figure L-3. Potential routes in Nevada for heavy-haul trucks.

Title 10 CFR Part 1022 also requires DOE to determine whether wetlands would be affected by the proposed action and, if necessary, to conduct a wetlands assessment. As required by 10 CFR Part 1022.11(c), DOE examined the following information with regard to possible wetlands in the vicinity of the Yucca Mountain site:

- *U.S. Fish and Wildlife Service National Wetlands Inventory.* Maps from the National Wetlands Inventory do not identify any naturally occurring wetlands in the vicinity of the Yucca Mountain site (FWS 1995, all).

- *U.S. Department of Agriculture, Soil Conservation Service Local Identification Maps.* The Soils Conservation Service (now called Natural Resource Conservation Service) has not conducted a soil survey of the Yucca Mountain site. However, DOE and other agencies have conducted comprehensive surveys and studies of soils at the Yucca Mountain site and in the surrounding area. These surveys are summarized in TRW (1999a, pages 2 to 6). The surveys indicate that there are no naturally-occurring hydric soils at Yucca Mountain.

- *U.S. Geological Survey Topographic Maps.* Topographic maps of the vicinity (for example, USGS 1983, all) do not show springs, permanent streams, or other indications of wetlands.

- *State Wetlands Inventories.* There are no State of Nevada wetlands inventories in the vicinity of Yucca Mountain.

- *Regional or Local Government-Sponsored Wetlands or Land-Use Inventories.* DOE has conducted a wetlands inventory of the Nevada Test Site (Hansen et al. 1997, page 1-161). The closest naturally occurring wetlands to Yucca Mountain is on the upper west slope of Fortymile Canyon, 6 kilometers (3.7 miles) north of the North Portal, outside of the proposed repository construction area. In addition, riparian vegetation occurs adjacent to four man-made well ponds east of Yucca Mountain (TRW 1999b, page 2-14), but these are outside of areas where construction or other proposed actions would occur.

Based on this information, DOE concluded that a wetlands assessment is not required to comply with 10 CFR Part 1022.

L.2 Project Description

If Yucca Mountain is selected as a site to construct a repository, DOE would ship spent nuclear fuel and high-level radioactive waste to the site for a period of about 24 years. Under the current schedule spent nuclear fuel and high-level radioactive waste emplacement would begin in 2010. One of five possible rail corridors leading to the site could be selected in Nevada (Figure L-2). In the vicinity of the Yucca Mountain site the five rail corridors converge to two possible routes. Alternatively, if heavy-haul transport were selected, one intermodal transfer station and one associated route would be identified from the three potential intermodal transfer station locations and five potential routes for heavy-haul trucks (Figure L-3). In the vicinity of the Yucca Mountain site, the potential routes converge to two possible routes that may require upgrades. At greater distances, routes would utilize public roads and existing Nevada Test Site roads to the extent possible.

Some transportation-related actions associated with the DOE proposal would occur in floodplains on the proposed repository site on land the Federal government would manage. Route construction and operation could affect the 100-year and 500-year floodplains of Fortymile Wash, Busted Butte Wash, Drillhole Wash, and Midway Valley Wash in the vicinity of the Yucca Mountain site. This assessment examines the potential floodplain impacts to all four washes although all four might not be affected. The effects on floodplains and areas that may contain wetlands elsewhere in Nevada along the five rail corridors and at the three intermodal station locations associated with heavy-haul transport are examined using available information. When DOE makes a decision whether to use rail or heavy-haul transport, more information would be obtained to support further environmental review.

This section is divided into two parts. Section L.2.1 discusses the proposed action in the vicinity of the Yucca Mountain site including rail access; heavy-haul truck access; and potential construction of an associated rail line, bridge, and roads. Section L.2.2 discusses possible actions elsewhere in Nevada including rail access and intermodal transfer station locations.

L.2.1 PROPOSED ACTIONS AT YUCCA MOUNTAIN

The preliminary layout of surface facilities at the repository is shown on Figure L-1. Except for a possible rail line and roads, no facilities are generally anticipated to be located within either the 100-year or 500-year floodplains of Fortymile Wash, Busted Butte Wash, Drillhole Wash, or Midway Valley Wash. The paragraphs below describe the rail line and roads that could affect the floodplains of these washes in the vicinity of the Yucca Mountain site.

L.2.1.1 Rail Access

At this time, there is no rail access to the Yucca Mountain site. DOE has identified five potential rail corridors in Nevada for transporting spent nuclear fuel and high-level radioactive waste to Yucca Mountain.

If DOE selected a rail corridor leading to the Yucca Mountain site from the west and south (either the Carlin or Caliente corridors), the rail line could cross Busted Butte Wash, Drillhole Wash just west of its confluence with Fortymile Wash, and Midway Valley Wash (Figure L-1). Cut, fill, drainage culverts or bridges could be used to cross Busted Butte, Drillhole, and Midway Valley washes. The widths of Busted Butte Wash and Drillhole Wash (including their floodplains) are about 150 meters (500 feet) each where they would be crossed by the rail line. The width of Midway Valley Wash (including its floodplain) is about 300 meters (1,000 feet) where it could be crossed by the rail line.

If DOE selected a rail corridor leading to the Yucca Mountain site from the east (Caliente-Chalk Mountain, Jean, or Valley-Modified corridors) the rail line could cross approximately 400 meters (1,300 feet) of Fortymile Wash and its associated floodplains. In this case, the rail line could cross the wash on either a bridge (with supports located in the wash) or on a raised rail line that could be constructed in the wash (with appropriately-sized drainage culverts). After crossing Fortymile Wash, the rail line could continue along the east side of Yucca Mountain and cross about 300 meters (1,000 feet) of Midway Valley Wash before arriving at the repository.

L.2.1.2 Heavy-Haul Truck Access

DOE has identified five potential routes for heavy-haul trucks in Nevada for transporting spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site.

If DOE selected a route leading to the Yucca Mountain site from the west and south, the route could cross Busted Butte Wash, Drillhole Wash, and Midway Valley Wash (Figure L-1). Cut, fill, drainage culverts or bridges could be used to cross Busted Butte, Drillhole, and Midway Valley washes.

If DOE selected a route leading to the Yucca Mountain site from the east, the route could cross Fortymile Wash. The route could either cross through the wash or a bridge could be constructed over it. After crossing Fortymile Wash, the route could continue along the east side of Yucca Mountain and could cross Midway Valley Wash before arriving at the repository.

During potential repository operation, some spent nuclear fuel and high-level radioactive waste would be transported to the Yucca Mountain site by legal-weight trucks. These trucks could access Yucca Mountain from the east by crossing Fortymile Wash along the existing road or access Yucca Mountain along the route used by heavy-haul trucks. The legal-weight trucks could then proceed along the east side of Yucca Mountain and cross Midway Valley Wash along the route.

L.2.1.3 Construction

Construction of a potential rail line near Yucca Mountain as well as upgrading the existing roads for heavy-haul and legal-weight trucks in the vicinity would take about one year to complete. Standard construction practices would be used, including the use of explosives and heavy earth-moving equipment. Standard measures would also be used to minimize erosion. Petroleum fuels, oils, lubricants and other hazardous materials would be used during construction, although these materials would be stored outside the 500-year floodplain.

Construction aggregate could be obtained from local borrow pits, but rail-bed ballast would need to be obtained from outside sources. Concrete would be obtained from a nearby concrete batch plant or from a new batch plant that may be built closer to the repository site. Neither the borrow pits nor the concrete batch plant would be located in a floodplain or wetlands.

If a bridge were constructed across Fortymile Wash, it would be about 30 meters (100 feet) wide. Supports for the bridge would be constructed in the floodplain of the wash. If a rail line were constructed across the bottom of Fortymile Wash, extensive earthwork (cut and fill) would be required to maintain the less than two percent grade required for the rail alignment.

L.2.2 POSSIBLE ACTIONS ELSEWHERE IN NEVADA

At this time there is no rail access to Yucca Mountain. This means that material traveling by rail would have to continue to the repository on a new branch rail line or transfer to heavy-haul trucks at an intermodal transfer station in Nevada and then travel on existing highways. DOE is considering construction of *either* a new branch rail line *or* an intermodal transfer station and associated highway improvements. The DOE has identified five possible rail corridors, each of which has alignment variations (Figure L-2), and three possible locations for an intermodal transfer station associated with heavy-haul trucks (Figure L-3).

For analytical purposes, it is assumed that construction of a rail line in Nevada would take approximately two and one half years. If a decision were made to proceed with development of a repository, it is likely that the DOE would decide at that time whether to build a rail line or to develop an intermodal transfer station site for heavy-haul waste transport. Should the DOE decide to construct a rail line, standard practices for construction of rail lines would be used, including minimizing steep grades, utilizing cut and full earthwork techniques, and crossing flood prone areas using culverts or bridges. Should the DOE decide to use a route for heavy-haul trucks, portions of the existing roads used for heavy-haul transport may require upgrades to accommodate the heavy loads.

L.3 Existing Environment

L.3.1 EXISTING ENVIRONMENT AT YUCCA MOUNTAIN

Fortymile Wash is about 150 kilometers (93 miles) long and drains an area of about 810 square kilometers (310 square miles) to the east and north of Yucca Mountain (Figure L-1). The wash continues southward and connects to the Amargosa River. The Amargosa River drains an area of about 8,000 square kilometers (3,100 square miles) by the time it reaches Tecopa, California. The mostly-dry river bed extends another 90 kilometers (56 miles) before ending in Death Valley.

Busted Butte and Drillhole washes drain the east side of Yucca Mountain and flow into Fortymile Wash (Figure L-1; Midway Valley Wash is a tributary to Drillhole Wash). Busted Butte Wash drains an area of 17 square kilometers (6.6 square miles) and Drillhole Wash drains an area of 40 square kilometers (15 square miles).

The existing environment at and near Yucca Mountain, including Fortymile Wash, Busted Butte Wash, Drillhole Wash, and Midway Valley Wash is described in Chapter 3 of the EIS. The information below summarizes several of the more important aspects of the environment that pertain to this floodplain assessment.

L.3.1.1 Flooding

Water flow in the four washes is rare. The arid climate and meager precipitation [about 10 to 25 centimeters (4 to 10 inches) per year at Yucca Mountain] result in quick percolation of surface water into the ground and rapid evaporation. Flash floods, however, can occur after unusually strong summer thunderstorms or during sustained winter precipitation. During these times, runoff from ridges, pediments, and alluvial fans flows into the normally dry washes that are tributary to Fortymile Wash. Estimated peak discharges in Fortymile Wash are 340 cubic meters per second (720,000 cubic feet per second) for the 100-year flood and 1,600 cubic meters per second (3,390,000 cubic feet per second) for the 500-year flood. Estimated peak discharges in Busted Butte Wash are 40 cubic meters per second (85,000 cubic feet per second) for the 100-year flood and 180 cubic meters per second (380,000 cubic feet per second) for the 500-year flood. Estimated peak discharges in Drillhole Wash are 65 cubic meters per second (140,000 cubic feet per second) for the 100-year flood and 280 cubic meters per second (590,000 cubic feet per second) for the 500-year flood.

The nearest man-made structure within Fortymile Wash is U.S. Highway 95 more than 19 kilometers (12 miles) south of the confluence of Drillhole and Fortymile washes. Lathrop Wells, the nearest population center to Yucca Mountain, is also about 19 kilometers to the south along U.S. 95 and 3.2 kilometers (2 miles) east of Fortymile Wash.

L.3.1.2 Wetlands

There are no springs, perennial streams, hydric soils, or naturally occurring wetlands at Yucca Mountain. There are two man-made well ponds within Fortymile Wash, and two east of that wash, that have riparian vegetation (TRW 1999a, pages 5 to 6; TRW 1999b, page 2-14).

L. 3.1.3 Biology

Vegetation at and near Fortymile Wash is typical of the Mojave Desert. The mix or association of vegetation in Fortymile Wash, which is dominated by the shrubs white bursage (*Ambrosia dumosa*), creosotebush (*Larrea tridentata*), white burrobush (*Hymenoclea salsola*), and heathgoldenrod (*Ericameria paniculata*), differs somewhat from other vegetation association at Yucca Mountain (TRW 1998a, pages 5 to 7). No plant species are known to be restricted to the floodplains. In addition, none of the more than 180 plant species known to occur at Yucca Mountain is endemic to the area.

None of the 36 mammal, 27 reptile, or 120 bird species that have been documented at Yucca Mountain are restricted to or dependent on the floodplain. These species all are widespread throughout the region. No amphibians have been found at Yucca Mountain.

The only plant or animal species that has been found at Yucca Mountain that is classified as threatened, endangered, or proposed under the Endangered Species Act is the desert tortoise (*Gopherus agassizii*) which is classified as threatened. Yucca Mountain is at the northern edge of the range of the desert tortoise (Rautenstrauch, Brown, and Goodwin 1994, page 11). Desert tortoises are known to occur within the floodplain of Fortymile Wash, but their abundance there and elsewhere at Yucca Mountain is low compared to other parts of its range farther south and east (TRW 1997, pages 6 to 11). Information on the ecology of the desert tortoise population at Yucca Mountain is summarized in TRW (1999b, page 2-8).

Four species classified as sensitive by the Bureau of Land Management occur at Yucca Mountain: two species of bats [the long-legged myotis (*Myotis volans*) and the fringed myotis (*Myotis thysanodes*)] (TRW 1998b, page 11), the western chuckwalla (*Sauromalus obesus obesus*) (TRW 1998c, pages 22 to 23), and the western burrowing owl (*Speotyto cunicularia hypugaea*) (Steen et al. 1997, pages 19 to 29). These species may occur within the floodplain of Fortymile Wash, but they are not dependent upon habitat there (TRW 1998b, page 8; TRW 1998c, pages 22 to 23; Steen et al. 1997, pages 19 to 29).

L.3.1.4 Archaeology

Archaeological surveys have been conducted in Fortymile Wash east of Yucca Mountain. Fortymile Wash was an important crossroad where several trails converged from such distant places as Owens Valley, Death Valley, and the Avawtz Mountains.

L.3.2 EXISTING ENVIRONMENT ELSEWHERE IN NEVADA

The following sections describe the environment along each of the five possible rail corridors (Figure L-2) and at the three intermodal transfer station locations (Figure L-3). Table L-1 lists surface-water-related resources along each of the five rail corridors. The corridors are about 0.4 kilometer (0.25 mile) wide, and the length of each corridor varies (Table L-2). Details of each of the corridors and surface-water-related resources are found in TRW (1999b, Appendixes E, F, G, H, and I).

More detail on each of the rail corridors is provided in Chapter 2, Section 2.1.3.3.2, and Chapter 3, Section 3.2.2. Chapter 6, Section 6.3.2, describes the potential impacts of rail implementing alternatives and Chapter 6, Section 6.3.3 describes the potential impacts of the construction and use of intermodal transfer stations under the heavy-haul truck implementing alternatives.

L.3.2.1 Caliente Rail Corridor

Flooding: The Caliente rail corridor crosses 352 washes en route to the Yucca Mountain site (TRW 1999c, pages 3 to 4). Approximately 12 washes along this route are large enough that bridges would be required to cross them. Floodplains associated with these washes have not been defined at this time.

Wetlands: At least four springs or groups of springs and three streams or riparian areas that may have associated wetlands are within 0.4 kilometer (0.25 mile) of the Caliente rail corridor. However, no field

Table L-1. Surface-water-related resources along candidate rail corridors.[a]

Rail corridor	Distance from corridor (kilometers)[b]	Feature
Caliente		
Caliente to Meadow Valley	0.5	Springs – two unnamed springs, in Meadow Valley north of Caliente
	Within	Riparian area/stream – corridor crosses and is adjacent to stream and riparian area in Meadow Valley Wash
Meadow Valley to Sand Spring Valley	1.0	Spring – Bennett Spring, 3.2 kilometers southeast of Bennett Pass
	0.05 - 2.6	Springs – group of five springs (Deadman, Coal, Black Rock, Hamilton, and one unnamed) east of White River
	Within	Riparian/river – corridor parallels (and crosses) the White River for about 25 kilometers. August 1997 survey found river to be mostly underground with ephemeral washes above ground.
	0.8	Spring – McCutchen Spring, north of Worthington Mountains
Sand Spring Valley to Mud Lake	0.02	Spring – Black Spring, south of Warm Springs
Mud Lake to Yucca Mountain	Within - 2.5	Springs – numerous springs and seeps along Amargosa River in Oasis Valley
	Within	Riparian Area – designated area east of Oasis Valley, flowing into Amargosa Valley
	0.3 - 1.3	Springs – group of 13 unnamed springs in Oasis Valley north of Beatty
	Within - 0.3	Riparian area/stream – Amargosa River, with persistent water and extensive wet meadows near springs and seeps
Carlin		
Beowawe to Austin	0.5	Spring – Tub Spring, northeast of Red Mountain
	0.8	Spring – Red Mountain Spring, east of Red Mountain
	0.9	Spring – Summit Spring, west of corridor and south of Red Mountain
	0.4	Spring – Dry Canyon Spring, west of Hot Springs Point
	0.8	Spring – unnamed spring on eastern slope of Toiyabe Range, southwest of Hot Springs Point
	1.0	Riparian area – intermittent riparian area associated with Rosebush Creek, in western Grass Valley, north of Mount Callaghan
	Within	Riparian/creek – corridor crosses Skull Creek, portions of which have been designated riparian areas
	Within	Riparian/creek – corridor crosses intermittent Ox Corral Creek; portions designated as riparian habitat. August, 1997 survey found creek dry with no riparian vegetation present
	0.1	Spring – Rye Patch Spring, at north entrance of Rye Patch Canyon, west of Bates Mountain
	Within	Riparian area – corridor crosses and parallels riparian area in Rye Patch Canyon
	0.7	Spring – Bullrush Spring, east of Rye Patch Canyon
Austin to Mud Lake	0.8	Springs – group of 35 unnamed springs, about 25 kilometers north of Round Mountain on east side of Big Smokey Valley
	0.6	Riparian area – marsh area formed from group of 35 springs
	0.6	Spring – Mustang Spring, south of Seyler Reservoir
	0.3	Riparian/reservoir – Seyler Reservoir, west of Manhattan
Mud Lake to Yucca Mountain		See Caliente corridor
Caliente-Chalk Mountain		
Caliente to Meadow Valley		See Caliente corridor
Meadow Valley to Sand Spring Valley		See Caliente corridor
Sand Spring Valley to Yucca Mountain	1.0	Spring – Reitman's Seep, in eastern Yucca Flat, east of BJ Wye
	0.8	Spring – Cane Spring, on north side of Skull Mountain on Nevada Test Site
Jean		None identified
Valley Modified		None identified

a. Source: TRW (1999b, Appendixes E, F, G, H, and I).

b. To convert kilometers to miles, multiply by 0.62137.

Table L-2. Length of each rail corridor implementing alternative.

Rail corridor	Length
Caliente	513 kilometers (319 miles)
Carlin	520 kilometers (323 miles)
Caliente-Chalk Mountain	345 kilometers (214 miles)
Jean	181 kilometers (112 miles)
Valley Modified	159 kilometers (99 miles)

searches or formal delineations of wetlands have been conducted along this route. Black Spring is near the corridor at the north end of the Kawich Range and an unnamed spring is near the corridor at the north end of the North Pahroc Range. An unnamed spring is 0.3 kilometer (0.2 mile) east of the corridor between Mud Lake and the Yucca Mountain site. A group of springs is in the corridor near the Amargosa River in Oasis Valley. The corridor crosses the Meadow Valley Wash south of Panaca. The corridor also crosses the White River between U.S. Highway 93 and Sand Spring Valley and parallels the river for approximately 26 kilometers (16 miles). That portion of the White River normally is dry. The corridor crosses the Amargosa River in the north end of the Oasis Valley, in an area designated as riparian area by the Bureau of Land Management (TRW 1999b, page 3-23).

Biology: The desert tortoise is the only threatened or endangered species found along the Caliente rail corridor. The southern 50 kilometers (30 miles) of this corridor is within desert tortoise habitat. This area is not designated as critical habitat and the abundance of tortoises in the area is low (TRW 1999b, page 3-23). Three other species (Meadow Valley Wash speckled dace [*Rhinichthys osculus* ssp.], Meadow Valley Wash desert sucker [*Catostomus clarki* ssp.], and Nevada sanddune beardtongue) classified as sensitive by the Bureau of Land Management or as protected by Nevada have been found along the Caliente rail corridor. This rail corridor crosses approximately 14 areas designated as game habitat and one area classified as waterfowl habitat (TRW 1999b, page 3-23). Two of these species, the speckled dace and desert sucker, are restricted to the floodplain of the Meadow Valley Wash. The designated waterfowl habitat also is generally restricted to the floodplain of Meadow Valley Wash and adjacent wetlands.

Archaeology: There are 97 archaeological sites that have been recorded along the Caliente route.

L.3.2.2 Carlin Rail Corridor

Flooding: The Carlin rail corridor crosses 273 washes en route to the Yucca Mountain site (TRW 1999c, pages 3 to 4). Approximately 10 washes along this route are large enough that bridges would be required to cross them. Floodplains associated with these washes have not been defined at this time.

Wetlands: There are at least three springs or groups of springs, six streams designated as riparian areas by the Bureau of Land Management, and one reservoir that may have associated wetlands within 0.4 kilometer (0.25 mile) of the Carlin rail corridor. However, no field searches or formal delineations of wetlands have been conducted along this route. Rye Patch Spring is on the edge of the corridor at the south end of the Simpson Park Mountains, an unnamed spring is 0.3 kilometer (0.2 mile) east of the corridor between Mud Lake and Yucca Mountain, and a group of springs is in the corridor near the Amargosa River in Oasis Valley. Seyler Reservoir is 0.16 kilometer (0.1 mile) from the corridor in the south end of Big Smoky Valley. There are five riparian areas (Skull, Steiner, and Ox Corral creeks, and Water and Rye Patch canyons) along the section of the route between Beowawe and Austin at the south end of Grass Valley. Two of these (Steiner and Ox Corral creeks, both at the south end of Grass Valley) are ephemeral and have little or no riparian vegetation where the route crosses them. The corridor crosses the Amargosa River in the northern Oasis Valley, in an area designated as a riparian area by the Bureau of Land Management (TRW 1999b, pages 3-25 to 3-26).

Biology: The desert tortoise is the only threatened or endangered species found along the Carlin rail corridor. The southern 50 kilometers (30 miles) of this corridor is within desert tortoise habitat. This area is not designated as critical habitat and the abundance of tortoises in the area is low (TRW 1999b, page 3-25). Three other species (ferruginous hawk [*Buteo regalis*], San Antonio pocket gopher [*Thomomys umbrinus curtatus*], and Nevada sand dune beardtongue [*Penstemom arenarius*]) classified as sensitive by the Bureau of Land Management or as protected by the State of Nevada have been found along the Carlin rail corridor. Additionally, the rail corridor crosses approximately 11 areas designated as game habitat by the Bureau of Land Management (TRW 1999b, page 3-25). None of these species or game habitats are restricted to floodplains or areas that may have wetlands.

Archaeology: There are 110 archaeological sites that have been recorded along the Carlin route.

L.3.2.3 Caliente-Chalk Mountain Rail Corridor

Flooding: The Caliente-Chalk Mountain rail corridor crosses 281 washes en route to the Yucca Mountain site (TRW 1999c, pages 3 to 4). Approximately five washes along this route are large enough that bridges would be required to cross them. Floodplains associated with these washes have not been defined at this time.

Wetlands: One spring and two streams that may have associated wetlands occur within 0.4 kilometer (0.25 mile) of the Caliente-Chalk Mountain rail corridor. However, no field searches or formal delineations of wetlands have been conducted along this route. An unnamed spring is near the corridor at the north end of the North Pahroc Range. The corridor crosses Meadow Valley Wash south of Panaca. The corridor crosses the White River between U.S. 93 and Sand Spring Valley and parallels the river for approximately 26 kilometers (16 miles). That portion of the White River normally is dry.

Biology: The desert tortoise is the only threatened or endangered species found along the Caliente-Chalk Mountain rail corridor. The southern 40 kilometers (25 miles) of this corridor is within desert tortoise habitat. This area is not designated as critical habitat and the abundance of tortoises in the area is low (TRW 1999b, page 3-27). Six species (Meadow Valley Wash speckled dace, Meadow Valley Wash desert sucker, Ripley's springparsley [*Cymopterus ripleyi* var. *saniculoides*], largeflower suncup [*Camissonia megalantha*], Beatley's scorpionweed [*Phacelia beatleyae*], and long-legged myotis [*Myotis volans*]) classified as sensitive by the Bureau of Land Management or protected by Nevada have been found in the Caliente-Chalk Mountain rail corridor. This rail corridor crosses approximately eight areas designated as game habitat and one area of waterfowl habitat (TRW 1999b, page 3-27). Two of these sensitive species, the speckled dace and desert sucker, are restricted to the floodplain of the Meadow Valley Wash. The designated waterfowl habitat also is generally restricted to the floodplain of Meadow Valley Wash and adjacent wetlands.

Archaeology: There are 100 archaeological sites that have been recorded along the Caliente-Chalk Mountain route.

L.3.2.4 Jean Rail Corridor

Flooding: The Jean rail corridor crosses 89 washes en route to the Yucca Mountain site (TRW 1999c, pages 3 to 4). Approximately five washes along this route are large enough that bridges would be required to cross them. Floodplains associated with these washes have not been defined at this time.

Wetlands: No springs, perennial streams, or riparian areas that may have associated wetlands have been identified within 0.4 kilometer (0.25 mile) of the Jean rail corridor (TRW 1999b, page 3-29). However, no field searches or formal delineations of wetlands have been conducted along this route.

Biology: The desert tortoise is the only threatened or endangered species found along the Jean rail corridor. This entire corridor is within desert tortoise habitat, but does not cross any areas designated as critical habitat. The abundance of desert tortoises is low along most of the rail corridor, although there is a higher abundance along some portions in Ivanpah, Goodsprings, Mesquite, and Pahrump valleys (TRW 1999b, page 3-28). One species, the pinto beardtongue (*Penstemon bicolor* spp.) that is classified as sensitive by the Bureau of Land Management has been found within the corridor. This rail corridor crosses approximately 12 areas designated as game habitat by the Bureau of Land Management (TRW 1999b, page 3-28). None of these species or game habitats are restricted to floodplains or areas that may have wetlands.

Archaeology: Six archaeological sites have been recorded along the Jean rail corridor.

L.3.2.5 Valley-Modified Rail Corridor

Flooding: The Valley-Modified rail corridor crosses 95 washes en route to the Yucca Mountain site (TRW 1999c, pages 3 to 4). Approximately three washes along this route are large enough that bridges would be required to cross them. Floodplains associated with these washes have not been defined at this time.

Wetlands: No springs, perennial streams, or riparian areas that may have associated wetlands have been identified within 0.4 kilometer (0.25 mile) of the Valley-Modified rail corridor (TRW 1999b, pages 3-29 to 3-30). However, no field searches or formal delineations have been conducted along this route.

Biology: The desert tortoise is the only threatened or endangered species found along the Valley-Modified rail corridor. This entire corridor is within desert tortoise habitat, but does not cross any areas designated as critical habitat. The abundance of desert tortoises is low along this rail corridor (TRW 1999b, page 3-29). Two plant species (Parish’s scorpionweed [*Phacelia parishii*] and Ripley’s springparsley) classified as sensitive by the Bureau of Land Management have been found in the rail corridor. None of these species are restricted to floodplains or areas that may have wetlands. The Valley-Modified rail corridor does not cross any Bureau of Land Management-designated game habitat (TRW 1999b, page 3-29).

Archaeology: Nineteen archaeological sites have been recorded along the Valley-Modified rail corridor.

L.3.2.6 Caliente Intermodal Transfer Station

Flooding: The two proposed sites for the Caliente intermodal transfer station are located in the Meadow Valley Wash south of Caliente. Both areas are outside the inundation boundary of the 100-year floodplain, but within the boundary of the 500-year floodplain.

Wetlands: Part of the proposed station location is moist during at least some portions of the year and may be classified as wetlands. The adjacent perennial stream and riparian habitat along Meadow Valley Wash also might be classified as wetlands, although no formal delineation of wetlands has been conducted for this proposed activity (TRW 1999b, page 3-35).

Biology: No game habitat, threatened or endangered species, or species classified as sensitive by the Bureau of Land Management or protected by Nevada occur within the proposed station location (TRW 1999b, page 3-35).

Archaeology: Four archaeological sites have been recorded at the Caliente intermodal transfer station site.

L.3.2.7 Apex/Dry Lake Intermodal Transfer Station

Flooding: The two proposed sites for the Apex/Dry Lake intermodal transfer station are located outside of the 100-year and 500-year floodplain.

Wetlands: There are no springs or riparian areas within the proposed station location (TRW 1999b, page 3-36).

Biology: The only resident threatened or endangered species at this site is the desert tortoise. The abundance of desert tortoises in Dry Lake Valley generally is low, although some areas there have a higher abundance. One plant species, Geyer's milkvetch (*Astragalus geyeri triquetrus*), classified as sensitive by the Bureau of Land Management has been found in the proposed location. Neither of these species are restricted to floodplains or wetlands. No game habitat has been designated there (TRW 1999b, page 3-36).

Archaeology: Two archaeological sites have been recorded at the Apex/Dry Lake intermodal transfer station site.

L.3.2.8 Sloan/Jean Intermodal Transfer Station

Flooding: The southernmost proposed site for the Jean intermodal transfer station is located in the same general area as a 100-year flood inundation zone. The northern site proposed for the Jean intermodal transfer station is not in an inundation zone and is outside the 500-year floodplain. The northernmost proposed site for the Sloan intermodal transfer station is in an area with no printed Federal Emergency Management Agency map and it is outside the 500-year floodplain.

Wetlands: There are no springs or riparian areas within the proposed station location (TRW 1999b, page 3-36).

Biology: The only resident threatened or endangered species at this site is the desert tortoise. The abundance of desert tortoises in Ivanpah Valley generally is moderate to high, relative to other areas within the range of this species in Nevada. One plant species, pinto beardtongue, classified as sensitive by the Bureau of Land Management has been found in the proposed location. Neither of these species are restricted to floodplains or wetlands. No game habitat has been designated there (TRW 1999b, pages 3-36 to 3-37).

Archaeology: Seven archaeological sites have been recorded at the Sloan/Jean intermodal transfer station site.

L.4 Floodplain/Wetlands Effects

According to 10 CFR 1022.12(a)(2), a floodplain assessment is required to discuss the positive and negative, direct and indirect, and long- and short-term effects of the proposed action on the floodplain and/or wetlands. In addition, the effects on lives and property, and on natural and beneficial values of floodplains must be evaluated. For actions taken in wetlands, the assessment should evaluate the effects of the proposed action on the survival, quality, and natural and beneficial values of the wetlands. If DOE finds no practicable alternative to locating activities in floodplains or wetlands, DOE will design or modify its actions to minimize potential harm to or in the floodplains and wetlands. The floodplains that are assessed herein are those areas of normally dry washes that are temporarily and infrequently inundated from runoff during 100-year or 500-year floods.

L.4.1 FLOODPLAIN/WETLANDS EFFECTS NEAR YUCCA MOUNTAIN

DOE has not determined if rail casks will be transported in Nevada by heavy-haul trucks on existing highways or whether to construct a branch rail line to bring the spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site. Near Yucca Mountain, however, it is possible that each of the four washes could be affected if a rail line and a road were to access the Yucca Mountain site from different directions. Because of this uncertainty, this assessment examines the configurations that would cause the most disturbances to the four washes and their floodplains, as follows:

- Potential construction of a heavy-haul-capable road west of Fortymile Wash that crosses Busted Butte Wash, Drillhole Wash, and Midway Valley Wash. Cut, fill, and drainage culverts could be used to cross Busted Butte and Drillhole washes. A bridge could be constructed over Midway Valley Wash. Heavy-haul trucks carrying spent nuclear fuel and high-level radioactive waste could travel along this road to the repository.

- Potential construction of a raised rail line through Fortymile Wash with appropriately-sized drainage culverts. The rail line could join the route for heavy-haul trucks north of Drillhole Wash and cross Midway Valley Wash on a separate rail-bridge before entering the repository. Trains carrying spent nuclear fuel and high-level radioactive waste could travel along the rail line to the repository.

- Potential upgrading of the existing road that crosses Fortymile Wash with appropriately-sized drainage culverts. The road could be used by legal-weight trucks to transport spent nuclear fuel and high-level radioactive waste to the repository, as well as transporting various types of hazardous and non-hazardous materials to and from the repository.

Construction in the washes would reduce the area through which floodwaters naturally flow. During large floods, bodies of water could develop on the upstream side of each of the crossings and slowly drain through culverts. Such floods, however, would not increase the risk of future flood damage, increase the impact of floods on human health and safety, or harm the natural and beneficial values of the floodplains because there are no human activities or facilities upstream or downstream that could be affected. A sufficiently large flood in Fortymile Wash could create a temporary large lake up-stream of the raised rail line and the legal-weight road. The water would slowly drain through culverts. If the flood occurred quickly and was sufficiently large, water would flow over the rail line and roads and continue downstream. Some damage to the rail line and the roads would be expected, but neither structure would increase the risk of future flood damage, increase the impact of floods on human health and safety, or harm the natural and beneficial values of the floodplains because there are no human activities or facilities downstream that could be affected.

During and after each flood, a large amount of sediment would accumulate on the up-stream side of each crossing. Periodically, this material would have to be removed so that future floods would have sufficient space to accumulate, rather than overflow the structures during successively smaller floods. This material would, when deemed necessary, be removed by truck and disposed of appropriately. Under natural conditions this sediment would have continued downstream and been deposited as the floodwaters receded. Compared to the total amount of sediment that is moved by the flood water along the entire length of the washes, the amount trapped behind the crossings would be small.

During a 100-year or 500-year flood, there would be no preferred channels; all channels across the entire width of each wash would be filled with water (Figure L-1). Therefore, the manmade crossings would not cause preferential flow in a particular channel or alter the velocity or direction of flow on the floodplains.

Potential construction of a route for heavy-haul trucks or rail line would require the removal of desert vegetation in the washes and the disturbance of soil and alluvium. These actions could adversely impact wildlife habitat and individuals, especially the desert tortoise, which is designated as threatened by the Fish and Wildlife Service. Prior to any construction, a biological survey would be conducted to locate and remove tortoises that are in the path of construction and other mitigation measures would be conducted as identified by the Fish and Wildlife Service during consultations under the Endangered Species Act for this action.

Construction in the floodplains could also affect unidentified cultural resources that may be present. Prior to any construction, archaeologists would survey the area following the procedure in DOE's Programmatic Agreement with the Advisory Council on Historic Preservation (DOE 1988, page 5).

Potential indirect impacts on flora and fauna include increased emissions of fugitive dust, elevated noise levels, and increased human activities. Emissions of fugitive dust would be short-term and would not be expected to significantly affect vegetation or wildlife. Likewise, no significant long-term impacts to wildlife are expected from the temporary increase in noise during construction. Wildlife displaced during construction would probably return after construction was completed.

There are no perennial sources of surface water at or downstream from the Yucca Mountain site that would be affected by the use of a route for heavy-haul trucks or the construction of a rail line. Two small well ponds with some riparian vegetation occur in Fortymile Wash downstream of the point where Drillhole Wash enters Fortymile Wash. During a 100- or 500-year flood, both riparian areas would likely be damaged or destroyed by floodwaters regardless of the existence of the crossings.

Neither the quality nor the quantity of groundwater that normally recharges through Fortymile Wash would be substantially affected due to the crossings. Water infiltration could increase somewhat after large floods as standing water slowly enters the ground behind the crossings. The total volume of these water bodies would be a few acre-feet at most, and much of the water would gradually drain through culverts or evaporate before reaching the groundwater table at 274 meters (900 feet) below the surface.

The use of petroleum, oil, lubricants, and other hazardous materials during construction would be strictly controlled and spills would be promptly cleaned up and, if needed, the soil and alluvium would be remediated. The small amount of these materials that might enter the ground would not affect the groundwater, which is 274 meters (900 feet) below the surface.

The nearest population center is about 19 kilometers (12 miles) to the south, along U.S. 95 at Lathrop Wells a few miles east of Fortymile Wash. If floodwaters from a 100- or 500-year flood reached this far downstream, there would be no measurable increase in flood velocity or sediment load attributable to the use of a route for heavy-haul trucks or construction of a rail line compared to natural conditions. Hence, disturbances to the floodplains of Fortymile Wash, Busted Butte Wash, Drillhole Wash, or Midway Valley Wash would have no adverse impacts on lives and property downstream. Moreover, impacts to these floodplains would be insignificant in both the short- and long-term compared to the erosion and deposition that occur naturally and erratically in these desert washes and floodplains.

During operation of the repository it would be extremely unlikely that a truck carrying spent nuclear fuel and high-level radioactive waste would fall into Busted Butte, Drillhole, or Midway Valley washes or that a train would derail in Fortymile Wash. However, even if this occurred, the shipping casks, which are designed to prevent the release of radioactive materials during an accident, would remain intact. The casks would then be recovered and transported to the repository. No adverse impacts to surface water or groundwater quality from such accidents would occur.

Hazardous materials needed during construction and operation of the repository would be transported along the legal-weight access road. If these materials were released during an accident, they would be cleaned-up quickly and the affected soil and alluvium would be remediated. No adverse impacts to groundwater quality from such accidents would occur because cleanup could be completed before contaminants reached the groundwater [the groundwater table is 274 meters (900 feet) below the surface].

There are no positive or beneficial impacts to the floodplains of Busted Butte, Drillhole, Midway Valley, or Fortymile washes that have been identified from the proposed action.

L.4.2 FLOODPLAIN/WETLANDS EFFECTS ELSEWHERE IN NEVADA

L.4.2.1 Effects along Rail Corridors

Potential rail routes would cross many small, and some large, washes. In general, the impacts caused by rail construction in any of these washes and their floodplains would be similar in magnitude to those described for Fortymile, Busted Butte, Drillhole, and Midway Valley washes. Regardless of the route selected, standard mitigation practices used throughout Nevada for highway construction would be used to minimize the impacts to floodplains. Most washes and their floodplains along the five potential rail corridors are in remote areas. Impacts to these floodplains from rail construction and operation would be insignificant in both the short- and long-term compared to erosion and deposition that occurs naturally and erratically in these desert washes and floodplains.

Based on current information, springs and riparian areas that may have associated wetlands occur within three of the rail corridors (Caliente, Carlin, and Caliente-Chalk Mountain). If the rail mode of spent nuclear fuel and high-level radioactive waste transport is selected by DOE, wetlands delineations along the selected route would be conducted and the effects would be described in a more detailed floodplain/wetlands assessment for public review.

L.4.2.2 Effects at Intermodal Transfer Stations

Neither the Dry Lake intermodal transfer station nor the Sloan/Jean intermodal transfer station would have any impacts on floodplains because these station locations are not in a floodplain. The Caliente intermodal transfer station, however, is located in Meadow Valley Wash, separated by the Union Pacific Railroad. If this site were selected, DOE would conduct a more detailed floodplain/wetlands assessment for public review to address the floodplain/wetlands effects at the Caliente intermodal transfer station location. The more detailed floodplain/wetlands assessment would also include potential upgrades to existing roads for heavy-haul use.

L.5 Mitigation Measures

According to 10 CFR 1022.12(a) (3), agencies must address measures to mitigate the adverse impacts of actions in a floodplain or wetlands, including but not limited to minimum grading requirements, runoff controls, design and construction constraints, and protection of ecologically-sensitive areas. Whenever possible, DOE would avoid disturbing wetlands and floodplains and would minimize impacts to the extent practicable, if avoidance was not possible. This section discusses the floodplain mitigation measures that would be considered in the vicinity of Yucca Mountain and elsewhere in Nevada and, where necessary and feasible, implemented during construction and maintenance in the washes.

Adverse impacts to the affected floodplains would be small. Even during 100- and 500-year floods, it is unlikely that differences in the rate and distribution of erosion and sedimentation caused by the use of a route for heavy-haul trucks or construction of a rail line near Yucca Mountain would be measurably different compared to existing conditions. Nevertheless, DOE would follow their reclamation guidelines (DOE 1995, pages 2-1 to 2-14) for site clearance, topsoil salvage, erosion and runoff control, recontouring, revegetation, siting of roads, construction practices, and site maintenance. Disturbance of surface areas and vegetation would be minimized, and natural contours would be maintained to the maximum extent feasible. Slopes would be stabilized to minimize erosion. Unnecessary off-road vehicle travel would be avoided. Storage of hazardous materials during construction would be outside the floodplains.

Before any potential construction could begin, DOE would require pre-construction surveys to make sure that the work would not impact important biological or archaeological resources. In addition, the site's reclamation potential would be determined during these surveys. In the event that construction could threaten important biological or archaeological resources, and modification or relocation of the roads and rail line is not reasonable, mitigation measures would be developed. Mitigation measures developed during the pre-construction surveys would be incorporated into the design of the work. These measures could include relocation of sensitive species, avoidance of archaeological sites, or data recovery if avoidance is not feasible.

If hazardous materials are spilled during construction of the crossings or during transport to the repository, the spill would be quickly cleaned-up and the soil and alluvium would be remediated. Hazardous materials would be stored away from all floodplains to decrease the probability of an inadvertent spill in these areas.

L.6 Alternatives

According to 1022.12(a)(3), DOE must consider alternatives to the proposed action. Alternative ways to access the Yucca Mountain site are considered in the following paragraphs, along with the no action alternative.

L.6.1 ALTERNATIVES NEAR YUCCA MOUNTAIN

To operate a potential repository at Yucca Mountain, heavy-haul-capable and legal-weight roads and a rail line to the facility would be considered so the spent nuclear fuel and high-level radioactive waste could be unloaded and emplaced underground. It is unreasonable to consider a railroad or heavy-haul-capable and legal-weight roads that access the repository directly from the west over Yucca Mountain because of engineering constraints, environmental damage, and cost associated with construction in such rugged terrain. Because of these concerns, this alternative was eliminated from detailed consideration.

Access to Yucca Mountain from the east side requires that Fortymile Wash be crossed. Alternative sites for these crossings were considered, but the impacts at any alternative site would be virtually identical to the proposed site. Moreover, the proposed sites provide the most direct routes to the repository and would cost less to build and/or upgrade than alternative sites that cross Fortymile Wash at wider locations.

L.6.2 ALTERNATIVE RAIL CORRIDORS AND ALTERNATIVE SITES FOR AN INTERMODAL TRANSFER STATION

Five potential rail corridors were identified by DOE through a winnowing process that considered a host of environmental constraints (see Chapter 2, Section 2.3.3). Other possible rail corridors in Nevada were examined but rejected because of such things as land use, private land, and engineering constraints. Identification of the three intermodal transfer station locations was limited to reasonable sites next to an existing rail line in Nevada. Other sites were considered by DOE, but rejected because of ownership and environmental concerns.

L.6.3 NO-ACTION ALTERNATIVE

Selection of the No-Action Alternative would avoid impacts to floodplains and wetlands. If Yucca Mountain was selected as a site to construct a repository, transport of spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site would be required. In that case there would be no other practicable alternative to taking action in floodplains and wetlands because there would be no way to transport spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site during repository operation without passing through some wetlands areas and floodplains.

L.7 Conclusions

DOE prepared this assessment in compliance with 10 CFR Part 1022. The assessment evaluates the effects to the floodplains near Yucca Mountain (Fortymile Wash, Busted Butte Wash, Drillhole Wash, and Midway Valley Wash) and generically to floodplains and wetlands elsewhere in Nevada from construction of a rail line or an intermodal transfer station and associated upgrades to existing highways for heavy-haul trucks.

Near Yucca Mountain, the closest man-made structure within Fortymile Wash is U.S. 95 more than 19 kilometers (12 miles) south of the confluence of Drillhole and Fortymile washes. Lathrop Wells, the nearest population center to Yucca Mountain, is also about 19 kilometers to the south along U.S. 95 and two miles east of Fortymile Wash. Construction- and operations-related impacts to the 100-year and 500-year floodplains of Fortymile Wash, Busted Butte Wash, Drillhole Wash, and Midway Valley Wash would be small. None of these impacts would increase the risk of future flood damage, or increase the impact of floods on human health and safety, or harm the natural and beneficial values of the floodplains. There are no positive or beneficial impacts to the floodplains of Busted Butte, Drillhole, Midway Valley, or Fortymile washes from the proposed actions that have been identified.

Elsewhere in Nevada, effects to floodplains and wetlands would probably be small, although a detailed floodplain/wetlands assessment would be conducted by DOE when more information is available upon selection of a rail corridor or route for heavy-haul trucks.

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