further during site characterization. Coal-bearing units are not present. Limited uranium resources have been identified near the sites, but these resources are restricted to near the surface (less than 60 feet deep), and little uranium has been produced within the area since 1973. Sand, gravel, and dimension-stone resources are present, but the distance to any market makes their value minimal. Iron and manganese are present but are not economic resources. These data suggest that the potential for human interference is low.

Bedded Salt in the Palo Duro Basin

Two potentially acceptable sites have been identified in the Palo Duro Basin, which is a part of the Permian Basin (see Figure 7-4): one in Deaf Smith County and one in Swisher County. The stratigraphic and hydrostratigraphic units are shown in Figure 5-6. The salt formation of interest is the Lower San Andres Unit 4. Because the salt is interbedded, a desirable bed has been defined as one in which the interbeds (of nonsalt and poor-quality salt) are less than 10 feet thick and the cumulative thickness of interbeds is less than 15 percent of the total bed thickness. In the area of the Deaf Smith County site, the potential repository bed is about 2550 feet deep and 150 feet thick, with a halite content of approximately 90 volume percent. The Lower San Andres contains numerous discrete argillaceous and carbonaceous interbeds as well as many lesser halite beds containing a high percentage of impurities. The interbeds are 0.3 to 2.0 inches in thickness. The spacing of the interbeds ranges from 1 inch to 11 feet. In addition, the lateral lithologic continuity of halite beds is sometimes interrupted by zones of chaotic mixing of salt and nonsalt interbeds. The structure of the Upper San Andres horizon in the vicinity of the site is nearly horizontal; dips appear to be on the order of 0.5 degree to the southwest.

The Ogallala Formation and the Dockum Group (Figure 5-6) are highly productive aquifers that are important water resources in the region. These aquifers have significant lateral variations and must be penetrated by all shafts and boreholes. The Wolfcamp, an aquifer that lies about 2500 feet below the host salt bed, is of lesser importance because it is separated from the host salt by a considerable thickness of interbedded salt units.

The geologic conditions of the Swisher County site are similar to those of Deaf Smith County. The potential repository horizon is in the Lower San Andres Unit 4, which is about 2700 feet deep and about 130 feet thick. The bed is nearly horizontal--it dips about 0.5 degree to the south-southwest. In three boreholes drilled near the site, one potential repository salt bed has a halite content ranging from 77 to 87 percent. The Lower San Andreas 4 contains numerous discrete argillaceous and carbonaceous interbeds as well as many lesser halite beds containing a high percentage of impurities. The interbeds range in thickness from 0.3 to 3.4 inches. The spacing of the interbeds ranges from 1 inch to 7 feet. In addition, the lateral lithologic continuity of halite beds is sometimes interrupted by zones of chaotic mixing of salt and nonsalt materials. The Ogallala-Dockum and the Wolfcamp are also the important aquifers in and near the Swisher County site.

ERA	SYSTEM	SERIES	GROUP	FORMATION	HYDROSTRATIGRAPHIC UNIT (HSU)
CENOZOIC	QUATERNARY			RECENT STREAM AND LAKE DEPOSITS	A FRESH-WATER FLOW SYSTEM
	TERTIARY			OGALLALA	
MESOZOIC	CRETACEOUS		DAKOTA		
				FREDRICKSBURG	
				TRINITY	
	JURASSIC			MORRISON	
				EXETER	
	TRIASSIC		DOCKUM	TRUJILLO	
				TECOVAS	
PALEOZOIC	PERMIAN	OCHOA		DEWEY LAKE	B SHALE AND EVAPORITE AQUITARD
				ALIBATES	
		GUADALUPE	ARTESIA/ WHITEHORSE	SALADO	
				YATES	
				SEVEN RIVERS	
				QUEEN/GRAYBURG	
				SAN ANDRES/BLAINE	
		LEONARD	CLEAR FORK	GLORIETA	
				UPPER CLEAR FORK	
				TUBB	
				LOWER CLEAR FORK	
				RED CAVE	
			WICHITA		
		WOLFCAMP			C DEEP-BASIN FLOW SYSTEM
	PENNSYLVANIAN	CISCO			
		CANYON			
		STRAWN			
		ATOKA/BEND			
		MORROW			
	MISSISSIPPIAN	CHESTER			
		MERAMEC			
		OSAGE			
	ORDOVICIAN		ELLENBURGER		
	CAMBRIAN		UNNAMED SANDSTONE		
	PRECAMBRIAN				

LEGEND:
UNCONFORMITY ----

SOURCES: HANFORD AND DUTTON 1980; PRESLEY 1980; NICHOLSON 1960; TAIT ET AL. 1962; TOTTEN 1956; KELLY AND TRAUGER 1972

Figure 5-6. Stratigraphy of the Palo Duro Basin.

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The Lower San Andres evaporites were deposited at the beginning of late Permian time (about 250 million years ago). Except for regional uplift, the beds have experienced practically no deformation at the Palo Duro sites since deposition. There is no conclusive evidence that Quaternary tectonism affected the sites. Infrequent earthquakes with magnitudes of less than V have occurred in the region, but estimates of maximum earthquakes imply upper bounds for free-field ground-surface accelerations of about 0.2g at the sites. A seismograph network has been installed to monitor any microseisms, and very low levels of activity are being detected. No uplift or subsidence has been detected.

Potential salt dissolution is an important consideration because active dissolution occurs about 33.5 miles from the Swisher County site and 19 miles from the Deaf Smith County site. Also, dissolution has been proposed for certain areas that are similar to the sites. The geologic studies to date do not disclose any active dissolution near the sites, nor is site encroachment likely from the known active dissolution areas.

Hydrocarbon production in the Palo Duro Basin is minor and generally occurs along the margins of the Basin. Local occurrences of favorable geologic conditions for hydrocarbon generation and accumulation may exist in the interior of the Palo Duro Basin. However, the potential for extensive undiscovered hydrocarbon deposits is low. Furthermore, the potential for the development of localized hydrocarbon occurrences is low in light of the potential economic returns versus development costs. The only well to date that has produced oil (Marathon/Mayfield No. 1 in Briscoe County) in the interior of the basin yielded less than 20,000 barrels and has been plugged and abandoned.

Caliche, crushed stone, sand, and gravel are produced in the Palo Duro Basin. Potential mineral resources in the region include uranium, copper, potash, gypsum, and salt. Small quantities of uranium have been produced from the Dockum Group in areas outside the basin. Salt resources are known to be substantial in the region, but the only producing well in the basin was abandoned in 1981. Thus, the Palo Duro Basin does not appear to contain unique mineral resources or concentrations greater than those of the surrounding areas.

5.2.3 TUFF

Tuff is the dominant component of the voluminous and widespread volcanic strata in the Basin and Range province of the western United States. The rock being considered for a repository at Yucca Mountain, Nevada (see Figure 7-8) is welded tuff; the mode of its formation is described in Appendix C.

The geology of the region that includes Yucca Mountain has been studied in detail during the last 30 years. As a result, the regional stratigraphy, structure, and volcanology are quite well known.

Volcanic activity about 15 to 7 million years ago resulted in the deposition of more than 1 mile of rhyolitic tuff, lava, and associated sedimentary rocks; it also produced numerous volcanotectonic collapse features called calderas. Calderas--some buried by volcanic rocks--lie north and west of Yucca Mountain (Christiansen et al., 1977)

Volcanism was accompanied by large-scale block faulting, which produced the characteristic Basin and Range terrain (Carr, 1984). These faults resulted from extensional stresses that persist to the present. Yucca Mountain is a fault block (tilted 3 to 6 degrees eastward) that was produced by this faulting.

The volcanic section (Figure 5-7) is thick. The volcanics are at least 2 miles thick throughout much of Yucca Mountain and thin to about 0.6 or 0.7 miles southward along the southeastern edge of the mountain.

The exposed part of Yucca Mountain consists of variously welded ash-flow tuff and minor airfall and water-laid tuff materials that have been divided into more than a dozen units on the basis of such factors as the degree of compaction and welding, devitrification, and the presence of lithophysae. The latter are cavities, as much as 7 inches long, produced by gases trapped during the cooling of the ash flow. Careful mapping of the tuff units has made it possible to delineate the structure of the mountain block in great detail (Scott and Bonk, 1984).

The candidate repository horizon is a zone of densely welded rhyolitic tuff of the Topopah Spring Member of the Paintbrush Tuff. This zone lies about 1000 to 1200 feet below the surface, in the unsaturated zone--more than 500 feet above the water table.

The detailed structural knowledge acquired to date indicates that the potential repository block is bounded by a major steep fault on the west, by a series of faults on the east, by a zone of closely spaced faults on the south, and by a fault zone on the north. The area within those boundaries is about 2000 acres, more than sufficient for the repository (Mansure and Ortiz, 1984, Nimick and Williams, 1984). If subsurface studies determine that the area to the north of the fault zone has a sufficient area of suitable rock, the size and capacity of the site could be somewhat larger. Mining through the fault zone itself is not believed to be a serious obstacle in the unsaturated zone (Dravo, 1984).

Three measurements of the depth of stream incision in dated alluvial deposits in the vicinity of Yucca Mountain have been made; from these, a mean rate of incision of 5×10^{-5} m/yr was calculated (USGS, 1984). The time spans represented by the measurements suggest that the average incision rate has been less than 10^{-4} m/yr during the past 300,000 years and certainly so during the past 10 million years.

Continued erosion at Yucca Mountain could affect radionuclide releases to the accessible environment by uncovering the repository itself or by changing the hydrologic conditions in the vicinity of the site. At an erosion rate of 10^{-4} m/yr, the expected time for uncovering the repository at its minimum depth would be 2.3 million years. To view this from another perspective, uncovering of the repository (or the water table downgradient from the repository) in 10,000 years would require an erosion rate greater than any known to have occurred anywhere on earth for periods of 10,000 years.

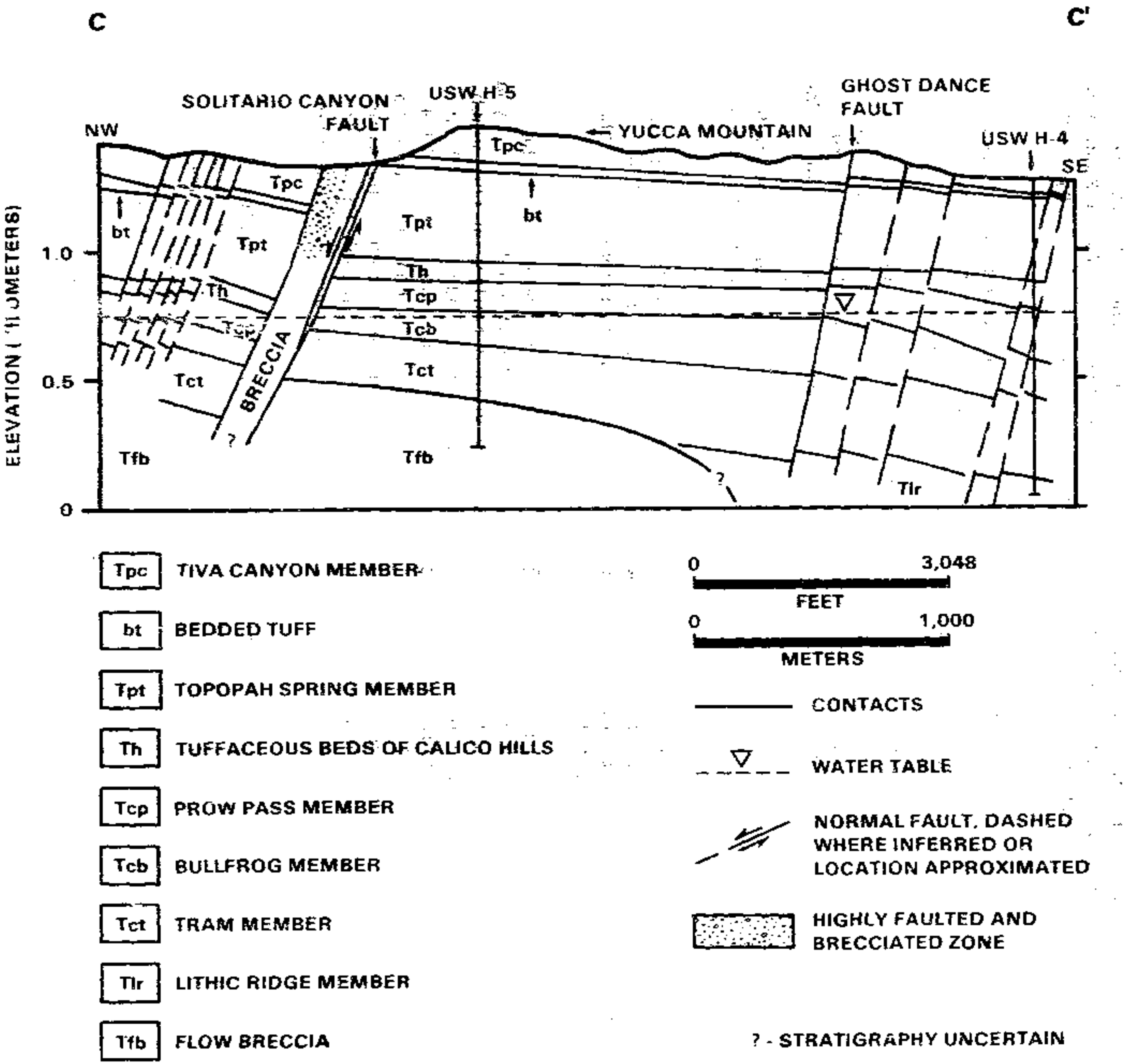

Figure 5-7. Northwest-southeast geologic cross section through drill holes USW H-5 and USW H-4 at the Yucca moutain site.

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There are no known mineral resources at Yucca Mountain, and its mineral-resource potential appears to be low (Bell and Larson, 1982). Within a radius of several tens of miles, there are several small mining districts, only one of which is active. Relative to other localities in the area, the geologic setting does not offer an attractive target for the mining of precious or base metals or for industrial minerals. Ground water of good quality that might be subject to development and use in the future is present in aquifers near the site; however, good water is also accessible at shallower depths or in less rugged terrain away from the site, thus reducing the possibility of human intrusion.

The potential for repository disruption by basaltic volcanism within 15 miles has been carefully studied (Crowe et al., 1982). The results of these studies include a calculated annual probability of 10^{-8} to 10^{-10} for a volcanic extrusion, which would be of small volume and would have limited surface dispersal of lava. The effects of rhyolitic volcanism would be more serious because it tends to be more voluminous, widespread, and violent, but there has been no such volcanic activity in the vicinity of the site (within approximately 62 miles) for the past 5 million years. The probability of repository disruption by this mechanism is judged to be negligible (Crowe et al., 1982).

Many faults in the region are active; others could have renewed activity in the future. Under the assumption that Yucca Mountain faults are not active, the most likely peak deterministic acceleration at Yucca Mountain is 0.4g, resulting from a full-length fault rupture on the Bare Mountain Fault (10 miles, magnitude 6.8), which is 8 miles west of the site (USGS, 1984). Studies of the effects of nuclear weapons testing nearby indicate that they are of less consequence than the probable natural earthquakes (Vortman, 1982).

The proposed repository site and adjacent areas have been free of earthquakes of moderate or larger size during the 6 years of monitoring; however, during 3 years of high-resolution monitoring, seven very small (magnitude less than 2) earthquakes have been detected within 6 miles of Yucca Mountain.

Investigations to date covering 425 square miles around the site have found no unequivocal evidence of surface faulting in the last 40,000 years. Thirty-two faults have been identified that offset or fracture Quaternary deposits. The Quaternary faults are divided into three broad age groups: 5 faults moved between about 270,000 and 40,000 years ago; 4 faults moved about 1 million years ago; and 23 faults moved probably between 2 million years and more than 1.2 million years ago (Swadley and Hoover, 1983).

In-situ measurements of the state of stress in the rocks, though too sparse to be representative of the entire area, are in agreement with analyses of structural data, the deformation of boreholes, and seismicity. They all suggest that existing northerly trending faults--which are common in the area--could experience slippage under certain conditions. Hydrofracture test results indicate that the least principal stress is horizontal, oriented about N 65° W; it is about one-third of the vertical stress. The greatest horizontal stress is on the order of one-half to two-thirds of the vertical stress, which indicates a northwesterly extensional stress field (Healy et al., 1984; Stock, et al., 1984). The limited data available so far do not suggest the imminence of fault movement, but they do indicate that the ratio of vertical stress to the minimum horizontal stress may be high enough to require consideration in designing the underground openings of the repository.

The known fractured condition of the tuffs in the unsaturated zone makes it unlikely that sophisticated techniques would be required for sealing the shafts since there is no point in making the seal tighter than the rock penetrated by the shafts. The fracturing is a disadvantage in terms of repository construction; however, limited mining experience in similar materials in nearby mesas indicates that this problem can be handled with conventional techniques.

5.3 SIGNIFICANT RESULTS OF HYDROLOGIC RESEARCH

Hydrologic research is directed at understanding the present flow dynamics of the geohydrologic system, including the three-dimensional distribution of hydraulic heads, ground-water hydrochemistry, and the hydraulic properties in the principal flow units. Studies are also being planned to evaluate potential short- and long-term changes in the geohydrologic system resulting from variations in climate or the tectonic setting. These data are used in modeling to derive the average velocity of ground-water flow, likely flow paths, and the geochemical conditions existing between the repository and the accessible environment.

Knowledge of present hydrologic conditions and estimates of future hydrologic conditions and processes are needed to qualify the site relative to its ability to isolate waste, to plan the construction and operation of the repository, to design shafts and seals and to evaluate whether they will function properly, to identify the conditions of ground-water flow to which the waste package will be subjected, to design other components of the engineered-barrier system, and to test materials. This knowledge will improve materially as a consequence of the site characterizations. It will be gained by analyzing present conditions; past changes in such attributes as climate, tectonism, and igneous activity; and the likelihood of comparable changes in the future.

5.3.1 BASALT

Reconnaissance hydrologic studies have been conducted in the Cold Creek syncline of the Hanford Site and adjoining areas. These studies have identified specific basalt intervals of high-to-low hydraulic conductivity, preliminary hydraulic-head distributions and hydrochemical trends, plus the hydraulic influence of local geologic structures.

Geohydrologic Setting

Ground water beneath the Hanford Site occurs in both a shallow unconfined aquifer that consists of stream and lake sediments that lie atop the basalts and in confined aquifers within basalt flow tops and interbeds. The unconfined aquifer is 0 to 250 feet thick across the Hanford Site. It lies in the Hanford and Ringold Formations (Figure 5-1) and is thickest along the eastern edge of the reference repository location, where 40 years of local water disposal to surface ponds has raised the water table by approximately 80 feet (ERDA, 1975). The base of the aquifer is defined either by silt and clay sediment of the lower Ringold Formation or the upper surface of the underlying Columbia River basalt. The water table marks the upper boundary of the unconfined aquifer. The hydraulic conductivity of the unconfined aquifer generally is 10^{-2} to 10^{-3} m/sec for coarse sand and gravels and as low as 10^{-7} m/sec for fine-grained, indurated sediments (Gephart et al., 1979). Storativity values typically range from 10^{-2} to 10^{-1}.

The wide range of hydraulic conductivities for formations within the unconfined aquifer reflect the heterogeneity of the geologic formations. Zones of higher conductivity are attributable to paleostream deposits within the Hanford Formation, while lower values commonly occur within the finer, more indurated sediments of the Ringold Formation. Two features are noteworthy. The first is an area of lower hydraulic conductivity beneath and in the vicinity of the reference repository location. This region consists of saturated Ringold sediments of relatively low hydraulic conductivity. The second feature is an area of high hydraulic conductivity (more than approximately 10^{-3} m/sec) occurring east and southeast of the reference repository location. This area consists of coarser-grained sediments deposited during Pleistocene glacial flooding.

The unconfined ground-water system is recharged by precipitation and runoff in nearby hills and waste-water disposal in surface ponds. The general direction of ground-water flow is from recharge areas toward and into the Columbia River. The hydraulic-head gradient along this flow path is about 10^{-3}. The general pattern of flow is locally interrupted by two ground-water mounds (rises in the water table) at the Hanford Site. These mounds result from the disposal of process water from existing facilities at the Hanford site. Piezometers located near water-disposal ponds at the Hanford Site show higher hydraulic heads at the top of the unconfined aquifer than at the bottom. This head distribution is characteristic of ground-water recharge areas. Piezometers near the Columbia River show increasing heads with depth during low river stages. This upward gradient identifies an area of ground-water discharge.

Existing hydrologic data do not support a single interpretation of the ground-water-flow system in the Columbia River Basalts. However, the important features of the overall basalt flow system as they appear to exist in and around the Hanford Site are summarized below.

Within basalt flows, ground water occurs and moves mainly in flow tops and interbeds. Basalt flow interiors appear to act as semiconfining beds through which some (as yet, unquantified) vertical leakage occurs along cooling fractures and structural features. The concept of lateral ground-water movement along flow tops and interbeds and low leakage across basalt interiors has been suggested by many investigators (e.g., La Sala et al., 1973; Luzier and Burt, 1974; Newcomb, 1965).

Local ground-water recharge to shallow basalts beneath the Hanford Site results from precipitation and runoff on basalt outcrops surrounding the Pasco Basin (La Sala and Doty, 1971; Gephart et al., 1979) and in places within the Basin by percolation from the overlying sedimentary aquifer. The regional recharge of deep basalts is thought to result from a combination of factors, including (1) interbasin ground-water movement (Tanaka et al., 1979), (2) leakage along structural and stratigraphic discontinuities, and (3) leakage across nondeformed basalt flow interiors.

Ground-water discharge from the shallow basalts probably is to the overlying unconfined aquifer and the Columbia River. The discharge area or areas for deep ground waters remain unknown. However, it is speculated that the discharge is south of the Hanford Site (La Sala and Doty, 1971; La Sala et al., 1973; DOE, 1982). Along these flow paths, water is under artesian pressures. Natural flowing artesian wells exist in the shallow basalts beneath the Cold Creek Valley, west of the reference repository location, and along the Columbia River where the land elevations are low.

On the basis of limited available data, hydraulic-head changes monitored in the deep basalts of the Cold Creek syncline appear to be slow and small. Head variations are comparable or slightly larger in shallower basalts, depending on location (Swanson and Levanthal, 1984).

When available piezometric data are combined with hydraulic-head information collected in progressive drilling and testing, a preliminary understanding emerges of the broad patterns of hydraulic heads that might exist across the Hanford Site. The western Hanford Site--the region closest to the Rattlesnake Hills, Yakima, and Umtanum Ridges--appears to be a recharge area for the shallow basalts. There, hydraulic heads decrease with depth. Eastward across the Hanford Site, heads become more uniform with depth in the central Cold Creek syncline. This suggests lateral ground-water movement. Close to the Columbia River, shallow hydraulic heads either increase with depth or have a variable pattern that suggests potential discharge.

In deep basalts, available data suggest either generally uniform heads or a slight increase with depth. The dominant head changes, characteristic of the shallower basalts, do not appear to exist in the deeper basalts. Overall, the ground water appears to flow southeast, toward the Columbia River, along a hydraulic gradient of about 10^{-4} m/m. The above head patterns have been reported or suggested by several investigators (e.g., La Sala and Doty, 1971; La Sala et al., 1973; DOE, 1982) and appear to be supported by hydrochemical data.

The above summary of hydraulic-head patterns is a conceptualization based on available information collected from piezometers and on a progressive drill-and-test basis. Because of the apparently low hydraulic gradients (vertically and horizontally) in the deep basalts beneath the Hanford Site and the uncertainty associated with the representativeness of heads collected during reconnaissance drilling and testing in the late 1970s and early 1980s, additional shallow and deep piezometers were installed in and around the proposed site. Preliminary data from these new piezometers appear to support earlier concepts of generally low hydraulic gradients existing in the deep basalts in and near the reference repository location.

The principal basalt aquifers exist within select sedimentary interbeds and basalt flow tops of the upper two basalt formations. Within the Saddle Mountains Basalt, the Rattlesnake Ridge, Cold Creek, and Mabton interbeds are frequently considered aquifers in addition to flow tops of the Elephant

Mountain and Umatilla Members. Some flow tops within the Priest Rapids, Roza, and Frenchman Springs Members of the Wanapum Basalt are also known to be aquifers. Comparatively few aquifers appear to exist within the Grande Ronde Basalt beneath the Hanford Site. As described by Gephart et al. (1983) and depicted in a report by Long and Woodward-Clyde Consultants (1983), flow-top hydraulic conductivity values are commonly heterogeneous, and therefore a zone identified as an aquifer in one location may not qualify as such at a second location. However, the aforementioned aquifers in the Saddle Mountains and Wanapum Basalts appear to be rather common features.

Areal and stratigraphic changes in ground-water chemistry, as detected from about 150 water samples, characterize basalt ground waters beneath the Hanford Site (Graham, 1983). These changes are believed to delineate flow-system boundaries (e.g., local versus regional flow systems) and identify chemical evolution taking place along ground-water flow paths. Some locations of potential mixing of deep and shallow ground waters have also been identified from these data. Overall, shallow and deep basalts are of the sodium bicarbonate and the sodium chloride chemical types, respectively. The stratigraphic boundaries separating these chemical types vary with the location. Studies are under way to understand the basalt and ground-water interactions controlling these chemical types and to interpret the role of hydrochemistry in developing a ground-water conceptual model.

<u>Physical Properties and Potential Ground-Water Pathways</u>

Ground-water movement in basalt may occur in (1) flow tops and interbeds, (2) cooling fractures within flow interiors, and (3) bedrock structural discontinuities (Gephart et al., 1983).

<u>Flow Tops and Interbeds</u>. A basalt flow top forms a more or less continuous layer atop the flow interior. The flow top of an areally extensive basalt flow may cover a few thousand square miles while its thickness, internal characteristics, and hydrologic properties spatially vary. Associated with some flow tops are sedimentary interbeds. Most interbeds are located in the Saddle Mountains Basalt, approximately 1300 feet above the shallowest basalt flow presently considered for repository construction. Flow tops and interbeds represent the zones of higher hydraulic conductivity.

To date, about 200 single-hole hydrologic tests have been conducted in flow tops and interbeds in some 35 separate boreholes across the Hanford Site. These data indicate that within both the Saddle Mountains and the Wanapum Basalts, the hydraulic conductivities of most individual flow tops and interbeds range between 10^{-4} and 10^{-7} m/sec, with a geometric mean of approximately 10^{-5} m/sec. Most hydraulic conductivity values within Grande Ronde Basalt flow tops range between 10^{-5} and 10^{-9} m/sec, with a geometric mean of approximately 10^{-7} m/sec (Long and Woodward-Clyde Consultants, 1983).

Two tracer tests have been conducted in the flow top of the McCoy Canyon flow (Bakr et al., 1980; Gelhar, 1982; Leonhart et al., 1982). Dispersivity values reported were 1.5 to 2.8 feet with an effective thickness of 6×10^{-3} to 10×10^{-3} foot.

<u>Flow Interiors</u>. Ten hydrologic tests (using pulse and constant-head injection test methods as described by Strait et al., 1982) have been con-

ducted across the dense entablature and colonnade portions of individual flow interiors at depths of about 1150 to 3900 feet. Horizontal hydraulic conductivities measured were less than or equal to 10^{-11} m/sec. Low hydraulic conductivities for flow interiors have been reported or suggested by other investigators (e.g., La Sala and Doty, 1971; Newcomb, 1982). The first field test (a ratio test) attempting to quantify the vertical hydraulic conductivity and to evaluate test methods within flow interiors has been completed (Spane et al., 1983). The results suggest a vertical hydraulic conductivity of approximately 10^{-10} m/sec for a test zone in the Rocky Coulee flow interior. However, the results indicate that in basalt the ratio method for determining vertical hydraulic conductivity may be of limited application in available boreholes. Other test methods are under evaluation.

In lieu of direct measurements, estimates of the anisotropic ratio for vertical-to-horizontal permeability in flow interiors have been derived by considering a hexagonal cooling-joint configuration and applying a flow balance (DOE, 1982). The ratio obtained was approximately 2:1. Statistical modeling of fracture sets indicates a maximum anisotropic ratio of approximately 3.5:1 (Sagar and Runchal, 1982). Thus, once several field measurements become available, it is believed that the vertical hydraulic conductivity of undeformed basalt flow interiors will probably be shown to be similar to the horizontal-conductivity values currently reported.

Some vesicular zones within basalt flow interiors have been hydrologically tested. Hydraulic-conductivity values ranged between 10^{-8} and 10^{-13} m/sec (Long and Woodward-Clyde Consultants, 1983). Whether such conductivities are typical of vesicular zones is not known at present.

Bedrock Structural Discontinuities. Bedrock structural discontinuities represent zones of potentially significant fracture anisotropy that may vertically connect flow systems or represent low-hydraulic-conductivity barriers to ground-water movement.

Synclinal troughs, where exposed in the Columbia Plateau outside the Pasco Basin, appear to exhibit less strain than do other portions of the Yakima fold structure (Price, 1981). However, the difficulty with directly extrapolating this regional characteristic to the Cold Creek syncline is that the latter is filled with sediment, which precludes direct observation. Geophysical surveys and borehole core samples are enabling geologists to map the geologic structure within the Cold Creek syncline. Because the trough of the Cold Creek syncline in which the proposed repository site lies is a broad, open structure, it is interpreted to contain fewer bedrock structures relative to anticlinal areas. Inferred or known bedrock structures in the Cold Creek syncline have been reported (Myers, 1981) and are under investigation.

The gently dipping limbs of anticlines and synclines within the proposed site contain small zones of tectonic breccia. These zones are typically about 3 feet thick in drill cores and are of unknown lateral extent (Moak, 1981).

One tectonic breccia in the Frenchman Springs Member of the Wanapum Basalt was tested and found to have a hydraulic conductivity of 10^{-11} m/sec. Future testing will determine whether this low value is characteristic of other tectonic breccias.

The Cold Creek hydrologic "barrier" is an example of what is interpreted as a bedrock structural discontinuity that represents a lateral impediment to ground-water flow. This feature runs north-south and is approximately 1 mile west of the reference repository location. From west to east across this feature, hydraulic heads abruptly drop as much as 500 feet. In addition, hydrochemical data suggest that mineralized deep waters may be mixing vertically with more dilute, shallower ground waters along or near this feature. The lateral extent and rate of possible ground-water mixing are as yet undefined.

Alternative Concepts of Ground-Water Flow

Because existing geohydrologic data are too preliminary to conclusively support a single quantified ground-water-flow model, four alternative working hypotheses were developed (Figure 5-8).

Concept A illustrates ground water moving mainly within heterogeneous, permeable flow tops that separate flow interiors of relatively low vertical and horizontal hydraulic conductivity. Ground-water movement across basalts can occur (1) along basalt flow tops, or (2) as leakage across flow interiors of low hydraulic conductivity. Basically, this concept depicts an anisotropic, heterogeneous flow system undisturbed by major folds and faults.

Concept B is similar to concept A except basalt flows are crossed by bedrock structural discontinuities with potentially larger vertical hydraulic conductivities than the confining aquitards. On a local scale, such discontinuities might represent individual tectonic fractures or shear zones. Regionally, these features could depict major faults or folds. Such structures are heterogeneities with the potential for vertically connecting shallow and deep flow systems. Depending on the extent of fracture mineral infilling or fine-particulate materials present, these discontinuities could act as conduits of high hydraulic conductivity or ground-water barriers. Overall, concept B depicts rock volumes of relatively low vertical leakage bounded by structures of potentially higher leakage.

Concept C represents a flow system characterized by lateral ground-water movement in flow tops bounded by basalt interiors of relatively high leakage. The anisotropy of flow-top and interior hydraulic conductivity is considerably less than in concept A. In concept C, ground-water movement between deep and shallow systems occurs as a result of the stratigraphic position and intersection of flow tops and vertical leakage through unfilled or partially filled cooling fractures or other possible primary features.

Concept D superimposes bedrock structural discontinuities on concept C. As described under concept B, such discontinuities might act as vertical conduits or barriers of low hydraulic conductivity. Overall, concept D depicts basalt flow interiors of relatively high vertical leakage bounded by structures.

The concept currently interpreted as most supported by available data is concept B. Bedrock structural discontinuities in this concept are considered less frequent and more widely spaced in the gently dipping limbs of the reference repository location in the Cold Creek syncline than in the hinge areas and steeply dipping limbs of the accompanying anticlines.

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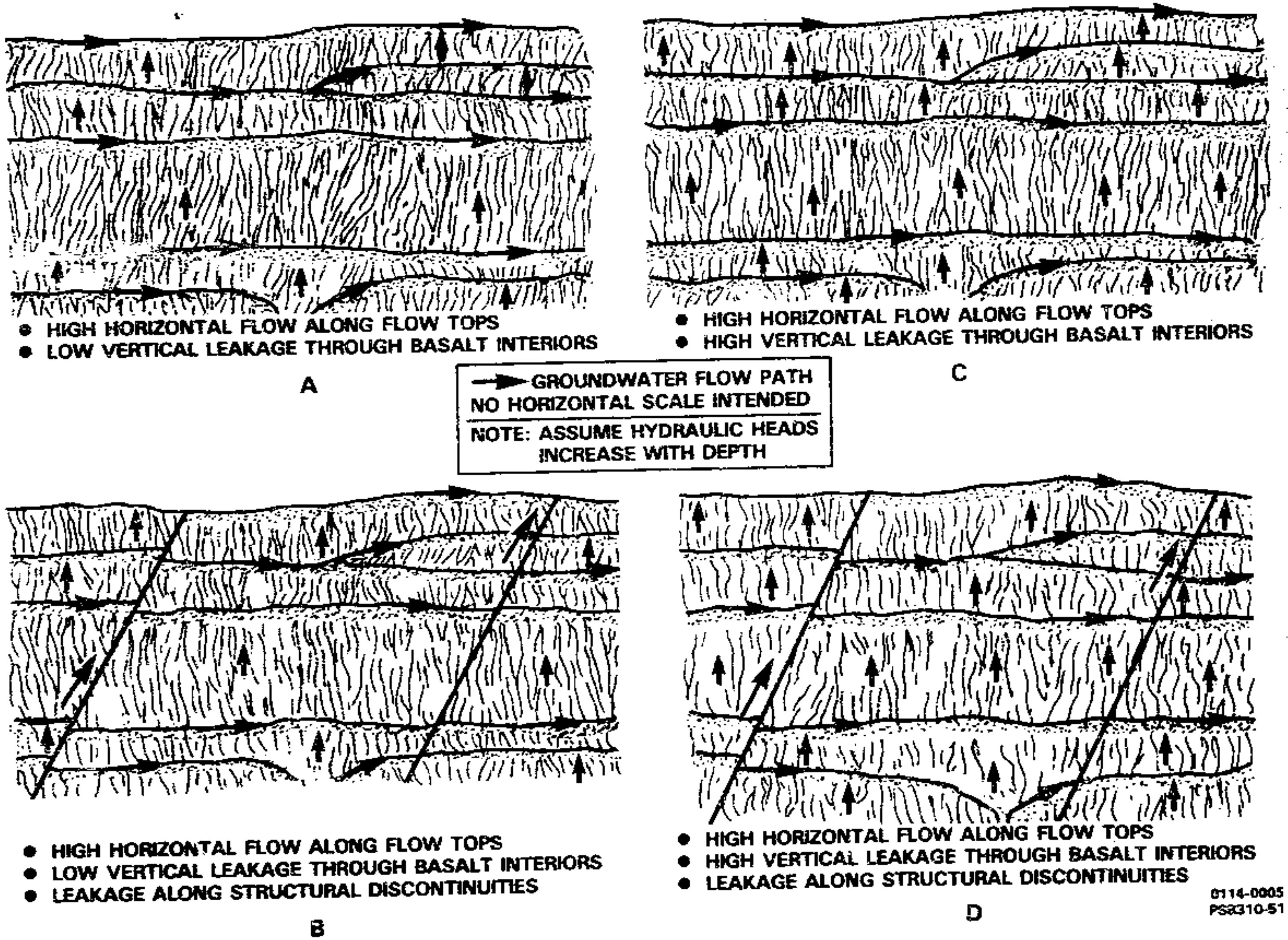

Figure 5-8. Alternative concepts of ground-water flow in basalt.

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Quantification of the hydrologic system so as to develop a technical consensus of ground-water movement in and around the reference repository location must await the completion of site characterization.

5.3.2 SALT

To date, hydrologic analyses of the five potentially acceptable salt sites have been made mainly from regional data. A limited amount of site-specific data has been gathered from exploration wells drilled at or very near the potential sites.

Studies of the aquifers that contain usable water have been limited to available data on water levels, aquifer characteristics, aquifer yields, and water quality. The properties of the deep brine aquifers have been obtained from preexisting data and from wells drilled by the DOE. From these preliminary data, potentiometric maps have been prepared, hydraulic pressure gradients determined, and conceptual models of the geohydrologic system constructed. These data serve as input to numerical modeling. Preliminary assessments of ground-water travel times, as required by the DOE siting guidelines (10 CFR Part 960), are provided in the draft environmental assessments for the salt sites (DOE, 1984c, d, e, f, g).

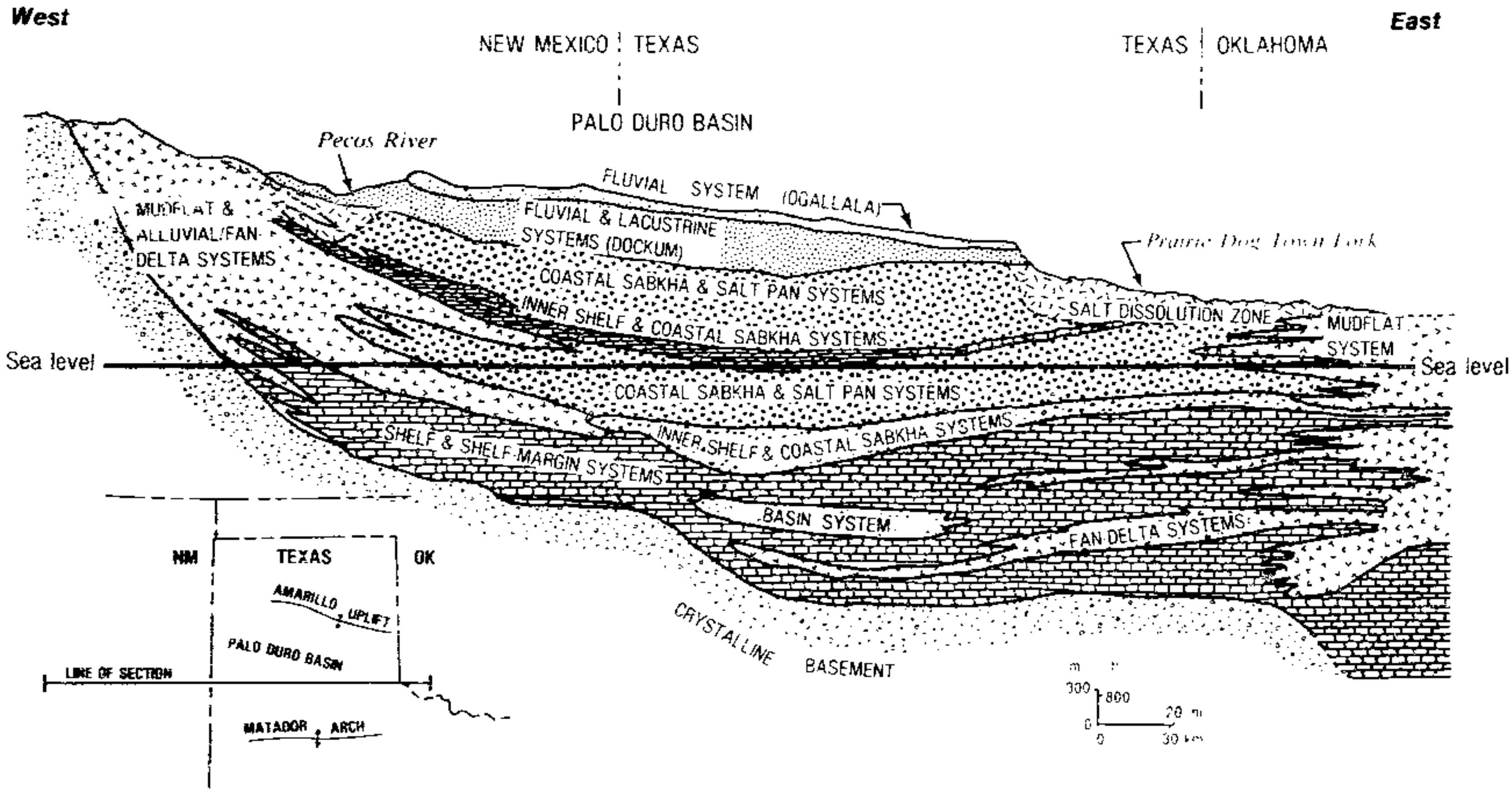
5.3.2.1 Bedded-Salt Sites in the Palo Duro Basin

Geohydrologic Setting

The geohydrologic setting at both sites can be divided into three hydrostratigraphic units (Figure 5-9). The upper unit consists of the shallow fresh-water flow system. With a total thickness of about 1150 feet, this unit consists of the Ogallala Formation and the Dockum Group (SWEC, 1983a, b). It is recharged by precipitation falling on the High Plains of Texas and eastern New Mexico. On a regional scale, flow in the upper unit is west to east, but local variations are common because of the pumping wells located throughout the Texas High Plains. Discharge from the upper unit occurs through extensive pumping for irrigation, municipal, and industrial water uses. Discharge also occurs along the escarpments and river valleys that bound the High Plains aquifer (Figure 5-9).

The middle unit is a section of carbonate rocks, shale, and evaporites. It is considered a regional aquitard and contains the Lower San Andres salt formation. This unit is 3200 to 3800 feet thick (SWEC, 1983a, c). Because of the low vertical hydraulic conductivity of the evaporites (10^{-12} m/sec or less), it is assumed that there is virtually no vertical flow in this unit; however, some interbedded carbonate units have higher hydraulic conductivities, and ground-water flow is primarily horizontal within them.

The lower unit of deep-basin flow consists of carbonate rocks, shales, and an arkosic sandstone, locally known as the "granite wash." Recharge occurs from precipitation at the outcrop areas in New Mexico and possibly through leakage along local discontinuities in the middle unit. Flow in the deep-basin aquifers of the lower unit is generally to the northeast throughout



Source: SENGER, 1983

Figure 5-9. Geologic cross section of the Palo Duro Basin.

the study area. Oil and gas production along the margins of the basin has distorted the regional flow patterns. The discharge areas of the deep-basin aquifers are not known yet but are thought to be to the east, in Oklahoma, where stratigraphically equivalent units crop out.

Pathways

Comparison of potentiometric maps of the upper unit (the Ogallala aquifer) and the lower unit (the Wolfcamp series) indicates a downward vertical gradient across the potential host rock. Thus, initial hydrologic modeling assumed that any release from the repository would tend to move downward through the middle-unit aquitard to the deep-basin lower unit. However, interbedded shale and carbonate strata in the aquitard also represent possible pathways for release.

Intera (1984) modeled the hydrology of the Palo Duro Basin. Simulations of the deep aquifer's potentiometric surface indicate that the average vertical hydraulic conductivity of salt is very low (10^{-13} m/sec or less). Other researchers also indicated similar low values (Aufricht and Howard, 1961; Gloyna and Reynolds, 1961). However, no in-situ testing of salt has been done to date in the basin. Nonsalt interbeds in the middle unit have been tested (SWEC, 1983a, b, c). The Lower San Andres Cycle 4 dolomite, which lies below the host rock, is considered the most permeable interbed. Drill-stem tests yielded a maximum hydraulic conductivity of 2.4×10^{-9} m/sec.

The upper part of the Wolfcamp is permeable and is the topmost deep-basin brine aquifer. Hydraulic conductivity generally ranges from 10^{-8} to 10^{-9} m/sec (Gustavson et al., 1982), though higher values were found in places along the margins of the basin and in producing oil and gas fields.

The "granite wash" is an arkosic sandstone that is likely to have a high permeability, especially along Precambrian uplifts, which were the source of the sediments. The granite wash lies approximately 7800 feet below the surface at the sites (1500 feet below the proposed repository depth), but its distance from the repository makes it a less-likely flow path.

Oxygen-isotope data show two groupings of deep-basin brines. One group of brines show the isotopic signatures expected for isotopic equilibrium with carbonates at the measured subsurface temperatures; these ground waters are present in the eastern part of the Palo Duro Basin. The second group of brines show the isotopic signatures expected for variable mixtures of rainwater (which are now brine) with carbonate-equilibrated brines; the mixed waters are present to the west of the carbonate-equilibrated brines. The simplest present working hypothesis is that the mixing of rainwater and brines occurs somewhere west of Deaf Smith County. Presumably, the rainwater acquired its salinity by dissolving salt along the western edge of the Permian evaporite sequence in the Palo Duro Basin.

Oxygen-isotope data have also been used to identify the origin of saline springs along and eastward of the caprock escarpment. It was found that rainwater was percolating downward, dissolving salt, and issuing as saline springs (Kreitler and Bassett, 1983). The alternative hypothesis, that the saline springs were discharging deep-basin brines, is refuted by the isotope data.

Seismic-reflection surveys of the study areas do not indicate any major structural discontinuities in the vicinity of the sites. Several faults are inferred to exist as high in the section as the Lower Wolfcamp, but do not offset any of the overlying units in the middle-unit aquitard.

As noted, the data base is regional, and local small-scale variations undoubtedly exist. However, the conceptualization presented here is felt to be an accurate representation of the geohydrologic setting of the Palo Duro Basin.

5.3.2.2 Bedded-Salt Sites in the Paradox Basin

Geohydrologic Setting

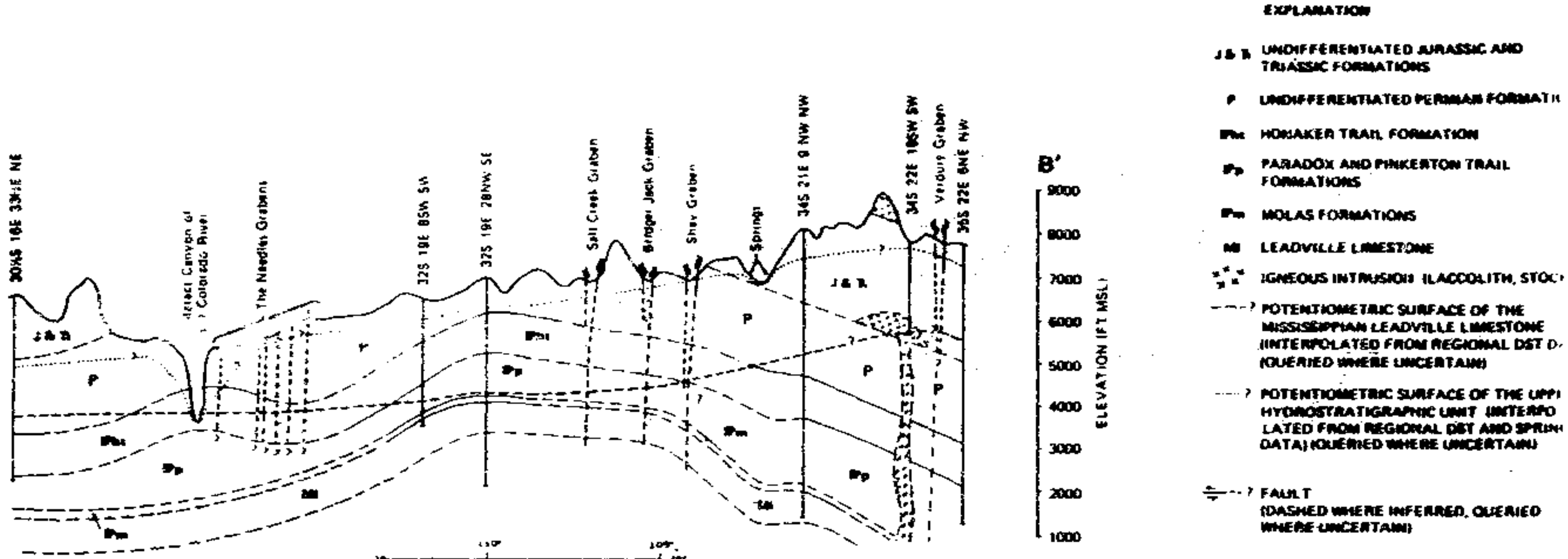
Three hydrostratigraphic units have been tentatively defined in the study area (Figure 5-10). The upper unit consists mainly of Permian sedimentary rocks and is approximately 2000 feet thick at the candidate sites. Its rocks are generally fine-grained sandstones and interbedded siltstone. The middle unit consists of shales, carbonate rocks, and evaporites. The host rock (Salt Cycle 6) lies within the middle unit. The middle unit is considered an aquitard on a regional scale and is more than 50 percent halite. The lower unit consists mainly of limestone interbedded with mudstone, siltstone, and sandstone in the upper parts. The Leadville Limestone is considered to be the major deep-basin aquifer.

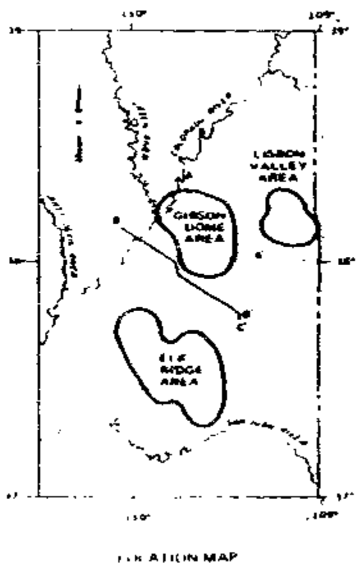
The sandstone formations of the upper unit can be considered local aquifers, though yields seldom exceed several gallons per minute. Water quality deteriorates with depth, and only the upper parts of this unit may contain potable water. In the area of the sites the upper unit is recharged by precipitation and influent streams. Because the data necessary to quantify the various components of recharge are not sufficient at present, these topics are addressed only qualitatively here.

Precipitation over most of the study area ranges from 8 to 12 inches per year (Butler and Marsell, 1972). The Abajo Mountain area, which is the point of origin for the perennial stream that flows through the area, has more than 32 inches of precipitation in an average year. Only a small portion of this precipitation is thought to recharge the ground-water system.

Perennial and ephemeral streams recharge the upper unit. Indian Creek, the perennial stream that flows from the Abajo Mountains across the area to the Colorado River, recharges the upper unit along at least part of its reach. Ephemeral streams like those in Lavender, Davis, and Rustler Canyons and Harts Draw may also act as sources of recharge. No data are available regarding the recharge contributed by these surface drainages, but Indian Creek may be the most significant contributor.

The major components of ground-water discharge from the upper unit in the site areas are springs, subriver seeps to the Colorado River and associated drainages, and evapotranspiration. The Colorado River has incised through most of the upper unit in the western part of the area and forms the major line sink or discharge zone (Figure 5-10). Extremely minor amounts of ground water are pumped from the shallow parts of the upper unit for domestic and





SOURCES:

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY, 1965

PETROLEUM INFORMATION CORPORATI

USGS GEOLOGIC MAPS
SALINA QUADRANGLE, 1971
MOAB QUADRANGLE, 1984
CORTEZ QUADRANGLE, 1972

Figure 5-10. Hydrologic cross section of the Gibson Dome area.

agricultural uses. Some discharge to the underlying units may occur in areas like the Lockhart Basin or, perhaps, Shay Graben, where structural features or salt dissolution may have created permeable pathways. Mineralization of fractures and alteration within Shay Graben are indicative of past ground-water movement. Similar pathways may be actively conveying fluids at depths.

Evapotranspiration is another significant component of discharge in the study area. Certain types of plants consume large quantities of water and account for a significant part of the discharge. The occurrences of these plants have not been comprehensively mapped, but field surveys indicate that most of them grow along surface drainages and the Colorado River.

Ground-water withdrawals from the upper unit in the area are limited to scattered small-capacity stock wells and domestic wells, including four wells that supply the Canyonlands National Park (Sumsion and Bolke, 1972). Such shallow wells can yield approximately 4 to 60 gallons per minute. The estimated total per capita ground-water use by visitors to the park is 15 gallons per day.

Springs associated with the outcrop of the Indian Limestone suggest that this thin but resistant limestone may impede downward flow where it is present in the western part of the site area. The springs may represent the discharge of regional ground water or, in some cases, perched-aquifer zones or rises of alluvial water beneath the stream channels. In either case, the discharge is not large (Sumsion and Bolke, 1972).

Significant recharge to, or discharge from, the middle unit does not appear to occur in the site area, except possibly where the normal stratigraphic sequence has been disrupted (e.g., Lockhart Basin and Shay Graben). Data on potentiometric levels, permeability, and regional water chemistry support this statement.

Lateral recharge and discharge at the boundaries of the area are hindered by low permeability. Potentiometric and permeability data for the middle unit in the area are from borehole GD-1 and several wells along the southeast part of the Gibson Dome study area. Horizontal flow and areas of recharge and discharge are not known. The low permeabilities measured in both interbeds and salt beds imply that significant horizontal flow is not likely in the middle unit.

Available data suggest that significant vertical flow (i.e., cross-formational flow) does not occur through the middle unit where the normal stratigraphic sequence has not been disrupted. The potentiometric surface in the lower unit at GD-1 is generally lower than that measured in the upper unit, which indicates that the middle unit is acting as an aquitard. This finding is supported by the difference in water quality above and below the middle unit.

Lateral inflow is the principal component of recharge for the lower unit in the site area. The regional potentiometric contours in the lower unit and the low permeability of the middle unit indicate that flow is principally horizontal. The ground-water recharge to the lower unit apparently occurs beyond the eastern boundary of the area and possibly in the vicinity of the Abajo Mountains. Lateral flow without surface discharge occurs through the southwestern and western boundaries of the area. Cross-formational flow to or from the middle unit probably does not occur within the area because of the low permeability of the middle unit. A drill core from GD-1 does not indicate any salt dissolution and thus provides evidence that little, if any, ground-water flow has occurred through the salt beds there. However, cross-formational flow may occur in Lockhart Basin and Shay Graben, where permeable conduits may exist through the middle unit. The potentiometric and geochemical data are too sparse to establish whether cross-formational flow is occurring at those locations.

Pathways

A Comparison of maps of the potentiometric surfaces of the upper unit and the lower unit indicates a downward vertical gradient across the host rock. This is supported by the results of long-term testing (Woodward Clyde Consultants, 1983) at borehole GD-1. Preliminary modeling assumed that this downward gradient would cause any release from a repository to move downward. In-situ and laboratory tests of the salt section in the GD-1 borehole indicate a hydraulic conductivity of less than 1×10^{-12} m/sec. Preliminary modeling also assumed that the likely pathway for released radionuclides is downward through the evaporite section and horizontally through the Leadville Limestone. The computed travel time through the low-permeability evaporite section (2000 feet thick below Salt Cycle 6) is 120,000 years. Long-term tests yielded a hydraulic conductivity of about 3×10^{-10} m/sec or less for the interbed below Salt Cycle 6.

The hydraulic conductivity of the deep-basin Leadville Limestone was calculated to be approximately 2×10^{-7} m/sec in the GD-1 borehole. However, interbeds within the middle unit, consisting of interrelated shale and carbonate strata, also represent possible pathways. The data base used to date is regional; it consists of data from water wells, springs, oil and gas wells, and DOE-funded exploration wells. The available data are too sparse to establish the effects of nearby structural features on the geohydrologic regime. Figure 5-10 shows geohydrologic cross sections based on currently available data.

5.3.2.3 Salt Domes

Geohydrologic Setting

Fresh ground water in the area of the Cypress Creek and Richton Domes occurs in discontinuous, lenticular sand deposits that are interbedded with clay, marl, and limestone primarily of Miocene age. Saline water occurs in deeper aquifers and in the caprock of the domes. Estimates of the transmissivity of the saline and fresh-water aquifers range from 38 to 2600 m^2/day, and estimates of the horizontal ground-water velocity range from 0.1 to 100 m/yr. The presence of saline water at relatively high elevations in wells near the domes suggests either salt dissolution at or near the tops of the domes or upward movement of saline water around the flanks of the domes (Bentley, 1983).

The major source of fresh ground water (i.e., water with less than 1000 mg/l of dissolved solids) in the study area is the Miocene aquifer system, which consists of the Catahoula Sandstone and the Pascagoula and Hattiesburg Formations (see Figure 5-3). The Citronelle Formation also is an important aquifer locally. The base of fresh water generally ranges from 400 to 1400 feet below sea level in the southeastern part of the basin. The depth to the base of fresh water, and the quality of water, may be altered locally by withdrawals, oil-field injection wells, salt dome dissolution or the upward movement of water from saline aquifers. The general movement of water in the Miocene aquifers is southward, toward the Gulf.

The Miocene aquifers are highly permeable. Hydraulic conductivities of about 30 m/day have been estimated from about 200 tests in southern Mississippi. Hydraulic conductivities may be as much as 37,000 m/day if based on the maximum cumulative thickness of sand in the aquifer system (Spiers and Gandl, 1980; LETCo, 1982a).

Sedimentary strata in the region of the Vacherie Dome generally dip to the south and east as a result of postdepositional subsidence, which continues at present. Ground-water flow in the identified units typically is in the downdip direction, except in areas where flow patterns are affected by ground-water withdrawal or local variations due to recharge and discharge to streams. Flow in the deeper aquifers tends to be toward the southeast, from recharge and outcrop areas northwest of the dome toward the Gulf Coast, though local variations do occur.

The natural downdip movement of ground water in the shallow units, mainly the Sparta aquifer (Figure 5-4), is affected by ground-water withdrawals at three pumping centers to the north and east of the dome (Ryals, 1982). Ground-water withdrawals from the Sparta have been extensive, and water levels are reported to have declined a total of 40 to 60 feet at Minden between 1965 and 1980 (Ryals, 1980a). Ground-water withdrawals from the Sparta aquifer average about 10 million gallons per day in the vicinity of the Vacherie Dome (Urban Systems Associates, Inc., 1982).

The salt-dome emplacement resulted in a topographic high above the salt body that constitutes a recharge area. Local recharge effects in the Carrizo Sand-Wilcox aquifer result in local ground-water flow to the northwest and to the south. Recharge over the dome produces significant effects on the local ground-water flow but only minor effects on the regional flow system (Ryals, 1980b).

Pathways

In the area of the Richton and the Cypress Creek Domes, extensive areal recharge occurs in the upper unconfined aquifer from the infiltration of precipitation in excess of direct runoff and evapotranspiration. A large proportion of this recharge either returns to the surface as discharge from the upper aquifer to the five major rivers in the region or is withdrawn for municipal or domestic use. Significant recharge from infiltration also occurs to the deeper aquifers of the upper Claiborne and the Wilcox, in the northern part of the regional system where they crop out. This recharge flows to the south and is discharged principally to the upper aquifer via leakage.

The flow system of the upper aquifer in the vicinity of the Richton Dome diverges slightly around the relatively impermeable dome and continues downgradient in a southerly direction until it intercepts the Leaf and the Pascagoula Rivers. There, the flow changes direction and moves upward, discharging into these rivers. The ground-water flow in the Wilcox unit remains generally to the south-southeast, but, in the upper Claiborne and alluvial aquifers, it flows toward the rivers downstream of the dome. Flow through the lower Claiborne unit, a confining layer, is upward downstream of the dome. Flow in the upper confining layer, the Vicksburg and Jackson units, is upward toward the shallow aquifer in most of the regional system.

Figure 5-11 is a simplification of the possible paths of release from the Richton Dome to the various aquifer units. Travel paths are primarily horizontal in aquifer layers and vertical in confining layers. Figure 5-11 shows how far a particle would travel from its release point outside the dome before entering the surface-water system. The paths would be similar for the Cypress Creek Dome.

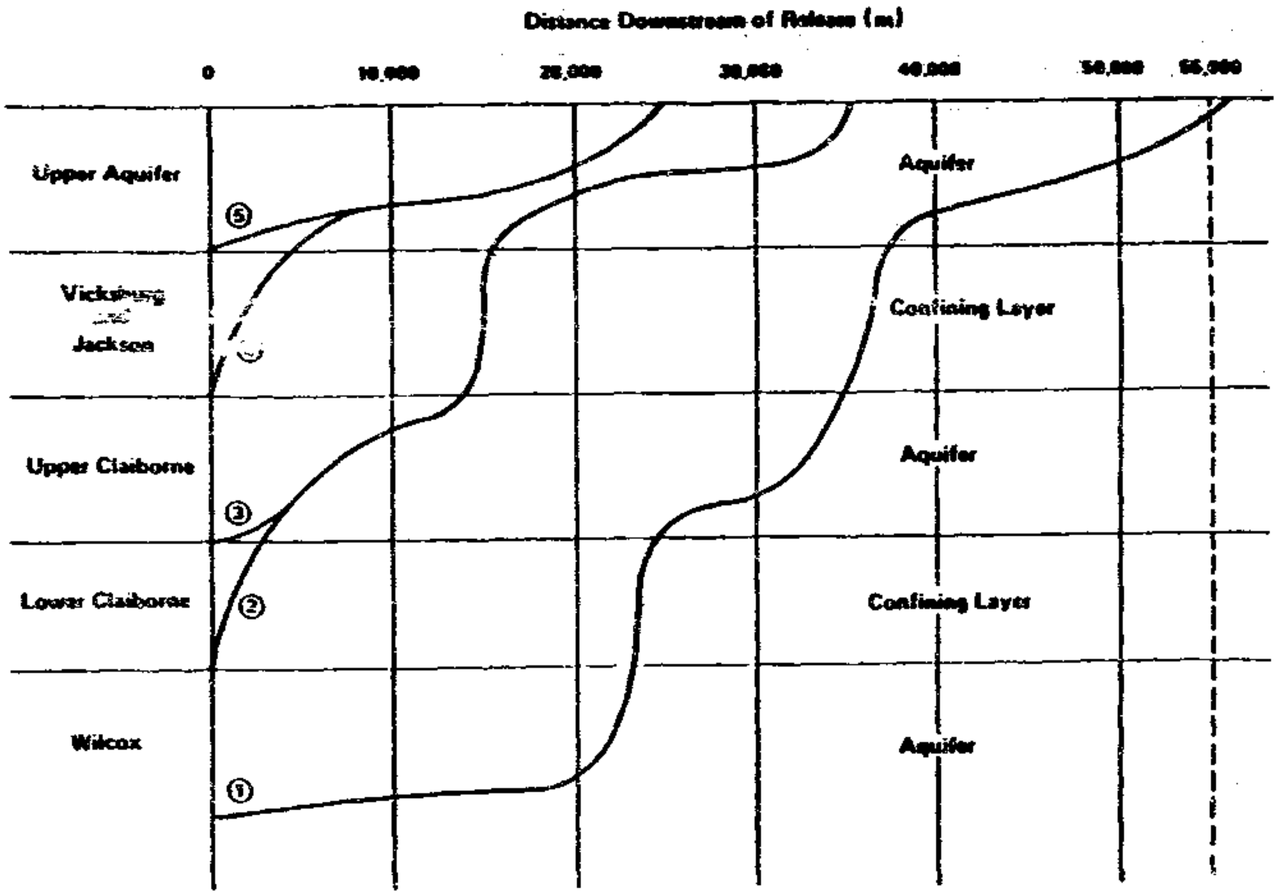
Because of the location of the repository level, it is likely that any release would occur into the Wilcox unit (travel path 1) at the Richton Dome. The proposed repository level at Cypress Creek is adjacent to the upper Claiborne unit, and any release would most likely follow a path similar to travel path 3. Releases into the upper units at Cypress Creek become progressively less likely as the depth of the unit decreases. A possible release directly into the upper aquifer unit (travel path 5) is considered extremely unlikely, but was included for completeness.

The pathways at the Vacherie Dome are similar to those for the other two domes. The major difference is that at Vacherie the transmitting geohydrologic units are lower in the stratigraphic column. In northern Louisiana, the Sparta Formation and the Wilcox Group are the major upper aquifers and the Austin Group is the major lower aquifer. It is currently thought that the most likely pathway is laterally to the side of the dome and from there to the southeast at great depth in the Austin Group.

This discussion of pathways assumes that releases occur at depth and that transport to the surface-water system is controlled by the regional ground-water-flow system. Knowledge of local ground-water flow in the vicinity of the domes is currently quite limited. Additional near-dome pathways such as along the dome sheath or along faults may exist, but data needed to define these potential paths are not available.

5.3.3 TUFF

The geohydrologic system at Yucca Mountain is composed of a thick unsaturated zone and a deep saturated-flow zone. Hydrologic investigations of the saturated zone have estimated the standard parameters of hydraulic conductivity, hydraulic gradient, effective porosity, and water flux. For the unsaturated zone, the same parameters are needed, but must be augmented with information on moisture content, its effects on moisture tension, hydraulic conductivity, and infiltration rates. These parameters have been used to identify the directions of ground-water flow and to estimate ground-water



Numbers represent the pathways discussed in the text. This simplification does not reflect consistent distances or scaled in the vertical direction.

Figure 5-11. Estimated travel paths for redionuclides released from a repository in the Richton dome.

velocities and travel times. In addition, studies of paleohydrology have been conducted to evaluate the potential hydrologic effects of future climatic changes.

Unsaturated Zone

Hydrologic testing in drill holes revealed that the water table is generally 1600 to 2500 feet below the mountainous land surface of the Yucca Mountain site and 1000 feet or more below the surface in areas surrounding the site. Thus, the water table is sufficiently deep to permit siting a repository in the unsaturated zone. Current hydrologic knowledge is based principally on results obtained from geologic mapping, from laboratory analyses of cores and cuttings, and from the drilling and instrumentation of test holes in the unsaturated zone.

The hydrologic properties of the rocks in the unsaturated zone and the amount of water infiltration control the moisture content and the manner and rates of flow. Only a few results of studies of the unsaturated zone are available, but these have allowed the definition of geohydrologic units and the development of preliminary conceptual flow models. The definition of different units is based principally on the degree of welding in the tuff, which strongly affects the hydrologic properties. In order of increasing depth, the units are the Tiva Canyon welded unit, the Paintbrush nonwelded unit, the Topopah Spring welded unit (which includes the repository horizon), and the lower part of Calico Hills nonwelded unit. The water table is generally beneath or within the Calico Hills nonwelded unit.

The welded tuffs generally have low matrix permeabilities (saturated hydraulic conductivities of 10^{-8} m/sec or less), low water contents (about 6 percent by weight), high tensions (as much as 40 bars), and high fracture densities (10 to 40 fractures per cubic meter). In contrast, the nonwelded units have higher hydraulic conductivities, high effective porosities (20 to 30 percent), and lower fracture densities (a few fractures per cubic meter).

Concepts of the unsaturated-zone flow system have been developed on the basis of preliminary data. These concepts will be tested in future studies, but indications are that the ground-water flux is very low. The Paintbrush nonwelded unit may serve as a natural capillary barrier to divert pulses of recharge flux beyond the boundaries of the repository. The welded unit of the Topopah Spring Member probably has a very low flux, both in fractures and the rock matrix.

The low volumetric downward rate of water movement coupled with possible preferential flow through fractures will minimize contact between the waste and water, thus providing the first hydrologic barrier to waste migration. This expected condition of the rock also mitigates concerns about such factors as induced fracturing, dehydration of clays or zeolites, and heat-induced high water pressures.

Saturated Zone

Extensive hydrologic testing of the saturated zone has been performed in test wells in the immediate vicinity of Yucca Mountain. These tests have included pumping tests of all or part of the saturated zone penetrated by the well and packer-injection tests of isolated intervals within the boreholes. In addition to identifying zones of water inflow during pumping, the data collected include the distribution of hydraulic heads and hydraulic conductivity. Chemical analyses have been made of water samples from 1[illegible] water wells and test wells. In addition, 14 other test wells have been drilled to provide data on the elevations of the water table.

Most test wells were drilled to depths ranging from [illegible]000 to 6000 feet. These wells penetrated volcanic rocks (mostly tuff) of Tertiary age. The hydraulic conductivities of the tuffs range from approximately 10^{-4} to 10^{-12} m/sec. Productive intervals in test wells are controlled mostly by the distribution of permeable fractures intercepted, rather than by stratigraphic position. As a result, no hydrostratigraphic units have been defined for the saturated zone.

Ground-water flow in the saturated zone is mainly through fractures in the moderately to densely welded tuffs. As a result, the effective porosity is probably low; it is assumed to be about 0.005, but it may be as low as 0.002. Multiple- and single-well tracer tests are planned to evaluate this parameter.

Preliminary water-table maps have been constructed on the basis of water-level measurements in test wells; however, the influence of geologic structures on the configuration of this surface has not been fully evaluated. Between Yucca Mountain and the accessible environment to the east and southeast, the hydraulic gradient is very low (3.4×10^{-4}).

One test well was drilled through the tuffs into prevolcanic carbonate rocks. These rocks are permeable, but the hydraulic head in this section is about 70 feet higher than the water table in the tuffs. Thus, the radionuclides in the repository would not be transported downward to an underlying permeable carbonate aquifer but, rather, laterally in the tuffs.

Pathways

Paths of likely radionuclide transport in the unsaturated zone at Yucca Mountain are downward to the water table, passing through the lower part of the welded unit of the Topopah Spring Member and the nonwelded unit of the Calico Hills tuff. Preliminary data indicate that the Calico Hills unit has a high effective porosity and that the matrix has a high enough conductivity to pass the probable prevailing flux of 1 mm/yr or less. The measured or estimated properties of the nonwelded unit of the Calico Hills tuff indicate that the probable travel time of ground water through this unit to the water table exceeds 20,000 years, and the ground water travels through highly sorptive minerals that will retard most radionuclides.

Between Yucca Mountain and the accessible environment, ground water in the saturated zone moves through the welded Crater Flat Tuff, the nonwelded tuffaceous beds of Calico Hills, and the welded Topopah Spring Member. Although the gradient is low, the relatively low effective porosity and the high hydraulic conductivity (about 1.8×10^{-6} to 1.6×10^{-5} m/sec) along the possible flow paths result in relatively short preemplacement ground-water travel times in the saturated zone. Thus, the qualification of the site on the basis of preemplacement ground-water travel times is dependent largely on travel times in the unsaturated, rather than the saturated, zone.

Future Hydrologic Conditions

Estimates of hydrologic changes that might result from future climatic changes have been based principally on an assessment of climatic extremes and the resulting hydrologic conditions during the Quaternary Period. The climates of the last 45,000 years have been reconstructed largely on the evidence of plant materials preserved in the middens of packrats. Interpretations of the positions of late Pleistocene water levels and discharge points have been made for the nearby Ash Meadows ground-water basin from the distribution of calcite veins in alluvium and lakebeds and of fossil-spring deposits of tufa.

The results of these studies indicate that even during pluvial periods the climate in the region was not substantially different from the modern climate. For example, the studies of packrat middens indicate that at the time of the global glacial maximum during Late Wisconsinan time (about 18,000 years before the present), the average annual temperature in the region was 6 to 7°C cooler and average annual precipitation was 30 to 40 percent above present values (Spaulding et al., 1984).

The climatic changes that resulted in pluvial conditions during the Quaternary Period probably had the following effects on the hydrologic system: increased recharge, increased elevations and gradients of the water table, upgradient shifts in discharge loci, and changes in surface-water drainage systems. Although there is little evidence in the immediate vicinity of Yucca Mountain to indicate the magnitude of these effects in that area, regional evidence indicates that, within the framework of the geologic setting and the arid-semiarid climate, the effects were minor (Winograd and Doty, 1980). Furthermore, the climatic changes expected during the next 10,000 years are not likely to adversely affect the performance of the repository.

5.3.4 GENERIC RESEARCH

The DOE is also conducting generic research that is related to hydrogeology and could be applicable in predicting repository performance. For example, at the Argonne National Laboratory, the Lawrence Berkeley National Laboratory, the Los Alamos National Laboratory, and the Lamont-Doherty Geophysical Laboratory, the DOE is supporting generic research in the following areas: solute migration in the earth's crust, with emphasis on the migration of heavy elements; fluid flow in fractured rock masses; fluid, heat and solute transport in underground formations; element fixation in crustal rocks; and the effects that organic compounds in ground water have on the mobility of trace metals and radionuclides.

5.4 SIGNIFICANT RESULTS OF RESEARCH IN GEOCHEMISTRY

The geochemical conditions in the ground water, the host rock, and in the vicinity of the waste package (i.e., the near field) will affect the containment of the waste by promoting or inhibiting the corrosion of waste containers. After the containment of the waste package is breached, they will also affect the long-term isolation of the waste through various processes that promote or inhibit the solubility, sorption, and mobility of radionuclides.

Research in geochemistry is therefore directed at understanding the chemical characteristics of the potential repository site, their effects on the containment of the waste, and their effects on waste isolation when the containment is breached. Specifically, the goal is to determine the following:

1. Ranges of expected geochemical conditions, over the repository lifetime and the geographical area, that directly affect radionuclide behavior.

2. Maximum steady-state concentrations of radionuclides in solution under representative geochemical conditions.

3. Characterization of important radionuclide-transport parameters to support hydrologic flow and transport models.

5.4.1 BASALT

Geochemistry of the Ground Water

At the Hanford Site, hydrochemical studies have been in progress since 1979. During that time over 30 boreholes have been drilled and sampled. Recent work has focused on the reference repository location.

An evaluation of the hydrochemical data has led to several preliminary conclusions about the ground water:

1. The ground waters can be divided into (a) relatively dilute waters in the upper basalt flows and (b) waters in the lower basalt flows that have higher chloride and fluoride concentrations. The source of chloride and fluoride in the deeper ground waters is uncertain.

2. Estimates of the oxidation-reduction potential (Eh) of the ground waters suggest that it is reducing. The low Eh* may be attributable to iron-containing minerals or to glasses that line fractures or are part of the basalt.

3. The ground waters are slightly alkaline, low in ionic strength, and very low in total organic carbon.

4. Analyses based principally on stable-isotope ratios suggest that there is vertical mixing between the lower and the upper aquifers, but the rate of mixing is still undefined.

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*In discussing Eh, the Basalt Waste Isolation Project (BWIP) uses the sign convention adopted by the International Union of Pure and Applied Chemistry and presented by Stumm and Morgan (1981, pp. 436-438). Thus, low Eh values represent reducing conditions and high Eh values correspond to oxidizing conditions.

The net effect of the low oxidation-reduction potential and the alkaline pH is to contribute positively to radionuclide retardation. The oxidation-reduction potential is the dominant factor, since most of the multivalent radionuclides should be reduced to their less-mobile valence states. This appears to result in a net decrease in the steady-state concentrations of multivalent cations like uranium and plutonium in a reducing aqueous environment. Under the expected reducing conditions, technetium, uranium, and neptunium are well sorbed, while iodine and carbon are poorly sorbed (Ames and McGarrah, 1980a, b; Ames et al. 1981; Barney, 1982, 1984; Barney et al. 1983; Salter et al., 1981).

Other simple cations such as cesium and strontium are also strongly sorbed. Although the current studies indicate that most of the radionuclides will be strongly sorbed, it must be emphasized that these experiments were conducted with crushed basalt in a batch system. Dynamic experiments with basalt core samples or field tests and evaluations of the effects produced by the speciation of the principal radionuclides will be required to confirm these results.

Geochemistry of the Host Rock

The basalt flow being considered for a repository is characterized by dense flow interiors consisting of calcic plagioclase feldspar and clinopyroxene in a matrix of volcanic glass, fractured flow tops of the same general composition, and vesicular zones that contain zeolites, cristobolite, iron smectite, and sometimes pyrite as secondary minerals inside the vesicles (Long et al., 1923). The entire flow is fractured from cooling. Current data suggest that the fractures are typically tight and filled with secondary minerals.

Geochemistry of the Near Field

Because the basalt repository horizon is located in the saturated zone, the host rock surrounding the waste package will resaturate after repository closure. Because the basalt-bentonite packing material has a finite permeability, it is not possible to preclude contact between the ground water and the overpack, and between the ground water and the emplaced waste after overpack failure.

An active program has been carried out to determine what reactions could be expected near the emplaced waste. The systems studied to date have been various combinations of ground water, basalt, sodium bentonite, and simulated waste (Apted and Myers, 1982; Wood et al., 1984; Myers et al., 1983; Lane et al., 1983). The major observations from these studies are as follows:

1. Ground-water solution chemistry approaches steady-state conditions in a geologically short time under hydrothermal conditions.

2. Major ground-water constituents are relatively unchanged by hydrothermal reactions. The Eh is reduced and the pH remains alkaline.

3. The main reaction products of the basalt-water system under hydrothermal conditions are smectites, zeolites, and a silica-rich phase (e.g., cristobolite) similar to those secondary minerals found naturally in basalts.

These data indicate that the basalt-bentonite packing material around an emplaced container (see Section 2.5) will produce an alkaline reducing environment. This will provide a highly reactive medium for radionuclide-precipitation reactions, which should reduce solution concentrations. The reducing environment will most likely maintain the multivalent radionuclides in their lower valency less mobile states and therefore control the maximum radionuclide-release rate from the waste package. Such a reducing environment also serves to inhibit the corrosion of the metal barriers. In addition, an iron silicate protective layer appears to form in container systems containing packing, which may further reduce container corrosion and increase waste-package lifetimes. Data are not yet available on the effects of gamma radiation on near-field geochemistry. Plans for collecting these data will be described in the site-characterization plan.

5.4.2 SALT

5.4.2.1 Salt Domes

Geochemistry of Ground Water

The uppermost aquifers in the Gulf Interior region contain potable water. The waters vary from the calcium bicarbonate type to the sodium bicarbonate type, which is typical of the entire Gulf Coast. The waters in the deeper aquifers and along the flanks of the domes are saline brines (10,000 to 100,000 mg/l of total dissolved solids (TDS)) and sodium chloride brines (over 100,000 mg/l TDS).

The uppermost potable aquifers are oxidizing and contain appreciable amounts of dissolved oxygen. The deeper saline and brine ground waters appear to be slightly reducing, as evidenced by the presence of methane. This reducing environment could be important in maintaining several radionuclides in less mobile valence states.

The important constituents in the ground waters that could mobilize radionuclides are bicarbonate and humic and fulvic acids. These anionic species tend to form strong complexes with many of the actinides, and these complexes tend to be very mobile.

Geochemistry of the Host Rock

The salt domes typically contain more than 90 percent halite, with no mineral impurity except anhydrite exceeding 1 percent by volume. Typical impurities include anhydrite and smectite (Drumheller et al., 1981; and Martinez et al., 1978). Because dome salt is typically low in brine inclusions (0.15 volume percent (Roedder and Chou, 1982)), little brine migration is expected, which in turn will minimize the corrosion of canister materials. These brines are typically low in magnesium.

Geochemistry of the Near Field

To simulate the conditions that would be expected around the emplaced waste, a series of studies have been conducted to determine the leach rates of spent fuel and borosilicate glass, the effects of radiolysis, and corrosion rates of the overpack material (low-carbon steel). These studies have been mainly conducted with sodium chloride brine (dissolved Permian salt). The results of these experiments are applicable to both the Gulf Coast domes and Permian Basin. The following conclusions can be drawn from these studies:

1. Borosilicate glass appears to react more slowly in sodium chloride brine than in deionized water, and the presence of iron increases the leach rate of the glass (McVay and Buckwalter, 1983; Gray et al., 1984).

2. Gamma irradiation increases the leach rate of the glass. However, because of the strong temperature dependence of leaching, at temperatures above 90°C the contribution of elevated temperature to increased leaching is much greater than the contribution of gamma irradiation (Pederson and McVay, 1984).

3. Gamma irradiation of solutions does not tend to affect their oxidation-reduction potential. However, alpha radiolysis can cause highly oxidizing conditions (Pederson and McVay, 1984).

4. Iron-canister corrosion is accelerated by factors of 3 to 20 at 150°C in the presence of gamma-irradiation fields of 10^5 rads/hr. At lower dose rates, such as 10^3 rads/hr, the enhancement over the unirradiated case is not statistically significant (Westerman et al., 1984). These dose rates are well above those expected at the waste-package surface.

5. The predominant corrosion products from iron canister corrosion are iron oxides, which act as an effective sorbent for some radionuclides, indicating that radionuclide release from the waste form may be retarded significantly by the presence of iron corrosion products (Gray et al., 1984; Mendel, 1984).

6. Brine migration in dome salt could result in 0.2 m^3 of brine migrating to the waste package, which is significantly less than that expected for the bedded-salt sites.

7. Because of the limited amount of brine that could migrate to the package, the lifetime of the waste package is predicted to be on the order of several thousand years, assuming uniform corrosion.

The draft environmental assessments (DOE, 1984c, d, e, f, g) provide details about the analyses leading to conclusions 6 and 7.

5.4.2.2 Bedded-Salt Sites in the Palo Duro Basin

Geochemistry of the Ground Water

The Palo Duro Basin has a major potable aquifer, the Ogallala, which is extensively used for irrigation. The water in the Ogallala is typically of the calcium bicarbonate type and is nearly saturated with calcite. The aquifers that are below the proposed repository horizons contain sodium chloride brines with a total-dissolved-solids content of more than 100,000 mg/l (Bassett and Bently, 1983).

The upper aquifers are all oxidizing, but the lower aquifers, the Wolfcamp and the Pennsylvanian (Sewell, 1984), appear to be reducing, as evidenced by the presence of methane. This reducing environment could be important in retarding radionuclides by maintaining them in lower valence states. The lower aquifers are saturated with barium sulfate, which will strongly affect the solubilities of strontium and radium. Carbonate and organic acids will dominate the speciation of radionuclides in the Ogallala and could mobilize some radionuclides. The brines in the lower aquifers have recently been dated radiometrically and appear to be at least 130 million years old in the eastern part of the Palo Duro Basin.

Geochemistry of the Host Rock

The salt in the Palo Duro Basin is typically halite (90 percent), with mineral impurities that include anhydrite, dolomite, clays, and quartz (Fukui, 1984; Hubbard et al., 1984). The occurrence of brine inclusions in the salt is estimated at about 1 percent, with the clays being able to raise this to about 1.8 percent. The brines contain fairly high concentrations of magnesium (50,000 mg/l (Hubbard et al., 1984)), which tend to increase the corrosion of canister materials.

Geochemistry of the Near Field

The geochemistry of the near field at the Palo Duro Basin will be similar to that discussed for the Gulf Coast except that the potential amount of brine that could migrate to the waste package would be in the range of 1.0 m^3 rather than the 0.2 m^3 predicted for dome salt.

5.4.2.3 Bedded-Salt Sites in the Paradox Basin

Geochemistry of the Ground Water

At the Paradox Basin salt sites, the uppermost aquifer, the Cutler, carries potable water of the calcium bicarbonate type. Below the Cutler is the Honaker Trail Formation in which the ground water varies from a calcium bicarbonate type in the upper part to sodium chloride brine in the lower part. The water in the Honaker Trail Formation is generally nonpotable. The Leadville brine aquifer is located well below the salt beds and contains a sodium chloride brine with approximately 80,000 mg/l of total dissolved solids.

The uppermost aquifers are oxidizing, while the lower aquifers contain sulfides, which strongly indicates a reducing environment.

Bicarbonate and organic acids in the upper aquifers are expected to dominate the speciation of radionuclides, which could mobilize radionuclides.

Geochemistry of the Host Rock

The salt in the Paradox Basin is similar to other sites in that it contains halite as the principal mineral (about 90 percent, Hite, 1983). It has, however, two significant impurities not seen at the other sites--carnallite and kieserite (Hite, 1983). These minerals are significant because they are sources of magnesium and water. Carnallite dewaters at approximately 100°C (Jockwer, 1980) and could act as a significant source of water.

The Paradox Basin salt typically contains less than 0.5 percent brine, with carnallite and kieserite being able to raise this to less than 5.0 percent in the upper half of the Cycle 6 salt (Hite, 1983). These brines are expected to be high in magnesium because of the mineral assemblages present and thus could increase the corrosion rates of canister materials.

Geochemistry of the Near Field

The geochemistry of the near field at the Paradox Basin differs in two respects from that described for dome salt. The first is that brine migration could cause about 1.0 m^3 to migrate to the waste package. The second is that the corrosion rate of iron canisters will be approximately 10 times faster because of the presence of magnesium in the brines.

5.4.3 TUFF

Geochemistry of the Ground Water

The repository horizon at Yucca Mountain is located in the unsaturated zone with no overlying aquifers. Water (more precisely, moisture) from the unsaturated zone has not been sampled yet; thus, little is known about its geochemistry. In contrast, a great deal of data are available on the aquifer underlying the proposed repository horizon. A well designated J-13, which produces water from the Topopah Spring Member, has been used as source for the the reference ground water. The composition of its water can be described as a sodium bicarbonate type nearly saturated with silica.

From the ground-water composition, several preliminary conclusions can be drawn:

1. The ground water at the water table is oxidizing; however, some of the deeper ground waters appear to be reducing.

2. The ground water is quite dilute (TDS of 90 ppm or less), with sodium, silicon, calcium, and magnesium being the only cations with concentrations exceeding 0.2 ppm (Heiken, 1982).

3. Bicarbonate and hydroxyl anions are the major actinide-complexing ligands present (Heiken, 1982).

4. Many of the important radionuclides exhibit minimal solubilities at the nominal pH of the ground water (pH 7) (Wolfsberg et al., 1982; Allard, 1982; Duffy and Ogard, 1982).

5. No detectable organic complexing agents are present (Means et al., 1983).

Geochemistry of the Host Rock

Within the Topopah Spring Member and beneath the proposed repository horizon, there are significant variations in the mineral composition of the host rocks (Bish et al., 1982), including localized occurrences of cristobolite, tridymite, smectite, and volcanic glass. The important sorptive minerals clinoptilolite and mordenite also occur in discrete horizons, their distribution changing horizontally and vertically (Bish et al., 1984).

Figure 5-12 is a cross section through Yucca Mountain showing geologic units at and beneath the proposed repository horizon. The major intervals of sorptive zeolites beneath the horizon are identified with Roman numerals. At all points, the zeolitized tuff is at least 80 feet thick beneath the repository horizon. In addition, large amounts of zeolitized tuff will be encountered by any water traveling through the saturated zone (Vaniman et al., 1984).

Sorption studies, both static and dynamic, have been conducted for most of the radionuclides of interest for the types of tuff to be expected at Yucca Mountain (Ogard et al., 1983a, b; Wolfsberg et al., 1983; Bryant and Vaniman, 1984). Simple cations (e.g., strontium and cesium) are strongly sorbed, and the reactions are rapid. There is good agreement between static and dynamic measurements. In batch experiments, actinides like plutonium and americium show strong sorption. These measurements, however, must be confirmed by dynamic measurements coupled with thermodynamic speciation calculations. An extensive data base for sorption ratios from batch experiments is available for the tuffs at Yucca Mountain (Daniels et al., 1983; Heiken, 1982).

In addition to retardation by sorption, radionuclide retardation is expected to occur by the diffusion of radionuclides from the more mobile water in fractures into the relatively immobile water in the interstices of the tuff matrix. Experiments are under way to try to quantify the contribution of this matrix-diffusion mechanism to the retardation properties of the site.

Geochemistry of the Near Field

The characteristics of the proposed repository horizon, located in the unsaturated zone, will be the overriding factor in limiting container corrosion and waste-form dissolution. Preliminary results of corrosion tests conducted on 304L stainless steel indicate that a 0.3 inch thickness of this material will be adequate to contain the waste for several thousand years, even under saturated conditions. In addition, results to date indicate that stress-corrosion cracking of spent-fuel containers fabricated from 304L stainless steel will not be a problem, even in a radiation field. Investigations of the stress-corrosion cracking of high-level waste containers are under way. It must be pointed out that these studies have not been conducted in a radiation field.

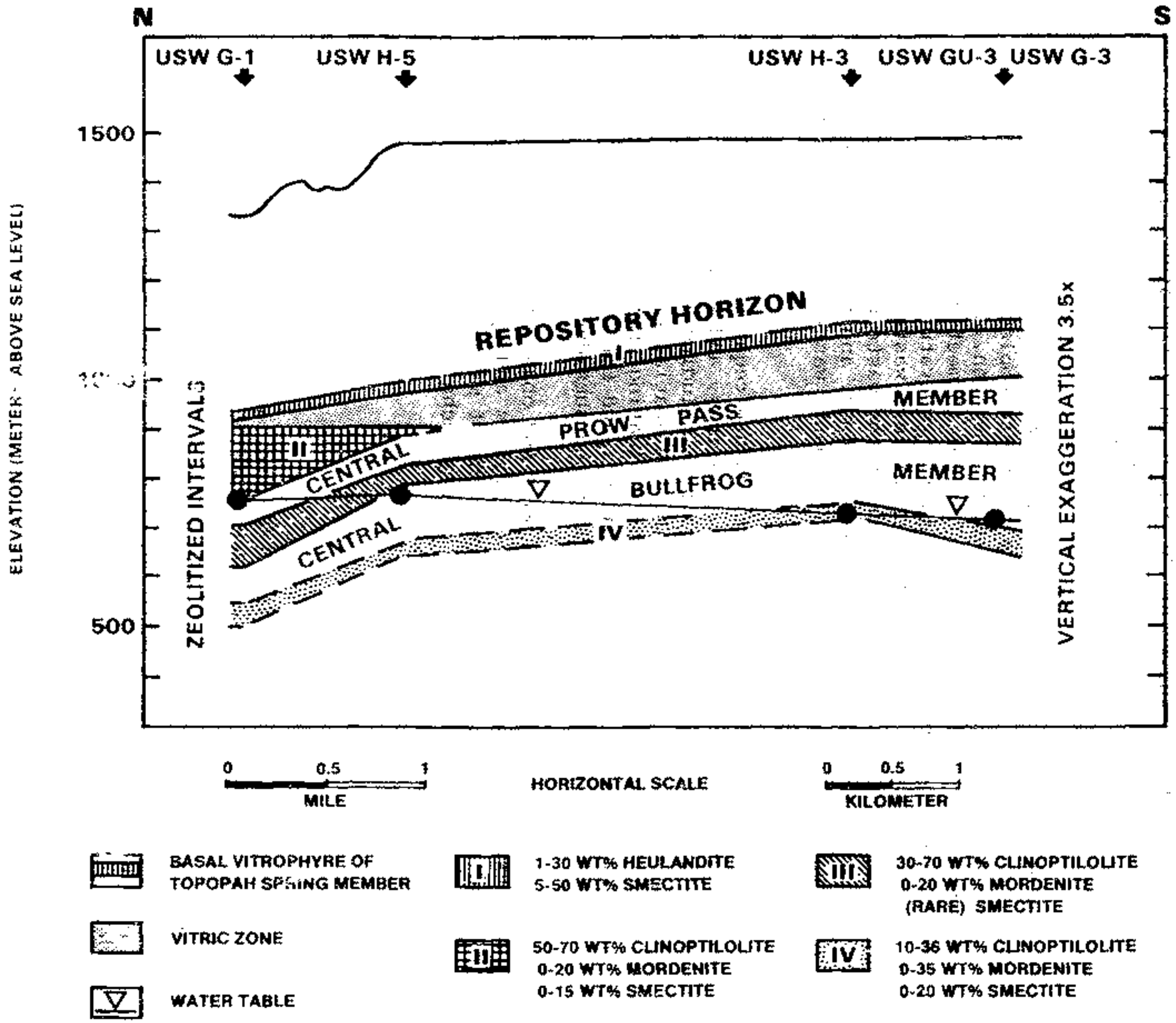

Figure 5-12. Sorption stratigraphy below the preferred repository horizon in tuff.

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5.5 SIGNIFICANT RESULTS OF RESEARCH IN GEOMECHANICS

Research in geomechanics includes studies to determine the impact of the thermal and mechanical properties of the host rock and in-situ stress on the location, size, shape, orientation, and stability of the underground openings. Also included are studies of the stress and temperature fields in the vicinity of a site, the excavation characteristics of the rock mass, thermal and thermomechanical modeling techniques, and the effects of radiation on the mechanical properties.

Predictions of rock temperature are required for establishing the spatial extent of the repository horizon acceptable for waste emplacement, for establishing the acceptable thermal loading within the horizon, and for evaluating the ability of repository and waste-package designs to meet constraints on the maximum allowable rock temperature. In addition, temperature predictions are an important prerequisite to the evaluation of pillar, waste emplacement hole, and intersection stability; to a determination of the waste-package environment, to the establishment of ventilation requirements, and to design tradeoff studies (e.g., horizontal versus vertical emplacement, waste-package sizing, canister spacing, and drift spacing).

Stress, strain, and displacement predictions are required for developing detailed design plans for room sizes, shapes, spacings, and support requirements; for evaluating emplacement-hole stability (including liner requirements, if any, for stability); for determining the spatial extent of acceptable host rock in the repository horizon; for evaluating shaft designs with respect to structural stability and liner loading; and for evaluating the magnitudes and consequences of far-field expansion and subsidence.

Excavation characteristics of the rock mass and observations made in other similar rocks with comparable stress conditions and hydrologic characteristics are required to determine the dimensions of mined openings, support requirements for these openings, efficient mining techniques, rock damage due to excavation and dewatering requirements.

5.5.1 BASALT

Testing in basalt has now progressed from the laboratory testing of rock cores to field tests at the Near-Surface Test Facility (NSTF). In addition, a series of hydraulic fracturing tests have been conducted in five surface-based boreholes to estimate the in-situ stress at the four candidate repository horizons. The data obtained from the laboratory studies have been used for developing a preliminary constitutive relationship for incorporation into numerical models. Preliminary measurements of in-situ stress have been used to derive opening configurations and waste-emplacement techniques for conceptual designs of the repository and waste package.

Laboratory Testing

A series of laboratory tests has been conducted on the cores from three boreholes at the site for the purpose of characterizing the physical, mechanical, and thermal properties of four candidate horizons in the basalt. An abbreviated summary of the results of this laboratory testing of intact rock is presented in Table 5-1 for the Cohassett flow, which is currently the preferred horizon.

Each flow consists of similar intraflow structures (flow-top breccia, vesicular zones, entablatures, and colonnades). Currently, the dense interior portion of the Cohassett flow (entablature and colonnade) has been chosen as the most suitable portion for a repository. From Table 5-1 it is apparent that the dense interior provides relatively high intact-rock strengths and Young's moduli with a corresponding low porosity. Joints and fractures within the basalt will produce rock-mass strengths and deformation moduli that will be less than the corresponding values for intact rock.

Table 5-1. The Physical, Mechanical, and Thermal Properties of Intact Basalt from the Cohassett Flow

Property	Entablature[a]	Colonnade[b]
Bulk density (g/cm^3)	2.84 ± 0.02	2.81 ± 0.05
Porosity (%)	2.85 ± 0.79	4.37 ± 1.47
Uniaxial compressive strength (MPa)	291.6 ± 18.90	288.3 ± 38.31
Young's modulus (GPa)	75.60 ± 5.83	72.76 ± 7.23
Poisson's ratio	0.25 ± 0.02	0.25 ± 0.02
Tensile strength (MPa)	14.54 ± 3.32	15.8 ± 2.36
Thermal conductivity (W/m-K)	1.51 ± 0.15[b]	
Coefficient of thermal expansion (10^{-6} K^{-1})	6.02 ± 0.42[b]	

[a]Dense interior intraflow structures.
[b]Entablature and colonnade test results were averaged to determine the thermal-property values given in the table.

The thermal and mechanical properties of basalt are important engineering parameters that are used in repository modeling and design. The effects of heat transfer through the rock mass from heat-generating waste containers are sufficiently well understood to predict temperature distributions. The behavior of the rock mass under thermally induced stresses is not yet fully understood. Until it is, the waste emplacement areal densities, emplacement-room spacing, container-hole spacing, and the estimated additional support requirements due to thermal loading are preliminary. The thermal properties of the rock mass experiencing stresses sufficient to close joints and fractures are not expected to be significantly different from those of intact rock.

The mechanical properties and behavior of the rock mass are not as well understood. Preliminary assessments of the effects of confinement stress, temperature, and loading time have been performed on intact rock and joints. Work is continuing in this field.

Field Tests at the Near-Surface Test Facility

Many types of field tests have been conducted at the Near-Surface Test Facility since its construction in 1979 at Gable Mountain. The location of the facility was chosen primarily because of the easy access to the Pomona flow, which possesses characteristics similar to the candidate horizons. The tests conducted at the facility can be grouped into four categories:

1. Geologic characterization studies.
2. Full-scale heater tests.
3. Jointed block tests.
4. Test method and instrument development tests.

These tests have yielded valuable information which has led to (1) an understanding of the generic behavior of Columbia River basalt; (2) the advancement of measurement methods and instrument technology; (3) the improvement of data-analysis methods; and (4) the development of predictive numerical models. The NSTF geologic studies, jointed block tests, and full-scale heater tests have been completed, and a variety of instrument development tests are continuing. The results of these tests are summarized below.

Mechanical Properties. Results from the triaxial block test indicate an anisotropic deformability behavior of the rock mass. The deformation-modulus values perpendicular to the basalt columns are only about 60 percent of those parallel to the columns at low confining stress levels (Cramer et al., 1983). This degree of anisotropy was also reflected in the values of dynamic deformation moduli calculated from compressional and shear wave velocities obtained in crosshole seismic tests. The rock-mass density and sonic velocities increase with increasing confining stress levels. These results indicate the need for a complex mechanical model.

Thermal Properties. Results from large-scale heater tests (Gregory and Kim, 1981) were used to determine a best-fit rock mass thermal conductivity value of 1.7 W/m-K. This value is close to the 1.51 W/m-K laboratory value presented in Table 5-1 and within the range of values measured in the laboratory (1.32-1.74 W/m-K), which tends to support the conclusion by other researchers that in-situ thermal performance can be adequately modeled with laboratory values.

Performance Characteristics. Examination of the walls of the 16-inch-diameter boreholes used for emplacement of the heaters in the large-scale heater tests at the Near-Surface Test Facility showed some new crack formation and joint opening, but no spalling or decrepitation as a result of heating to approximately 600°C. While this temperature level is about twice that expected in a repository, it should be noted that the in-situ stress condition at the facility is much lower than that expected at the repository depth.

Measurements of In-Situ Stress

The basalt flows underlying the Hanford Site have been known to be under high horizontal compressive stress acting in a general north-south direction. Core-disking and borehole-spalling phenomena observed in exploratory boreholes are indicative of such in-situ stress. Hydraulic-fracturing tests have been conducted to determine the magnitudes and the orientations of the principal stresses. Three boreholes at the reference repository location and two boreholes at other locations at the Hanford Site have been used for the tests. The results obtained from these tests confirmed that the maximum principal stress is acting in a general north-south direction and the maximum horizontal-to-vertical stress ratio ranges from 2.1 to 2.7 (Kim and Haimson, 1982; Rundle and Kim, 1983). Although this technique has some uncertainty associated with the theoretical basis for the data interpretation, it is the only currently accepted method for measuring in-situ stress in deep boreholes. The measured high horizontal stresses suggest the need for increased rock-support requirements and thus greater mining costs. In addition, these results suggest a currently undefined potential for rock bursts that could pose hazards to miners or make waste retrieval difficult.

Requirements for Artificial Support

Several rock-mass classification systems have been developed for the primary purpose of providing empirical methods for estimating rock-support requirements. In addition, the use of these classification methods has been extended to estimate the strength and the deformability of the rock mass.

The two most commonly used classification systems are the "Q" system (Barton et al., 1974) and the "RMR" system (Bieniawski, 1974, 1976). Both of these systems have been used to classify the rock-mass quality of the Cohassett dense interior and estimate the rock-support requirements. The "Q" system led to a classification of very poor to fair, whereas the "RMR" system classified the same basalt rock as fair to good. This discrepancy is due to different definitions of what constitutes poor or fair quality in a rock mass. Both methods, however, result in very comparable estimates of support requirements. Depending on rock conditions, these requirements appear to range from a minimum of one layer (0.7 to 1.7 inches) of fiber-reinforced shotcrete to a maximum of systematic tensioned rock bolts with wire-mesh-reinforced shotcrete (1.7 to 4.2 inches).

Laubscher and Taylor's (1976) method of estimating rock-support requirements by modifying the "RMR" system was also used to evaluate support requirements. This method resulted in a slightly greater rock-support recommendation than did the "RMR" system, but was still within the maximum bounds of the previously recommended range of rock support.

It should be noted that these are empirical methods based on case histories quite different from the rock type, temperature, and stress environment that would be encountered in a repository located in the Cohassett flow. To confirm the empirical estimates, other methods of evaluating rock support will be used, such as in-situ tests, numerical modeling, and observational methods. During the proposed exploratory shaft testing program, observational methods will be used to better evaluate and confirm support requirements.

It should also be noted that preliminary estimates of excavation and thermally induced stresses were considered in these empirical studies. Site-specific experimental data on the effects of thermally induced stresses will be extensively evaluated by in-situ testing during site characterization.

5.5.2 SALT

An initial data base of geomechanics properties is being established for the seven salt sites under consideration. This data base is composed of the results of thermophysical and thermomechnical laboratory tests of various rock salt and nonsalt rock units and is enhanced by field tests at Avery Island, Louisiana, and the Asse salt mine in the Federal Republic of Germany. Limited site-specific data are also available from the geophysical monitoring of selected boreholes and seismic surveys. In addition, field data from the Waste Isolation Pilot Plant studies and previous experience gained in Project Salt Vault serve as a supplement to the data base. At present the laboratory data obtained encompass unconfined compressive strength, indirect tensile strength, triaxial compression and extension, creep, thermal conductivity, thermal expansion, and specific heat capacity, together with various density measurements and rock-fabric studies. The average thermomechanical and thermophysical properties of bedded and dome salt are given in Table 5-2.

Testing of the thermomechanical properties of various salt units indicates that the strength of these units varies with the site and varies substantially with confining pressure and temperature. To describe the increase in salt strength with increasing confining stresses, a nonlinear failure envelope was used (Pfeifle et al., 1983). This envelope describes the brittle tensile and compressive strength of the units at room temperature under rapid loading conditions. In salt, the ability to withstand sustained differential stress decreases with temperature, but "failure" at elevated temperatures is no longer brittle and is purely plastic. Studies are under way to quantify this behavior in rocks of different impurity content and volume.

Thermomechanical testing has established that a number of factors in the ductile response of salt are advantageous to a repository. The time-dependent creep of salt (which will tend to close and seal openings in the repository) has been represented by an exponential creep equation (Pfeifle et al., 1983). Laboratory studies are investigating the response of crushed salt, especially the reduction of its permeability as backfill and its increase in strength due to creep closure of the rooms. Testing has also indicated that fractures in salt heal rapidly under applied stresses (Costin and Wawersik, 1980) and that salt exhibits a rapidly decreasing permeability with flow (Gevantman, 1981).

From field and laboratory testing it is evident that the thermophysical properties of salt are influenced by impurity content and grain size, and hence, vary somewhat from site to site. In addition, the thermal conductivity of salt is typically temperature dependent. On the basis of laboratory test-

Table 5-2 The Average Thermomechanical and Thermophysical Properties of the Salt Sites

Parameter	Palo Duro Basin	Paradox Basin	Gulf Interior Domes[a]
Bulk density (g/cm^3)	2.15	2.20	2.20
Young's modulus (GPa)	26.6	26.9	31.5
Poisson's ratio	0.31	0.33	0.36
Thermal conductivity coefficients[b] (W/m-K)			
A	4.30	4.19	3.38
B	0.988	0.899	0.547
Specific heat capacity (J/kg-K)	904	932	919
Thermal expansion coefficient (10^{-6} K^{-1})	39	42	36

[a]Data based primarily on results from the Richton Dome.

[b]The equation for thermal conductivity is

$$L = A \frac{(300)^{B}}{T}$$

where L is the thermal conductivity, T is the temperature in kelvins, and A and B are material constants.

ing, a nonlinear representation of thermal conductivity has been established for the basins (Lagedrost and Capps, 1983). The thermal expansion and specific-heat-capacity coefficients for all basins are similar, but the thermal conductivity values differ substantially between dome and bedded salt. The conductivity of dome salt is less than that of the bedded units. Also, the dependence of the thermal conductivity decreases as the anhydrite content increases. However, in comparison with other rock types, the conductivity of dome salt is still high. The presence of interbeds in a salt unit will tend to reduce its thermal conductivity.

Research on in-situ stress and stress changes in the rock mass is under way. Preliminary data indicate that, because salt is plastic, the measurement of stress by standard techniques based on the theory of elasticity is not appropriate. Development of stress-change and displacement transducers is focusing on the longevity and reliability of such devices under the temperature and pressure conditions of a repository.

Because of the relative ease of excavation in rock salt, studies of the excavation characteristics of the salt have concentrated on definition of the zone of rock salt disturbed by mining. Initial estimates of this zone suggest a disturbed zone ranging in depth from 3 to 7 feet, based on various field permeability studies, to an order of tens of meters for a highly anisotropic evaporite unit. Further details of these estimates are given in the draft environmental assessments.

Radiation Effects on Salt

Limited studies of the effects of ionizing radiation on the physical properties of salt indicate that the effects vary with temperature, duration, the intensity of radiation, as well as the type and dimensions of the salt sample.

Uniaxial compression and creep tests were carried out on bedded salt from a mine in Kansas and dome salt from Texas. The tests were performed on specimens 2 inches in diameter. Stress-strain curves were obtained for three samples each of dome and bedded salt. The radiation effects on salt strength are summarized as follows:

1. The compressive strength of rock salt exposed to 5×10^8 roentgens at room temperature is, without exception, somewhat less than the compressive strength of unirradiated rock salt.

2. Without exception, the modulus of elasticity is greater for exposures of 5×10^8 roentgens than for unirradiated specimens.

The magnitude of these changes in strength and modulus does not appear to be significant to rock stability and the design of artificial support systems because significant irradiation of salt only takes place within a few centimeters of the waste package.

5.5.3 TUFF

The development of the geomechanics data base for a potential repository at Yucca Mountain is well under way. At present the data base consists primarily of the results of laboratory tests on core samples, but is enhanced by initial results from field observations and tests being made on a different welded tuff in G-tunnel at the Nevada Test Site. The selection of the Topopah Spring tuff as the target horizon for the repository was based in part on the average thermal and mechanical properties defined for each of the four horizons considered from tests of thermal conductivity, thermal expansion, and unconfined and pressure-dependent mechanical properties; mechanical tests on jointed rock samples; and mineralogical and petrological analyses. Definition of the properties to be expected in the candidate repository horizons has relied on combining the measured thermal and mechanical data with the corresponding bulk properties (porosity and degree of fracturing). Downhole geophysical logs were combined with mineralogical analyses of cores to produce stratigraphic descriptions of the thermal, mechanical, and chemical properties of candidate horizons. The more important data are summarized in Table 5-3.

Table 5-3. Average Thermomechanical Properties of Tuff in the Topopah Spring, Calico Hills, Tram, and Bullfrog Members

Parameter	Topopah Spring[a]	Calico Hills	Bullfrog	Tram
Porosity (%)	0.17 ± 0.09	0.32 ± 0.02	0.23 ± 0.03	0.19 ± 0.03
Grain density (g/cm^3)	2.55 ± 0.03	2.40 ± 0.02	2.59 ± 0.02	2.64 ± 0.04
Thermal conductivity (W/m-K), isotropic				
Saturated	1.8 ± 0.4	1.4	2.0 ± 0.1	2.2 ± 0.1
Dry	1.6 ± 0.4	1.0 ± 0.05	1.4 ± 0.2	1.6 ± 0.2
Linear thermal expansion coefficient (10^{-6} K^{-1})				
Predehydration	10.7 ± 1.7	6.7 ± 3.7	8.3 ± 1.4	8.3 ± 1.4
Transdehydration	31.8 (to 300°C)	-56.0 (to 150°C)	-12.0 (to 125°C)	-12.0 (to 125°C)
Postdehydration	15.5 ± 3.8 (to 400°C)	-4.5 ± 4.0 (to 300°C)	10.9 ± 0.8 (>125°C)	10.9 ± 0.8 (>125°C)
Young's modulus (GPa)	26.7 ± 7.7	8.1 ± 2.3	15.5 ± 4.5	21.8 ± 0.3
Poisson's ratio	0.14 ± 0.05	0.16 ± 0.06	0.19 ± 0.08	0.19 ± 0.07
Unconfined compressive strength (MPa)	95.9 ± 35.0	30.6 ± 11.1	56.9 ± 20.8	79.2 ± 28.9

[a]Preferred repository horizon.

Mechanical Properties

Studies of the mechanical properties of intact samples from Yucca Mountain indicate that the observed variations in material from the four horizons depend mainly on porosity. Rock fabric also plays a significant role in controlling the compressive strength. Preliminary assessments of the effects of water, temperature, confining and fluid pressure, loading time, voids, and anisotropy have been performed. Additional testing is concentrating on the Topopah Spring tuff to assess both the lateral and vertical variability of the properties. Studies of the mechanical properties of discontinuities and contacts (e.g., joints, bedding planes, and faults) have focused in earlier years on simulated joints precut in samples of tuffs from the Grouse Canyon and Prow

Pass Members. These results are important because of the physical and mechanical similarities of these units to the Topopah Spring tuff. More recent testing has focused on cores from a Topopah Spring outcrop to determine shear and normal compliance of the joints and conditions for the onset of joint slip. These data are used as input to numerical models that assess the stability of the mined openings and the effects of waste emplacement. Variations in the mechanical properties of simulated joints due to the effects of displacement rate, water saturation, and time-dependent behavior have been quantified for use in predicting the mechanical response of the rock mass. Furthermore, preliminary results from the heated-block experiment indicate that the modulus of deformation for fractured welded tuff is about 50 to 60 percent of the modulus measured on intact laboratory-scale samples.

Thermal Properties

Saturated and dehydrated thermal conductivities are variable and show dependence on variations in porosity and grain density (mineralogy). Studies indicate that the effects of layering (fabric anisotropy) on the thermal conductivity of welded and nonwelded tuffs are negligible. It appears that the effects on the conductivity of air-filled voids (lithophysae) that occur within the Topopah Spring tuff can be modeled as additional air-filled porosity; however, the distribution of these voids remains poorly defined, and the above assertion requires further confirmation. The presence of fractures is expected to have a negligible effect on the in-situ rock mass conductivity below the water table. Within the target horizon and at other locations above the static water level, fractures may locally decrease thermal conductivity by as much as 10 percent. However, the results of the small-diameter heater tests in G-tunnel indicate that heat transfer calculations based on properties measured in the laboratory effectively reproduce the measured temperature fields.

Laboratory measurements on Topopah Spring tuff indicate that the thermal expansion is approximately linear at temperatures between 25 and 200°C. Above 200°C, transformation of the cristobolite within the tuffs increases the thermal expansion coefficient. Studies indicate that the effects of bedding and textural anisotropy on the matrix thermal expansion behavior of densely welded tuffs are negligible. The presence of thermally induced or preexisting fractures is expected to reduce rock-mass stresses to below those predicted by laboratory tests, primarily because of the lower effective deformation modulus in the field.

For a repository in the Topopah Spring tuff, analysis has shown that the partial saturation and prevalent fractures preclude significant thermally induced decrepitation of the tuff. Measurements of thermally induced water migration are continuing in order to quantify its effect on ventilation requirements and on the effective thermal conductivity of the tuff.

In-Situ Stress

The stress field at Yucca Mountain appears to reflect the superposition of regional tensional tectonic stress onto gravitational loading. It is assumed that measurements in nearby mesas can be extrapolated to provide first estimates of the state of stress at depths in the unsaturated zone in Yucca Mountain, where measurements have not yet been feasible. Under mesas, gravity loads and contrasts in material properties for densely welded and nonwelded tuffs appear to result in layering effects and differential stresses between stiffer and softer layers. This complicating effect is expected to be substantially smaller in a repository in Yucca Mountain because of the thickness and depth of the Topopah Spring tuff.

Excavation Characteristics and Artificial Support Requirements

Experience gained in welded tuff in G-tunnel and evaluation of cores from Yucca Mountain indicate that controlled blasting can be used to excavate the welded tuff. In addition, repository-size openings can be stabilized with rock bolts and wire mesh. The excavation characteristics of Yucca Mountain tuffs have been evaluated using several empirical approaches and information obtained from boreholes and cores as well as through the use of more sophisticated numerical analyses. These empirical correlations and numerical studies suggest that no unusual support systems will be required for the exploratory shafts or tunnels excavated in the Topopah Spring tuff. Confidence in the predictions by empirical methods and the numerical studies was increased by applying them to the tuffs of Rainier Mesa, where there is substantial mining experience.

5.6 RESULTS OF RESEARCH IN OTHER ROCK TYPES

Field and laboratory testing in granitic rocks provides a source of geomechanical, hydrologic, and instrumentation data generically applicable to hard, brittle rocks like basalt and welded tuff, which are under consideration for the first repository. The extent to which data are directly transferable is, of course, limited by mechanical and hydrologic differences among the rocks and is hence site specific. Clearly, the results will be more directly transferable to the second repository program, which currently is exploring for sites in granite or other so-called crystalline rocks.

Current information on the geohydrologic setting of crystalline rocks in the regions being investigated by the Crystalline Rock Project (CRP) is based on published literature and on data available from various agencies and organizations. Field investigations by the CRP will commence after the selection of candidate areas.

Thus, very little specific ground-water flow information is available at expected repository depths (approximately 3300 feet) in crystalline rocks. However, a considerable amount of general understanding of flow systems has been gained over the past two decades through computer modeling (Toth, 1962, 1963; Freeze and Witherspoon, 1966, 1967, 1968; Stokes, 1977; and Gale, 1982). These analyses are based on the fact that the ground-water table in crystalline terrain is a subdued replica of topography. Under these water-table conditions, the ground-water flow system is governed by elevation-head differences between topographic highs (ridges) and topographic lows (valleys). The amount of recharge is also governed by topography, with greater amounts of precipitation occurring at higher elevations providing more opportunity for recharge. Under steady-state conditions (e.g., at equilibrium) it is possible to envision a system with uniform topography and homogeneous rocks, where recharge occurs on the ridges and discharge occurs in adjacent valleys. However, because the elevation of ridge tops is not uniform and crystalline rocks are not hydraulically homogeneous, the ground-water flow system is more complex than described by that system.

The complex nature of these systems was first modeled by Toth (1962, 1963), who defined local, intermediate, and regional ground-water flow systems. Local flow systems are characterized by shallow ground-water circulation, generally extend over an area of several square miles, and discharge areas are immediately adjacent to recharge areas. Regional flow systems are characterized by deep circulation, extended over many miles, and contain several local systems. Intermediate flow systems have characteristics between those of the local and regional flow systems and contain more than one local flow system.

In general, the movement of ground water in fractured and low-permeability rocks is not yet well understood. As a consequence, mathematical models that can reliably predict ground-water movement in these rocks do not presently exist. Although the parameters potentially influencing ground-water movement in these rocks are known, their relative importance is not yet known, and, consequently, the required degree of detail for field measurements cannot be defined at this time. Most current field-measurement techniques are designed for high-permeability rocks and sediments that are of interest for water-resource development. Reliable techniques that may be necessary for fractured and low-permeability rocks must be developed.

A significant amount of research and development is being conducted world wide to improve the understanding of hydraulic and other physical and chemical processes in fractured and low-permeability rocks and to develop the field measurement techniques and mathematical models required for characterizing and evaluating these processes. The relevant state of the art as of 1978 is documented in the Proceedings of the 1978 Symposium on Geotechnical Assessment and Instrumentation Needs (GAIN--Lawrence Berkeley Laboratory, 1979). An update is being prepared on the the basis of the GAIN 1984 Symposium.

Research on the mathematical modeling of ground-water flow in crystalline rocks directly sponsored by the Crystalline Rock Project has been conducted at the Lawrence Berkeley Laboratory (LBL). Mathematical representations of discrete fracture patterns and mathematical models of ground-water flow in networks of discrete fractures have been developed (Long, 1983; Long et al., 1983; Endo, 1984). The current LBL models consider the rock matrix between the modeled fractures to be impervious and assume the fractures to be circular parallel plates. Work is in progress to test the models on actual data and to develop criteria for determining whether a particular fractured rock can be modeled as an equivalent porous medium. Considerable research remains to be accomplished, however, to relate the models to field data that can reasonably be expected to be measured and eventually to validate the models with actual field measurements.

5.6.1 CLIMAX STOCK, NEVADA TEST SITE

A test of the engineering feasibility of the packaging, transport, deep geologic emplacement, and retrieval of spent reactor fuel was conducted in underground workings in the Climax granitic stock. These workings are about 1400 feet below the surface and about 500 feet above the water table (Murray, 1981). Although the test facility is thought to be in the unsaturated zone, ground water is present in fractures and faults at this test level. Monitoring indicates that about 20 tons of water are removed in the ventilation air stream each year.

The specific objectives of the test include the following:

- Simulation of the thermal environment of a panel of a full-scale repository.
- Evaluation of the effects of heat in combination with intense ionizing radiation on the canister environment.
- Measurement of the thermal and thermomechanical response of the facility and comparisons with model calculations.

In addition, this test provided important engineering data on handling systems, operational controls, and radiation safety (Patrick et al., 1982; Raschke et al., 1983).

A large data base has been developed during the 3-year testing phase and 6-month post-retrieval cooling phase of the test to address these objectives. Some of the significant results and their implications are summarized here.

A series of calculations of thermal and thermomechanical response were conducted to help design the test and associated instrumentation and later to predict the transport of heat, the generation of stresses, and the displacements throughout the test facility. During the 3-year heated phase of the test, measured temperatures agreed with calculated temperatures generally within 2°C (Patrick et al., 1982). This relatively good agreement between modeling and experimental results was seen throughout the 10,000-m^3 instrumented volume of the test. This finding is significant in two ways: it builds confidence in the ability to calculate heat flow in the unsaturated zone, and it implies that geologic structure plays a minor role in affecting heat flow.

Comparisons of calculated and measured displacements indicate that differences of approximately 20 percent occurred during the heated phase of testing (Yow and Butkovich, 1982). Since the calculated and measured displacement curves are nearly parallel in time, it appears that the basic thermomechanical phenomena are being properly modeled.

Monitoring of displacements and stresses also took place during the excavation of the facility, before heat sources were installed. In this case, calculations did not agree with measurements. Analysis of these data indicates that the geologic structure had a significant effect on the response of the rock mass (Heuze et al., 1981). Models based on the theory of elasticity were therefore inadequate.

Implicit in the comparisons of calculations and measurements is the availability of high-quality data. The data acquisition system recorded and archived nearly 9-million data records. The overall reliability was 96 percent. This degree of reliability was achieved through the use of redundant components and the application of stringent calibrations of key measurement-system components, such as digital voltmeters. Although the use of redundant components is not unique to this test, the need for redundancy was found to be much greater than expected because of the remoteness of the site and the need to locate part of the system underground.

Two notable classes of instrumentation failures occurred, which highlight the need for further development of instrumentation for long-term monitoring. First, borehole rod extensometers were found to fail in two modes: malfunctioning of transducers because of corrosive vapors, and breakage of connecting rods by stress corrosion (Patrick et al., 1981). Both problems are preventable. Second, stress gauges were found to fail because of internal corrosion. Cooperative work with the gauge manufacturer has already produced a solution to this problem.

The results of in-situ stress measurements at Climax, though not directly applicable to basalt and tuff, provide important insights into the behavior of fractured hard rocks. In addition to confirming the highly anisotropic nature of the in-situ stress reported by previous researchers, preliminary results indicate the apparent existence of stress "domains" (Creveling et al., 1984). A possible implication is that such domains may need to be identified, characterized, and appropriately treated in performance assessments.

Stability of emplacement holes under the influence of a combined thermal and radiation field was investigated in the Climax tests in a fundamental way by hammer-drilling 17 holes 2 feet in diameter and 16 feet deep. No macroscopic degradation of any emplacement hole was observed. Microscopic studies are under way to examine possible thermal, radiation, and geochemical effects on the rock. These studies will augment earlier investigations that revealed an unexpected 10 percent decrease in Young's modulus and a 20 percent decrease in unconfined compressive strength of this rock after it was subjected to an intense radiation dose from a cobalt-60 source (Durham, 1982). Studies at Climax have also provided limited, though important, data on the corrosion of stainless and carbon steels in a geologic environment. Observations of materials recovered from the test indicate the potential importance of augmentation of normal corrosion processes by the radiolytic formation of nitric acid.

5.6.2 STRIPA MINE, SWEDEN

As part of an international cooperative program, numerous tests have been conducted in underground workings in granite at Stripa, in central Sweden. The main test workings are about 1150 feet below the surface and below the water table. This site provides a contrast to that of the Climax test, which is above the water table.

The types of tests and analyses performed include the following:

- Comparison of predictions made with computer codes against temperature profiles measured in a wet, jointed hard rock.

- Measurement of the rock-mass permeability as a function of temperature and pressure.
- Determination of the magnitudes and principal directions of in-situ stresses in the rock mass.
- Determination of thermally induced stresses and deformations in the rock mass around electrical heater emplacements and of any related phenomena due to heating of the rock.
- Testing of a macroscopic method to define the combined bulk and fracture permeability of the rock.

The significant results to date of this set of experiments can be summarized as follows:

- Two different experiments with heaters have demonstrated that existing computer models can accurately calculate the temperature profiles in the rock. The experiments demonstrate that the predictions are accurate over a period of 20 years (this prediction results from the ability of one of the tests to compress 20 years of heat flow into 2 years).
- Work at Stripa has demonstrated that a large-scale method of measuring the in-situ permeability of a low-permeability (10^{-6} darcy) rock mass is feasible. The method can be adapted to rock masses whose permeabilities are far less than this. The measurements of the permeability of the rock mass indicated that the permeability decreased with increasing rock temperature. Other measurements showed that the permeability was independent of pressure.
- The measurement of in-situ stress in the hard rock showed that there was substantial scatter in the magnitude and direction of the stress.
- The calculated deformation resulting from heating of the rock mass was greater by a factor of 3 than that measured in the experiments. Three potential causes for the discrepancies currently being investigated are: the validity of the input data, the factors considered in the thermomechanical model, and the adequacy of the measurement instrumentation.
- The calculation of the change in stress resulting from heating of the rock mass agreed closely with the measurements.
- Laboratory tests by transient methods (pressure pulses) consistently gave lower permeability values than did steady-state tests on the same samples of fractured granite. The disparity increased with decreasing permeability. The transient tests are very sensitive to minor leaks in the test assembly and to temperature variations as small as 0.05°C in the cavity fluid (Forster and Gale, 1980).
- Collectively, the in-situ tests identified the importance of the coupled effects that control the migration of aqueous solutions of radionuclides away from a site. The mechanical, thermal, hydraulic,

and chemical behavior of a repository in any rock mass involves coupling of these processes, as influenced by the in-situ state of stress, the properties of the rock, and, more important, by discontinuities in the rock mass.

5.6.3 COLORADO SCHOOL OF MINES EXPERIMENTAL MINE

The Colorado School of Mines (CSM) has driven a tunnel in its Experimental Mine for use in the DOE program. The CSM Experimental Mine is located near Idaho Springs, Colorado, and is situated in granite gneiss. The room for the test facility lies above the water table and approximately 300 feet below the surface. The objectives of the test are to

- Assess the effects of blasting on the rock mass.
- Determine constitutive relationships for crystalline rocks.
- Evaluate the heated flat-jack test as a method for obtaining the mechanical properties of jointed rock masses for input to thermo-mechanical models.

Extensometers and leveling pins were installed during construction to monitor the rock-mass behavior. Permeability measurements were made in boreholes parallel to the tunnel as the excavation proceeded. Additional work will include measurements of in-situ stress and a statistical evaluation of fracture parameters and permeability measurements.

This ongoing program has demonstrated that the nature and extent of blast damage done to surrounding rock during excavation procedures is predictable and can be used in the design of repositories in hard rock. In-situ measurements of the thermal expansion of a heated jointed block of rock (about 1 m^3) were not reproducible and lower than predicted because of the inability to predict the behavior of the joints.

5.6.4 UNDERGROUND RESEARCH LABORATORY, CANADA

Atomic Energy of Canada Ltd. (AECL) is constructing an underground research laboratory (URL) for the exclusive purpose of developing and proving radioactive waste disposal technologies. The URL is located in Precambrian granitic rocks of the Lac du Bonnet batholith approximately 60 miles east of Winnepeg, Manitoba. The geologic setting is similar to that of Precambrian crystalline rock bodies in the north-central United States.

As of January 1985 the URL shaft had been sunk to a depth of 720 feet. The planned depth for the underground test chambers is 775 feet.

The URL site was chosen on the basis of having repository-quality rock conditions. This criterion contrasts with other test facilities, which were located in existing mines that had been sited for other purposes such as mining (Stripa, CSM) or nuclear testing (Climax). Prior to shaft sinking, an extensive program of surface mapping and borehole drilling was carried out. The data base from this work will be used to determine how well underground conditions can be predicted prior to excavation. Instruments installed in boreholes drilled from the surface and in advance of the shaft are being used to monitor the hydrologic and mechanical effects of construction.

Among the tests planned for the URL are the following: (1) tests of large scale mechanical response to excavation (mine-by test), (2) a pressure chamber test to check coupled hydro-thermal-mechanical effects, (3) radionuclide migration experiments, (4) hydrologic testing and monitoring, (5) moisture balance to determine total water inflow, (6) container-buffer interaction tests, (7) borehole and shaft sealing tests, (8) instrumentation development (9) heated rock block experiments, and (10) shaft construction monitoring experiments. The DOE has participated in the URL program by providing funds for U.S. researchers to participate in the design, execution, and analysis of the experiments. Specifically, U.S. groups are working in (1) design of the mine-by experiment, (2) instrumentation development, (3) determination of porous media equivalence for ground-water flow in the URL fracture system, (4) geophysical borehole logging methods to determine the opening of fractures, and (5) microseismic monitoring to improve measurement of rock stresses.

5.7 IMPLICATIONS OF CURRENT RESEARCH ON THE POTENTIAL HOST ROCKS FOR THE FIRST REPOSITORY

On the basis of research described above each potential host rock has been found to have certain intrinsic advantages and disadvantages. The purposes of this section are to provide a summary and some perspectives on potential host rocks under consideration for siting of the first repository. The limited discussion that follows should not obscure the fact that (1) variations exist in the properties of any geologic formation and between separate formations of the same rock; (2) repository sites will be chosen on the basis of isolation capabilities, potential environmental impacts, land-use considerations, and other social and economic considerations (see Appendix B); and (3) detailed site-specific investigations will be required to establish the ultimate suitability of any potential site for the location of a repository. Furthermore, being generic, the discussion is not conclusive. The results of preliminary evaluations of each potentially acceptable site against the guidelines are reported in the draft environmental assessments (DOE, 1984c-k). More-detailed information will be presented in the site-characterization plans.

Two different approaches were used in site exploration. In the host-rock approach, a potentially suitable rock--salt--was selected on the basis of its favorable intrinsic properties. Then regions that contain that rock (e.g., the Gulf Interior) were delineated as starting points for site screening. This approach was recommended by the National Research Council (1957). The starting point for the site investigations being conducted in basalt at the Hanford Site and in tuff at the Nevada Test Site was current land use. Investigations of these government lands dedicated to defense activities were initiated in the mid-1970's to determine whether geologic and hydrologic conditions would allow the use of these lands for repositories. Subsequently, in 1979, the General Accounting Office and the Congress recommended that existing

Federal "nuclear reservations" be considered for siting repositories before other areas were selected. This land-use approach to finding sites should not obscure the fact that the isolation capabilities of the host rock are considered primary and that the evaluation of all candidate host rocks will be performed on the same basis--that is, compliance with the siting guidelines.

The discussion that follows is based on information contained in a recent report by the National Research Council (1983). This reference (NRC, 1983) is intended to describe the source from which the information was obtained and not to imply endorsement by the National Research Council. Table 5-4 summarizes the more important advantages and disadvantages of the potential repository rocks. For simplicity, bedded and dome salts have been combined. The draft environmental assessments for the various sites discuss the favorable and potentially adverse conditions of the different media relative to their suitability as a host rock for a geologic repository. Chapter 7 of the draft environmental assessments compares the merits of the various media and sites relative to design, operation, and waste isolation of a repository. The interested reader is referred to this more detailed discussion of the characteristics of the different host rock types.

5.7.1 BASALT (HANFORD SITE)

Basalts of the Columbia Plateau comprise a very thick sequence of lava flows (see Appendix C). Initially, the deposited flows had permeable tops and bottoms. Many flows are separated by interflow sediments of high permeability. With time and exposure to ground water, basalt flows and their interbeds generally become less permeable because of the deposition of secondary minerals, especially silica, clays, and zeolites. This system of alternating aquifers and relatively impermeable zones is complex, will be difficult to characterize and model, and will require specially designed aquifer tests.

Basalt is among the strongest of common rock types; however, this makes excavation of the rock expensive, and pervasive fracturing necessitates the use of supports, such as rock bolts. Because it has a moderate thermal conductivity and a high melting temperature, basalt can withstand a high thermal load. Thick accumulations of basalt are unlikely sources for mineral and energy resources, but resources may exist in underlying rocks.

A chemical characteristic of these basalts is that secondary clay minerals and zeolites commonly line joints and fractures. These minerals have high sorption capabilities and hence a potential for inhibiting the migration of many radionuclides. Another chemical characteristic of most basalts is the strong reducing capacity (i.e., low oxidation-reduction potential) of deep ground water, buffered by ferrous minerals, which are more abundant than in other candidate host rocks. Most radionuclides are least soluble in reducing environments, as indicated in Section 5.4.

5.7.2 SALT

Bedded and domal deposits of rock salt have long been considered as potential host rock for geologic repositories. Favorable properties of salt include high thermal conductivity (which minimizes temperature gradients for a given waste loading); very low permeability (in the absence of discontinuities); no moving ground water for the transport of radionuclides; abundant availability in thick and widespread masses that have uniform properties; plasticity that permits tight closure and self-sealing at repository depths; and low cost of mining. Furthermore, because of their high salinities, the waters associated with salt deposits are not normally attractive for domestic and industrial uses. However, salt deposits may be overlain, underlain, or bounded by aquifers that contain potable water.

The sorptive capacity of salt is the lowest of all the candidate host rocks, but interbeds higher in silicate minerals have higher capacities. Being highly soluble in water, salt is always associated with saline waters (saturated or nearly saturated chloride brines), which are highly corrosive to metals, especially at high temperatures. Many metals that have low solubilities in dilute waters (less than 0.1 percent dissolved matter) are highly soluble in hot brines as metal-chloride complexes.

Some salt and associated brines are attractive sources of common salt, potassium, bromine, and other minerals. Most sedimentary basins that contain salt deposits are also attractive targets for oil and gas exploration.

The plasticity of salt, which is greater at higher temperatures and higher lithostatic pressures, can be an advantage in tending to heal fractures and seal excavated openings. However, it may create some problems in maintaining underground openings over time intervals required to emplace waste and to backfill emplacement rooms. It might also create some problems in keeping emplacement rooms open for decades if direct access for waste retrieval for that long is required. The thermal expansion of salt is nearly three times that of other potential host rocks. Thus, with thermal loading, the possibility of vertical uplift and induced stresses in more-brittle surrounding rocks may become important.

Little site-specific research has been conducted on salt. Therefore, R&D for salt has treated salt largely in a generic sense.

5.7.2.1 <u>Bedded Salt</u>

Bedded-salt deposits are never pure sodium chloride. They contain variable proportions of other evaporite and silicate minerals, which tend to maintain roughly uniform proportions parallel to original layers of deposition but differ greatly in earlier and later deposited layers. Water content is very low in massive salt (ca. one percent or less) but is generally higher in interbeds containing other minerals and in cross-cutting breccia pipes and other discontinuities.

Issues of concern for bedded salt include the effects of solution features, such as sinkholes, on anisotropic permeability in overlying aquifers;

identification, genesis, and significance of breccia pipes; potential for dissolution; brine migration; potential occurrence, origin and significance of pressurized brine reservoirs; and the potential for human intrusion.

5.7.2.2 Salt Domes

Dome-salt deposits are similar in many respects to bedded salts, but they are discrete pluglike bodies whose internal structures are highly complex and essentially vertical. The margins of salt domes also tend to be structurally complex. This makes the prediction of radionuclide transport less certain. Another potential disadvantage of domes is that their tops and borders may be regions where extensive dissolution has occurred. Also, adjacent strata penetrated by domes tend to be faulted and folded in a complex manner, and hence, their physical continuity and effects on water flow are difficult to characterize and model. Fluid inclusions in dome salt tend to be smaller and of lesser total volume than those in bedded salt that has not been subjected to as much pressure. Upwarped and faulted sedimentary strata on the margins and tops of salt domes are especially attractive for oil and gas exploration. Domes are also attractive as sources of nearly pure rock salt, as sites of deposits of elemental sulfur (in the caprock rather than in the salt itself), and as sites for storing oil, gas, and other fluids.

Domes are limited in number and easy to locate, making them targets for future human intrusion. Because they penetrate various water-yielding sedimentary rocks to great depths, they are subject to dissolution near their margins and may be surrounded by both potable water at shallow depths and saline ground water at greater depths. The buffer zone of relatively pure halite (90 percent +) surrounding the repository and its associated low permeability and porosity (NBS, 1981) will result in a very low ground-water flux and only a small potential for long-term radionuclide release. Additional studies must be carried out, however, to define flow paths and rates outside of the dome. Various lines of evidence attest to the structural stability of salt domes. Long-term future changes in sea level may alter ground-water-flow systems in coastal plain aquifers by increasing or decreasing path lengths and water velocities, but the consequences of such possible changes can be adequately bounded.

5.7.3 TUFF (YUCCA MOUNTAIN SITE)

Tuffs, which are explosively erupted volcanic rocks rich in silica, have some favorable characteristics for repositories. Some ash-flow tuffs were so thick and hot when erupted (600 to 1000°C) that their siliceous glass fragments deformed plastically and formed dense "welded" tuff (see Appendix B). Other ash flows and air-fall tuffs retained their initial high porosity, but their glass commonly has altered to zeolites and clays which have high sorption capacities. Such minerals usually are absent in welded tuffs of nearly identical chemical composition, which devitrified from natural glass at high temperatures to more-stable silica and silicate minerals.

The potential for siting a repository in the unsaturated zone in an arid region is considered an advantage. The very low flux and moisture content to be expected in the repository horizon would allow the construction and operation of a repository under nearly dry conditions, would allow the design of engineered-barrier systems that could keep canisters virtually dry, and would minimize concerns about the design and functioning of shafts and seals. However, concepts of hydrologic flow and radionuclide transport in unsaturated, fractured rocks are not well developed. The testing of these concepts will require specially designed field tests. Thus, the flow system will be difficult to characterize in detail.

Silicic tuffs generally are low in iron, most of which has been oxidized to ferric iron. Ground water is likely to be dilute in dissolved matter, oxidizing, and unfavorable for the long-term retention of uranium and other radionuclides of low solubility in reducing environments. However, silicic tuffs have offsetting advantages in the high sorption capacities of associated manganese and iron oxides, clays, and zeolites and diffusion into pores.

Tuffs are relatively homogeneous in their original horizontal dimensions but are generally very heterogeneous vertically, each layer differing in porosity, permeability, strength, and extent of devitrification and sorption capacities. Also, permeable sedimentary rocks commonly form interbeds above or below uniform tuffs, and individual units have been faulted and fractured in response to tectonic activity. Thermal conductivities of tuffs are moderate but variable, depending chiefly on porosity. Most silicic tuffs are sufficiently strong after welding, devitrification, and cementation to maintain stable mined openings. Oil and gas seldom occur in the tuffs but may be present in underlying sedimentary rocks.

5.7.4 PERSPECTIVES

As illustrated in Table 5-4 and discussed in the preceding text, there are intrinsic advantages and disadvantages associated with each of the potential host rocks for the first repository. Table 5-4 lists advantages and disadvantages that are generic to domal and bedded salts, but specific to the Hanford site basalts and Yucca Mountain tuffs. It is evident that no rock type is clearly superior. The suitability of any of these rocks for hosting a repository cannot be judged by such a simple table. Suitability can only be judged by analyzing all of the intrinsic advantages and disadvantages--as influenced by the conditions prevalent at a specific site--and by analyzing the performance of the total isolation system. Ultimately, site-specific performance assessments will be used for detailed comparisons of sites. The data to be used in these performance assessments will not be available until after site characterization.

Table 5-4. General Comparison of the Potential Host Rocks for the First Repository[A]

Advantages	Disadvantages
BASALT (HANFORD SITE)	
Very strong rock	Complex hydrology very difficult to characterize and model
Low permeability at depth due to secondary minerals in fractures	Variations in lateral and vertical extent and properties make it difficult to characterize and model
Minerals that fill fractures and minerals that will form by chemical reactions during thermal pulse are commonly highly sorptive	Reduced mechanical stability due to fracturing
Characterized by geochemical conditions that generally inhibit radionuclide transport	Relatively expensive to excavate
No resource potential of the rock	Some layers have high permeability at shallow depth where they constitute aquifers
	Unknown resource potential in deep underlying rocks
BEDDED SALT AND SALT DOMES	
Very low water content	Natural resources (other than salt) are commonly associated with salt deposits; these include potash in bedded salt and sulfur, oil, and gas near salt domes
Very low permeability	Highly soluble in water; extent and rate of dissolution difficult to characterize
High thermal conductivity	Creep closure of mined openings complicates modeling
Deforms by plastic flow rather than fracture; fractures tend to self-heal	Likelihood of pockets of gas or brine
Low cost of excavation	Low sorptive capacity
Bedded salt is relatively easy to characterize and model	Salt domes are relatively difficult to characterize and model
Extensive mining experience	Highly corrosive to metal
TUFFS (YUCCA MOUNTAIN SITE)	
Virtually no mineral or energy resource potential	Because composition and physical properties are highly variable, strata are relatively difficult to characterize and model
Highly sorptive minerals constitute large proportion of many beds	Reduced mechanical stability because of fracturing
Very low flux of water in arid regions	Aquifers in arid regions may be attractive to future generations
Present in significant thicknesses above the water table	Unsaturated zone hydrology not well understood and difficult to characterize and model
	Seismic activity tends to be high in regions where tuffs occur

[A]The information contained in this table is a summary based on Section 5. See also Section 5.7.4 for a brief discussion of the perspectives from which these advantages and disadvantages are to be viewed.

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Chapter 6

GUIDELINES FOR RECOMMENDING SITES FOR REPOSITORIES

The guidelines issued under Section 112(a)

--Nuclear Waste Policy Act, Section 301(a)(6)

In response to the above stated requirement of Section 301(a)(6) of the Nuclear Waste Policy Act of 1982 (the Act), the DOE is including in the Mission Plan (see Appendix B) its final rule 10 CFR Part 960, "General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories." Prepared in response to the requirement of Section 112(a) of the Act, these guidelines were developed through a lengthy process that involved extensive public comment; consultation with the States, affected Indian tribes; and Federal agencies; and the concurrence of the Nuclear Regulatory Commission. After receiving the Commission's concurrence by unanimous vote, the guidelines were approved for issuance in final form on November 30, 1984, and published in the Federal Register on December 6, 1984. They became effective 30 days after issuance.

Preceding the guidelines in Appendix B is the supplementary information, also referred to as the "preamble" or the "statement of basis and purpose." It provides background information on the process by which the guidelines were developed, including details about the consultation process, and the organization and format of the guidelines. The supplementary information also discusses the comments received on the draft guidelines and explains the disposition of the comments. In addition to general comments on such topics as specificity, relationship to NRC and EPA regulations, and implementation, it summarizes and discusses specific comments on every guideline.

Chapter 7

SITE CHARACTERIZATION

A description of known sites at which site characterization activities should be undertaken, a description of such site characterization activities, including the extent of planned excavations, plans for onsite testing with radioactive or nonradioactive material, plans for any investigation activities which may affect the capability of any such site to isolate high-level radioactive waste or spent nuclear fuel, plans to control any adverse, safety-related impacts from such site characterization activities, and plans for the decontamination and decommissioning of such site if it is determined unsuitable for licensing as a repository

--Nuclear Waste Policy Act, Section 301(a)(7)

7.1 DESCRIPTIONS OF SITES

The sites at which site characterization will be undertaken have not yet been selected (the Secretary of Energy is to recommend three sites to the President in November 1985). Therefore, in response to the first requirement in Section 301(a)(7) of the Act, this chapter presents brief descriptions of the nine sites identified as potentially acceptable for the first repository. More information about the geologic, hydrologic, geochemical, and geomechanical characteristics of the host rocks at these sites can be found in Chapter 5 of Part II. Detailed discussions about the characteristics of the nine sites are presented in the draft environmental assessments (see the bibliography at the end of this volume), which also contain preliminary evaluations of the sites against the siting guidelines. The interested reader is referred to these more detailed descriptions of sites. The locations of the nine sites are shown in Figure 7-1.

7.1.1 THE BASALT SITE

The basalt site is located on the DOE's Hanford Site in the State of Washington. The site lies within the central portion of the Cold Creek syncline (see Figure 7-2). The syncline is part of the Pasco Basin, one of several structural and topographic basins located within the Yakima Fold Belt of the Columbia Plateau.

The Hanford Site is a 570-square-mile tract of land selected in 1942 by the U.S. Army Corps of Engineers as a site for the production and purification of nuclear materials for defense purposes. It lies in Benton, Franklin, and Grant Counties.

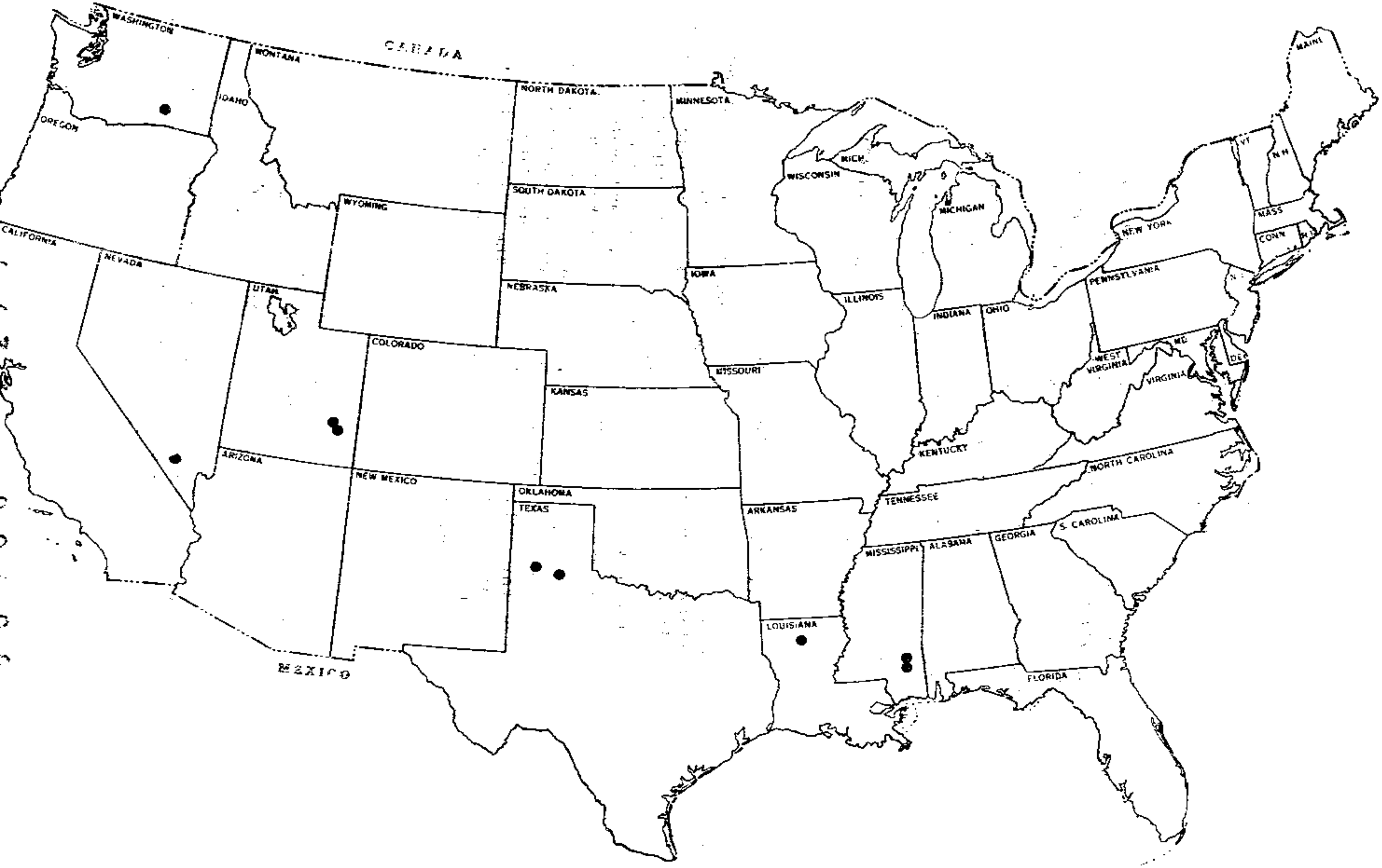

Figure 7-1. Potentially acceptable sites for the first repository.

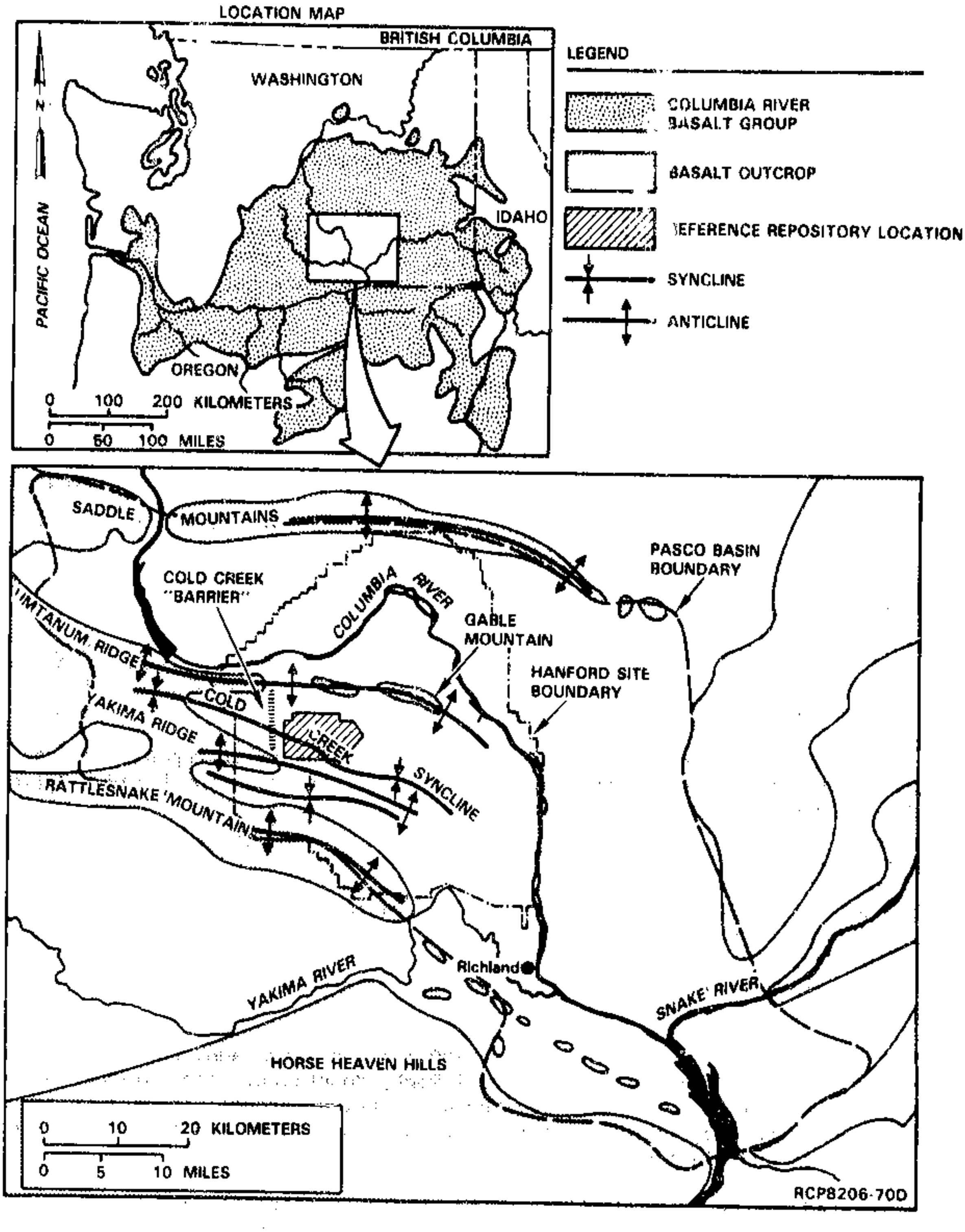

Figure 7-2. Extent of the Columbia River Basalt Group, the Pasco Basin, and the proposed site for a repository in basalt.

The Pasco Basin is underlain by basalt lava flows that erupted 17 to 6 million years ago, with most of the basalt having been extruded early in these eruptions. The volcanic vents from which the basalt flows are mostly in the eastern and southeastern portions of the Columbia Plateau but, because of their low viscosity and large volume, the basalt lavas spread over considerable distances. The origin and nature of the eruptions are described in Appendix C.

The region of the potential repository site is underlain by at least 50 basalt flows with a cumulative thickness of more than 9800 feet. The flows identified as candidate horizons for the repository are between 2850 and 3460 feet below the surface.

The climate in the region of the site is arid, with an average annual precipitation of 6.3 inches. The land of the Pasco Basin is used for agricultural purposes and for Federal Government installations. The agricultural land is mostly north and east of the Columbia River and south of the Yakima River; most of it is used for growing irrigated crops. The Government installations consist of the DOE's Hanford Site and the U.S. Army Yakima Firing Center.

The closest Indian reservation is owned by the Yakima Indian Nation. It is approximately 16 miles west of the Hanford Site and 31 miles from the proposed site.

7.1.2 THE BEDDED-SALT SITES

Four of the potentially acceptable sites for the first repository are bedded-salt sites in two different geohydrologic settings--the Paradox Basin of Utah and the Palo Duro Basin of Texas.

Paradox Basin

The Paradox Basin sites are located in Davis and Lavender Canyons in San Juan County (see Figure 7-3). The nearest towns are Moab (approximately 35 miles north in Grand County), Blanding (approximately 35 miles south in San Juan County), and Monticello (approximately 25 miles southeast in San Juan County).

The Paradox Basin was formed some 300 million years ago, coincident with the main deformation along the ancestral Rocky Mountains. The Paradox Formation was formed in a northwest-trending asymmetrical trough; it is a lens-shaped mass with a cyclical repetition of thick salt beds and thin marker beds of carbonates and clastics.

Located in the Colorado Plateau, the basin is characterized by rugged terrain and classic desert landforms. Because the Colorado Plateau has been slowly and steadily uplifted, erosional features are intensely developed. Drainages are deeply incised into the surfaces of the plateau, and benchlike canyon sides are common.

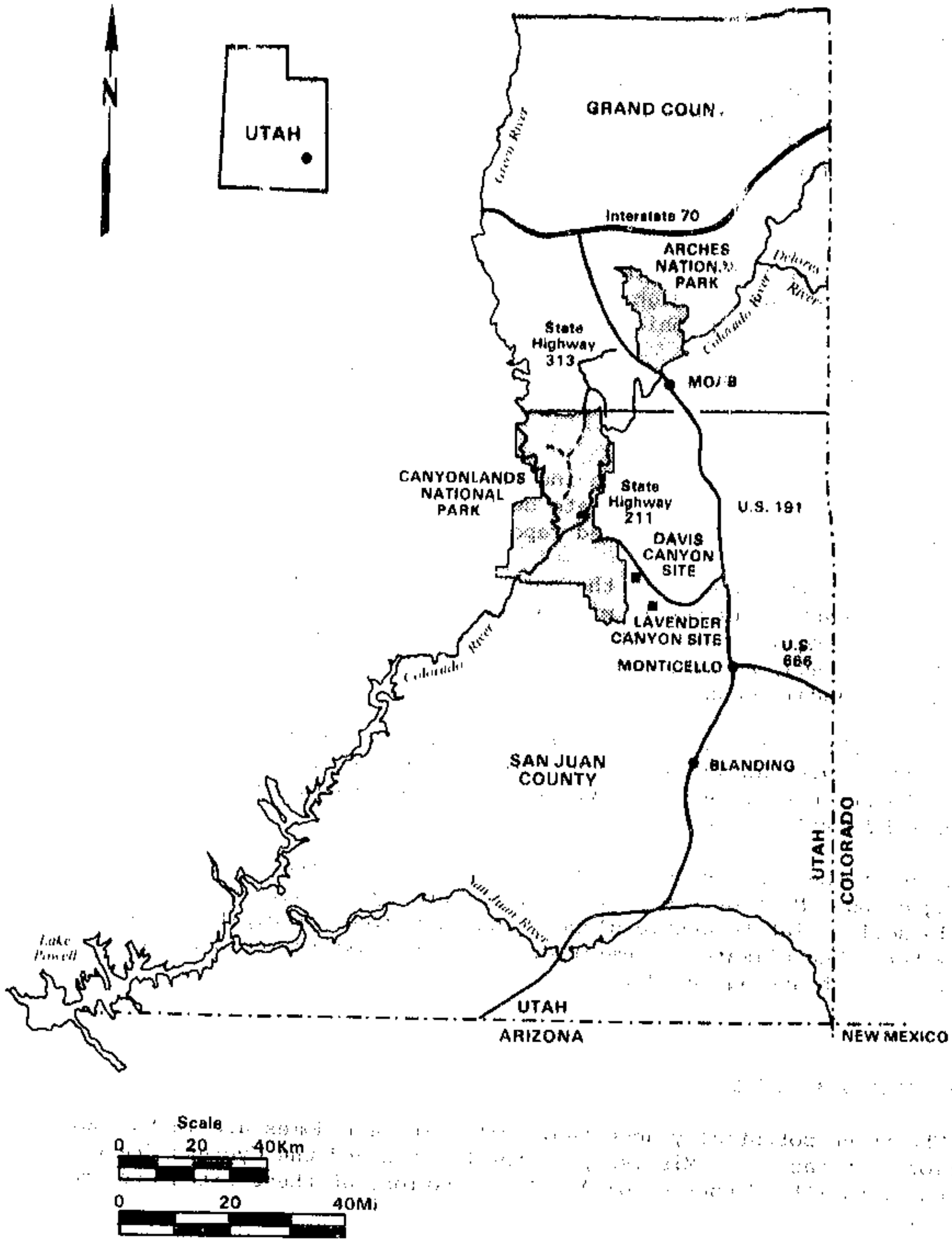

Figure 7-3. Location of the Davis Canyon and the Lavender Canyon sites in San Juan County, Utah.

Land in the area of the Lavender and the Davis Canyon sites is used principally for recreation. There is also some agriculture, primarily cattle grazing in winter and limited alfalfa production. The important recreational resources within and adjacent to the area consist of the Needles District of the Canyonlands National Park; the Manti-La Sal National Forest; the Newspaper Rock State Historical Monument; and three areas managed by the U.S. Bureau of Land Management: the Canyon Rims Recreation Area, the Beef Basin, and the Dark Canyon Primitive Area.

Palo Duro Basin

The Palo Duro Basin, which is part of the much larger Permian bedded-salt basin, is in the Southern High Plains of the Texas Panhandle; it is part of the Great Plains physiographic province.

Two potentially acceptable sites have been identified in this basin--one in Swisher County, and the other in Deaf Smith County. Both sites are shown in Figure 7-4.

The rock strata of the basin include a thick sequence of limestone, shale, dolomite, and thick evaporate deposits, the thickest salt portion of which was selected as the proposed repository horizon.

The Deaf Smith site is in the north-central portion of Deaf Smith County. Its setting is rural, with an average population density of about 30 persons per square mile. The nearest cites and towns are Hereford in Deaf Smith County; Vega, Adrian, and Wildorado in Oldham County; and Canyon and Amarillo in Randall County.

The Swisher site is in the north-central portion of Swisher County, a rural setting with an average population density of five persons per square mile. The nearest cities and towns are Tulia and Happy in Swisher County and Canyon and Amarillo in Randall County.

Most of the land in Deaf Smith County and in Swisher County is used for growing crops. Most of the farmland is generally classified as "prime," with fertile soils, flat to gentle slopes, and sufficient precipitation or irrigation water. The climate is semiarid, with warm summers, cold winters, and relatively high average winds.

7.1.3 SALT-DOME SITES

The three potentially acceptable sites in salt domes are in the Gulf Interior salt basins of Mississippi (the Richton and the Cypress Creek Domes) and Louisiana (the Vacherie Dome). The locations of these sites are shown in Figure 7-5.

Both the Mississippi and the Louisiana salt basins have a similar geologic history; both contain a sequence of poorly to moderately consolidated sands, silts, clays, and evaporites.

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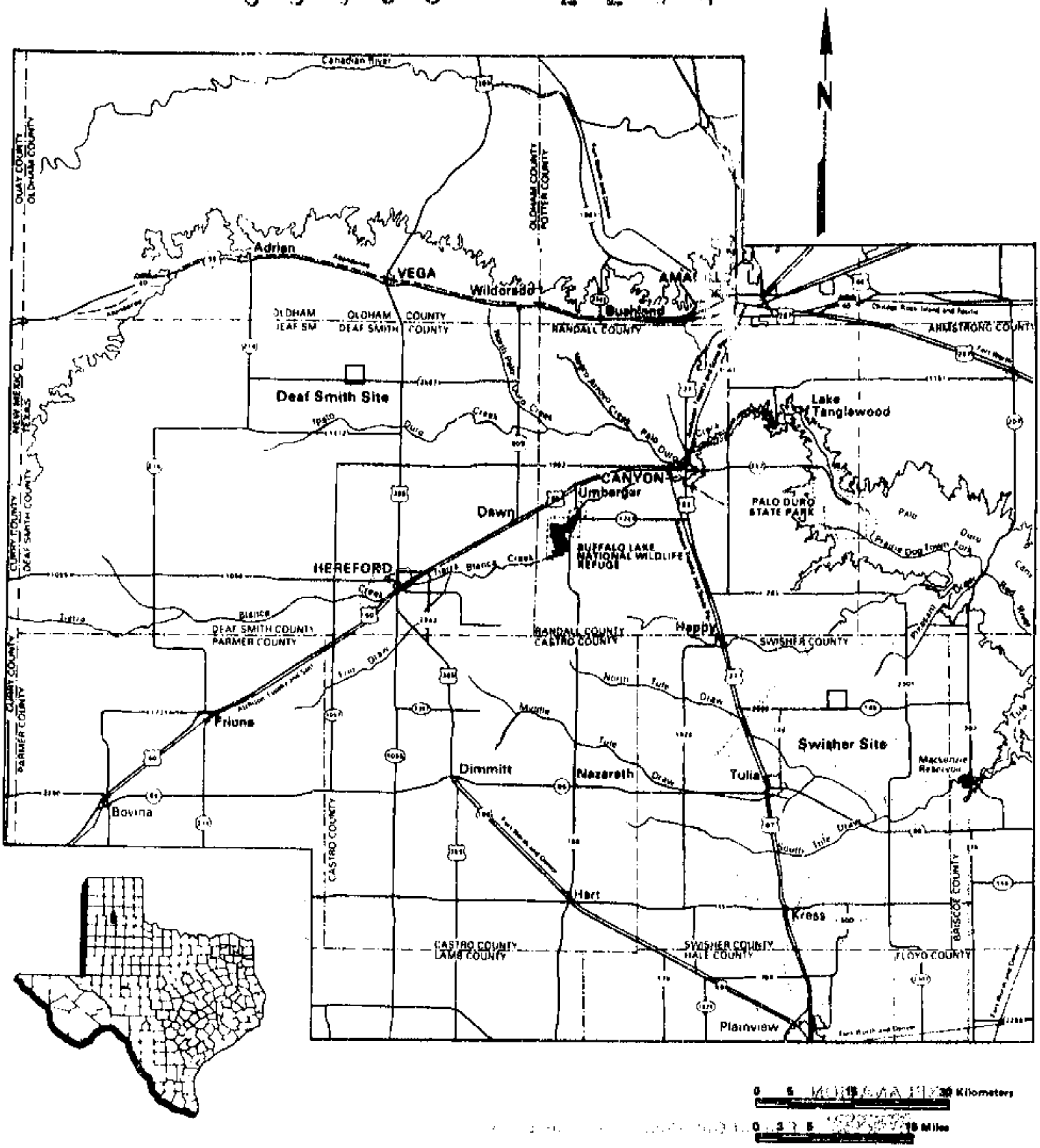

Figure 7-4. The study locations in Swisher and Deaf Smith Counties, Texas.

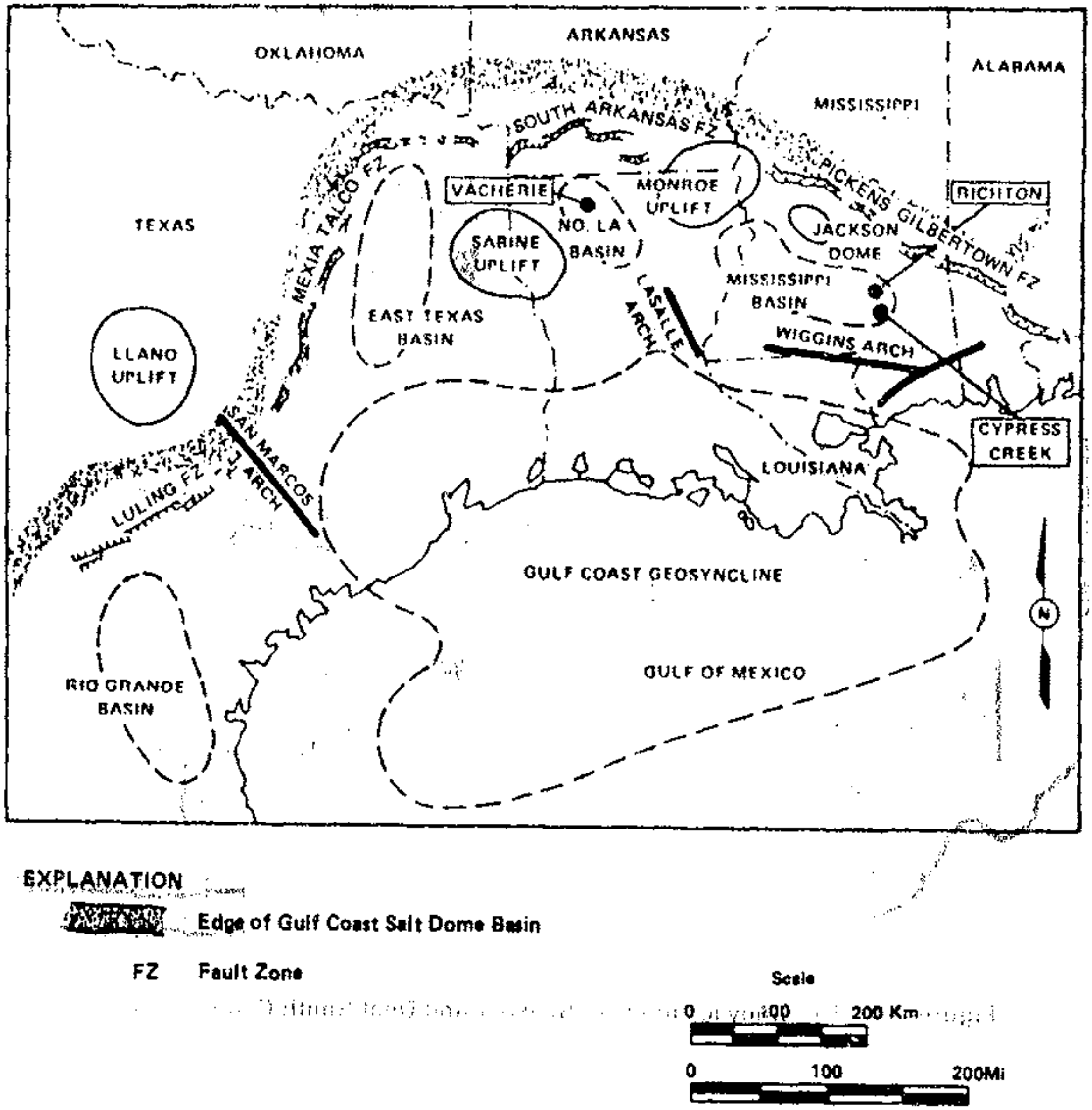

Figure 7-5. Map of the Gulf Coast Region, showing the major structural features and the locations of the domes identified as potentially acceptable sites.

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The Cypress Creek Dome site (see Figure 7-6) is located on the headwaters of Cypress Creek, in Perry County, Mississippi. It is about 4 miles southwest of Beaumont and 3 miles southeast of New Augusta. All of the site is within the boundaries of the DeSoto National Forest and the Camp Shelby Military Reservation. The local terrain is characterized as gently rolling to hilly, with moderate topographic relief. There are no residential, commercial, or institutional structures in the area. Much of the land on, and adjacent to, the dome has been cleared by logging and military operations.

The Richton Dome, also shown in Figure 7-6, is also in Perry County, Mississippi, about 20 miles east of Hattiesburg and 10 miles north-northeast of New Augusta. The nearest town is Richton, which lies adjacent to the boundary of the controlled area and has about 1200 residents. The terrain here is characterized as rolling. Away from the site, the terrain is classified as gently rolling. Most of the land in the area of the site is used for forestry and agriculture.

The Vacherie Dome site is in Webster and Bienville Parishes (see Figure 7-7). The nearest town is Heflin, about 2 miles west, and Shreveport is about 35 miles away to the northwest. The terrain is gently rolling to flat. Most of the land on the dome is in a commercial forest, but the site also contains numerous residences, many with small adjacent agricultural uses. Immediately north of the site are several oil- and gas-producing wells and gravel pits.

7.1.4 THE TUFF SITE

The potentially acceptable site in tuff is at Yucca Mountain in southern Nevada (see Figure 7-8). Yucca Mountain is a prominent group of north-trending fault-block ridges located in the southern part of the Basin and Range physiographic province, a broad region of generally linear mountain ranges and intervening valleys. At an elevation of 4950 feet above the mean sea level, northern Yucca Mountain rises more than 1200 feet above Jackass Flat to the east and over 990 feet above Crater Flat to the west.

Yucca Mountain is composed of a thick sequence of mostly silicic volcanic rocks (tuff) deposited between 16 and 8 million years ago. The origin and nature of these volcanics is described in Appendix C. Subsequent normal faulting and tilting of the rocks produced the present rugged terrain.

The climate in the region of the site is arid, with an average annual rainfall of less than 6 inches, most of which is returned to the atmosphere by evaporation and plant transpiration. Consequently, the ground-water flux through the candidate repository horizon (in the unsaturated zone) is quite low, and the water table is deep, more than 650 feet below the repository horizon.

The site is located exclusively within lands controlled by the Federal Government. The land parcel under consideration, which includes both the proposed geologic repository, repository surface operations area and all of the proposed controlled area, is divided as follows: (1) the U.S. Department of Energy controls the eastern portion through the withdrawn land of the

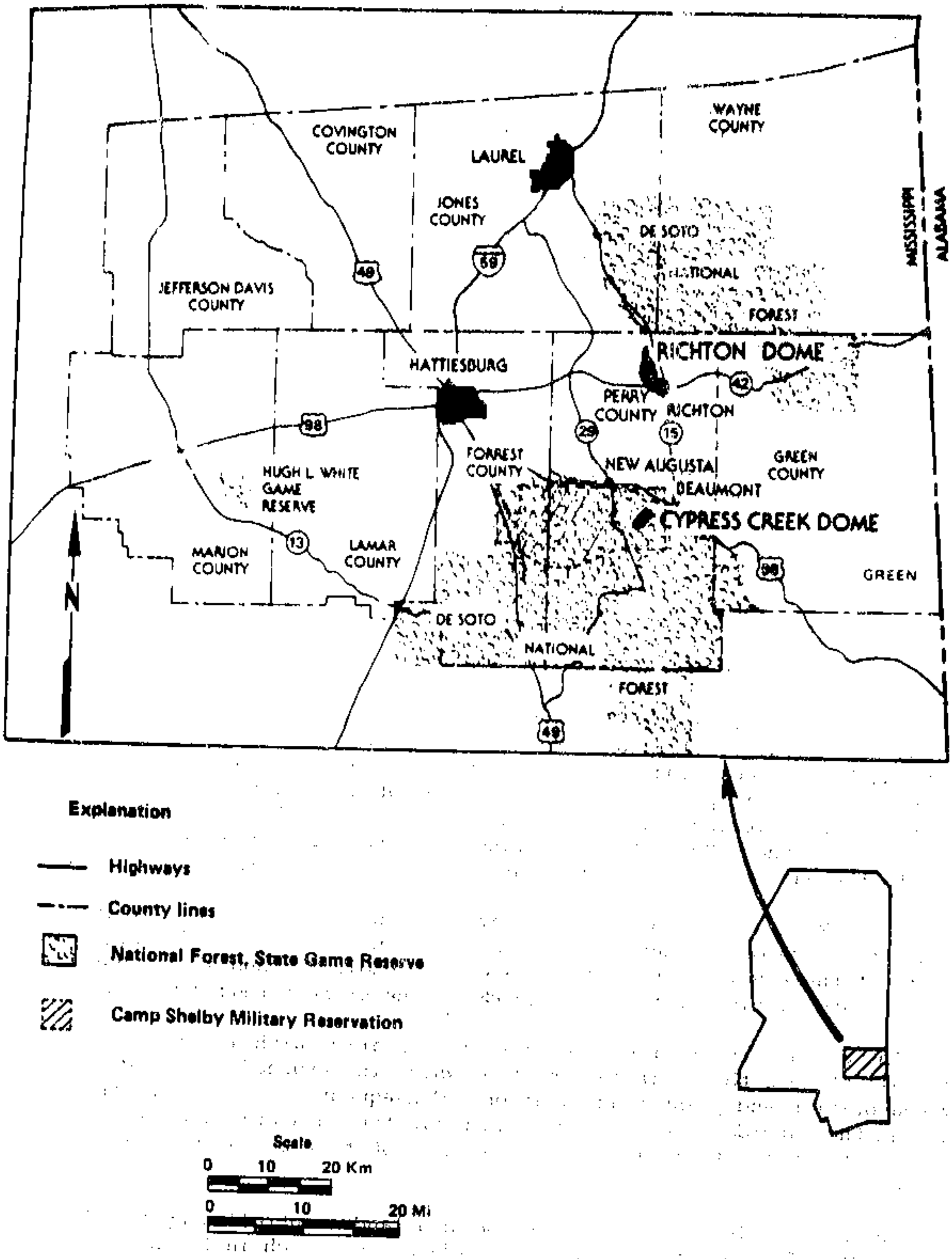

Figure 7-6. Location of the Richton and the Cypress Creek domes.

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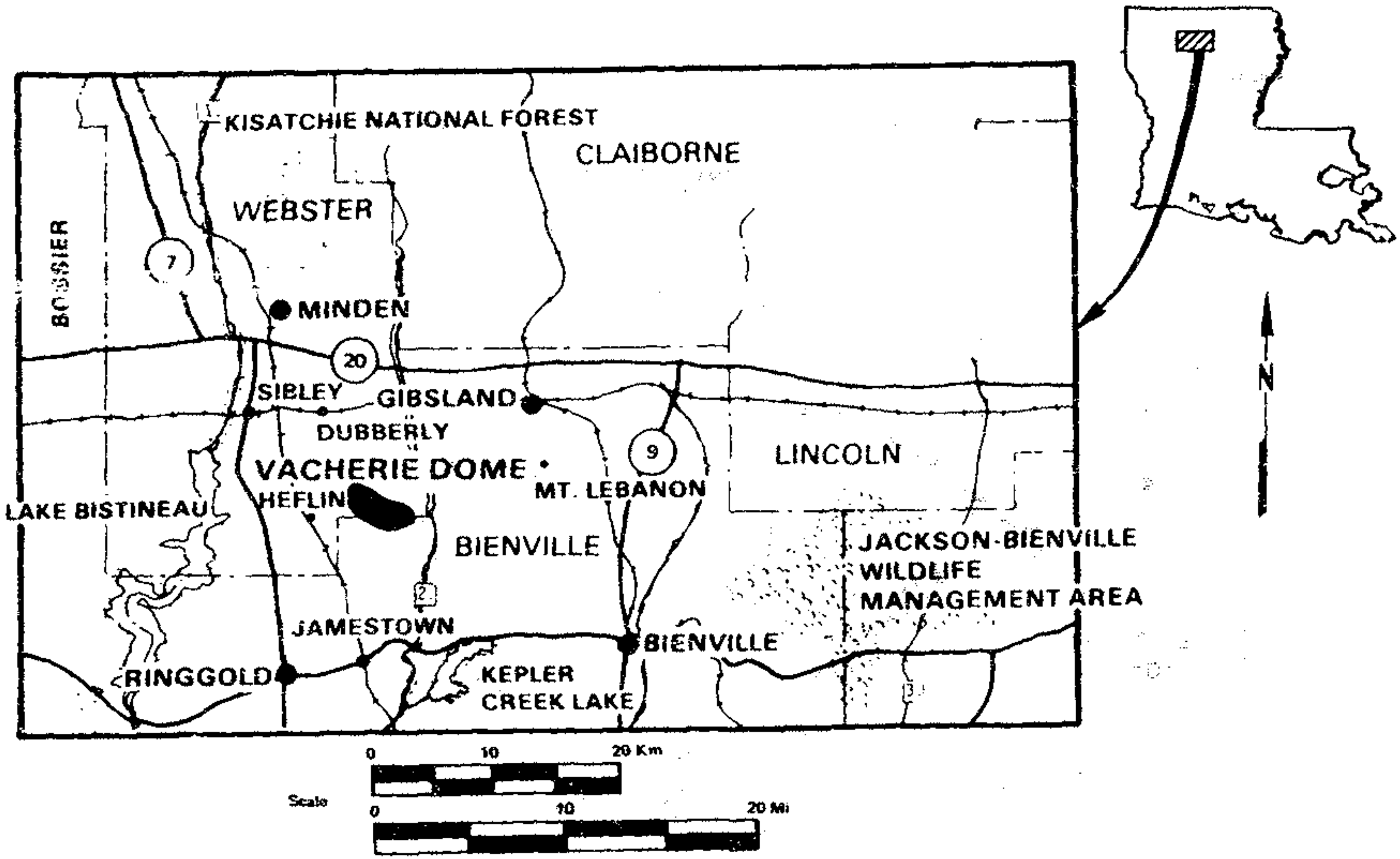

Explanation

1. Bayou Dorcheat Natural and Scenic River
2. Black Lake Bayou Natural and Scenic River
3. Saline Bayou Natural and Scenic River

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Figure 7-7. Location of the Vacherie dome.

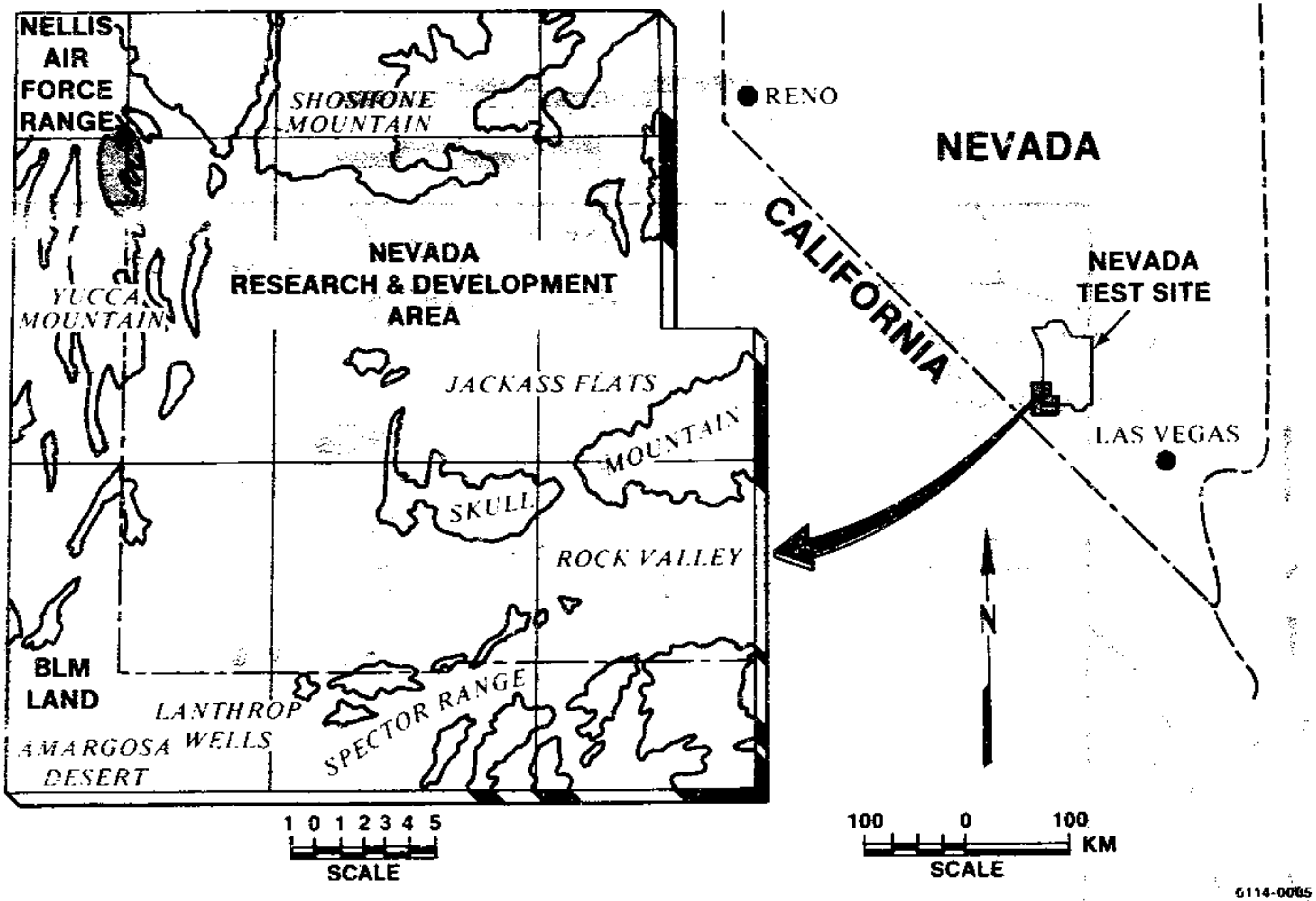

Figure 7-8. Location of the Yucca Moutain site.

Nevada Test Site; (2) the U.S. Air Force controls the northwestern portion through the land-use permit for the Nellis Air Force Bombing Range; and (3) the Bureau of Land Management (BLM) holds the southwestern portion in public trust. There are no competing land-use activities in the area. The U.S. Air Force land involved is used exclusively for overflight and contains no facilities. The BLM-administered portion of the land has no grazing permits or mineral claims and is not used for recreational purposes.

7.2 SITE-CHARACTERIZATION ACTIVITIES AND FOLLOW-ON TESTS

To demonstrate that a candidate site is suitable for a repository and meets the general siting guidelines (see Appendix B), the DOE will conduct a program of site characterization. This program will consist of surface-based investigations (e.g., geologic mapping and the collection of weather data), investigations conducted by means of deep and shallow boreholes, laboratory tests of the mechanical and thermal properties of the host rock, and, most important, tests conducted in the host rock at the proposed depth of the repository horizon. The latter can be performed only by constructing exploratory shafts and mining the tunnels and rooms in which the tests will be conducted.

The site-characterization program will vary somewhat with the host rock and the site. Before proceeding to sink shafts at any candidate site, the Secretary of Energy will submit a site-characterization plan (SCP) for the candidate site to the NRC and to either the Governor and legislature of the State in which such candidate site is located or the governing body of the affected Indian tribe on whose reservation such candidate site is located as the case may be, for their review and comment. The sinking of the exploratory shafts will commence after public hearings have been held in the vicinity of candidate sites in order to receive comments on the SCPs. The comments that are unrelated to the sinking of shafts will be addressed in semiannual SCP reports.

The NRC's agreement on the SCP in its entirety is not required before the sinking of the exploratory shafts is begun. The DOE has exchanged information with the NRC concerning shaft-construction techniques and intends to reach agreement on this particular issue before starting shaft construction. Other issues, however, will be addressed when the NRC issues the site-characterization analysis (SCA) required by 10 CFR Part 60. The SCA is not required before the start of shaft construction.

The SCP will be issued after the site has been recommended by the Secretary of Energy for characterization. The sections that follow discuss the safety and programmatic considerations that influence the exploratory-shaft program and the activities required for shaft construction and use. A more detailed discussion of the activities to be conducted can be found in Section 2.3 of Part II and in Chapter 4 of the draft environmental assessments.

7.2.1 SAFETY AND PROGRAMMATIC CONSIDERATIONS FOR THE EXPLORATORY-SHAFT PROGRAM

The initial mission for the exploratory-shaft program was formulated in 1980. Since then, the scope and the duration of the in-situ test program have expanded significantly. In considering the implications of these changes on the exploratory-shaft facility (ESF), the DOE has taken into account industrial and mining safety issues. The safety codes adopted by the DOE are encompassed by DOE Order 5480.1A, which requires compliance with the Federal Mine Safety and Health Act of 1977, together with California Mine and Tunnel Codes. Where regulations overlap, the most stringent rule is to govern.

These rules have been interpreted to require that where a hazard to underground workers may result from having only one access to, or egress from, the subsurface facilities, two shafts are required. In assessing the need for two shafts, the DOE considered accepted practices in the mining industry as well as the geologic conditions that are likely to exist at each of the candidate sites.

At the basalt site, the candidate horizon is overlain by highly productive aquifers, and hence the potential for flooding of excavated openings must be considered. In-situ stress conditions indicate a potential for rock bursts, and the possibility of roof falls in previously unexplored ground must be considered (see Section 5.5.1). Possible dangers associated with the presence of methane will be evaluated, although a repository in the Cohassett Flow is unlikely to be classified under Mine Safety and Health Administration regulations as a gassy mine. Because of the small diameter of the exploratory shaft and the depth of the candidate horizon, there is concern that, should an emergency arise, underground workers would be isolated without a second means of escape or could not be brought to the surface quickly. A second exploratory shaft will therefore be sunk if the basalt site is selected for characterization.

At all the salt sites except those in the Paradox Basin, the reference horizons are also overlain by aquifers, such that the potential for flooding is present. At all the sites the possibility of encountering pockets of brine or gas must be taken into account. In fact, it is possible that the underground operations may be designated a "gassy mine" because of precedents set by other underground construction projects in the same vicinity as the salt sites and because of evidence that methane is present in the overlying formations. Again the DOE has determined that two exploratory shafts will be necessary to ensure the safety of all underground workers.

At the tuff site in Nevada, it appears that some of the potential problems identified for the other two host rocks are not significant. The reference horizon is above the water table, which diminishes the danger of flooding. Because of the shallower depth of the horizon and the expected geologic conditions, there is little potential for rock bursts, roof falls, and the like, nor is danger from explosive gases considered to be likely. In spite of such favorable conditions, the DOE has come to the conclusion that it is advisable to provide two exploratory shafts to enhance the safety of personnel. In the design of the shafts, due consideration for seismic loads from both earthquakes and nuclear explosions at the Nevada Test Site will be included.

The DOE has established and implemented a policy for the exploratory-shaft configurations that requires them to--

1. Ensure compliance with the intent of Sections 113(a) and (c)(1) of the Act.

2. Provide adequate margin for compliance with all established safety criteria.

3. Provide adequate flexibility both in the construction and in the operation of the ESF in terms of site-characterization and potential follow-up in-situ work.

4. Be institutionally acceptable.

5. Be cost effective with emphasis on near-term expenditures of program funds.

6. Meet site-characterization schedule requirements (e.g., start of in-situ testing).

The policy noted above has led the DOE to select the following shaft configurations at the proposed candidate sites:

Host Rock	First Shaft	Second Shaft
Basalt	6-foot finished diameter, drilled	6-foot finished diameter, drilled
Salt	12-foot finished diameter, conventionally mined	12-foot finished diameter conventionally mined
Tuff	12-foot finished diameter, conventionally mined	6-foot finished diameter, drilled

The DOE believes that this policy is consistent with the NRC regulations restricting the commencement of construction until the construction authorization has been issued and that the construction of these exploratory shafts during site characterization will comply with the requirement that construction be reasonably and functionally related to the objectives of site characterization.

The DOE notes that if significant modifications are required to the in-situ test programs currently envisioned, further modifications in the exploratory-shaft configurations may be necessary, including enlargement of one or both shafts.

Furthermore, the DOE currently intends to use the exploratory shafts, as required, to ensure that the construction of the repository can be completed in time to meet the Act-mandated repository operation date of January 31,

1998. It will als continue to evaluate the most cost-effective use of the exploratory shafts in the operating repository.

The exploratory-shaft program is intended to demonstrate the suitability of the site to perform as a geologic repository, and a information gained will be integrated into the ongoing design of future repositories. The DOE feels that this is fully consistent with the intent of the Act and the objectives of the NRC, as stated in 10 CFR Part 60.

7.2.2 ACTIVITIES

The exploratory-shaft project at each candidate site will require site preparation, shaft construction, outfitting (i.e., the installation of internal shaft equipment), and the mining of a few tunnels and rooms near the base of the shaft for testing purposes. The preparation will consist of constructing an access road, clearing and grading the site, and constructing foundations and impoundments. The construction of each shaft will consist of sinking and lining the shaft to the proposed depth of the repository. The construction method will vary from site to site because of different geologic conditions. The shafts will be large enough to allow workers and test equipment to be transported and to provide adequate ventilation.

The shafts will be outfitted their full length to support the ventilation system; the underground utility, safety, and communication needs; and the conveyances, rock, men, and materials. Test tunnels will then be excavated in preparation for the testing program. The geometric configuration and the extent of the test tunnels will vary from site to site because of different site-suitability issues.

Tests to be performed in the exploratory shafts are listed in Section 2.3. In general, the in-situ tests will concentrate on characterizing the rock mass; they will assess in-situ stress, permeability, thermomechanical parameters, geochemical properties, thermal properties, heat dissipation, and, in the case of salt, the tendency for brine migration.

7.3 PLANS FOR ONSITE TESTING WITH RADIOACTIVE OR NONRADIOACTIVE MATERIAL

The current plans for site characterization do not include tests with radioactive materials to simulate wastes. Sources of radiation will be used in some geophysical investigations and hydrologic studies (e.g., radioactive tracers). Such techniques are routinely used in oil and gas exploration and in the evaluation of ground-water resources.

Radioactive materials may be used in a test and evaluation facility (see Chapter 4 in Part II). However, the decision on proceeding with such a facility will not be made until 1987, and therefore the test plans are unavailable at this time.

7.4 PLANS FOR INVESTIGATIONS THAT MAY AFFECT ISOLATION CAPABILITIES

Two site-characterization activities have the potential for affecting the waste-isolation capabilities of a site:

1. The drilling of deep boreholes (more than 990 feet deep).

2. The drilling or mining of the exploratory shafts and excavation of related underground workings.

Drilling is necessary to confirm information obtained by other methods (e.g., geophysical surveys) and to directly observe rocks from selected sampling points below the surface of the ground. Holes are drilled in locations deemed to have the greatest potential for resolving uncertainties.

To the extent possible, work requiring boreholes over the proposed repository will use existing holes to minimize the total number required. Similarly, new boreholes will be used for as many purposes as possible and will be located to coincide with the locations of shafts or pillars to the extent practicable. Where possible, boreholes will be located outside the immediate repository area.

As already mentioned, the exploratory shafts will be sunk to the depth of the repository. The plans for these shafts are described in more detail in Section 2.3 of Part II.

7.5 PLANS TO CONTROL ADVERSE SAFETY-RELATED IMPACTS

Detailed plans for controlling any adverse safety-related impacts from site-characterization activities will be contained in the SCPs. These plans will be site specific.

The boreholes will be sealed permanently and the decision on sealing of exploratory shafts will be made after repository construction is completed and prior to waste emplacement. Fortunately, much relevant experience is available from the sealing of boreholes used in petroleum exploration and mining operations. Site-specific sealing materials and techniques will be used to limit the potential for compromising the integrity of sites (see also Section 7.6 in this Chapter). The ability of the seals to remain intact over the long periods required for waste isolation will have to be demonstrated to the NRC before a construction authorization is received. Moreover, permanent sealing is considered in the selection of shaft designs and excavation techniques. Included in this evaluation of excavation techniques is the extent of fracturing in the surrounding rock or residual stresses in the rock. If extensive fractures are created, it may be necessary to fill the fractures with grout or similar material. Techniques that cause extensive fracturing will be modified if necessary.

7.6 PLANS FOR DECOMMISSIONING SITES UNSUITABLE FOR LICENSING

Plans for decommissioning a site determined unsuitable for licensing can be discussed only in general terms; detailed, site-specific discussions will be given in each SCP.

The general principle guiding the decommissioning strategy is that a site will be returned, as nearly as practicable, to its original condition. This principle has served as one of the bases for selecting the locations of drilling and other activities. The screening process that led to the identification of potentially acceptable sites included environmental considerations at every stage. Using this approach in the selection of study locations serves to reduce the requirements for restoration measures and enhances the success of measures that might have to be implemented. In this way, restoration planning begins before an area is disturbed. Another general principle is that Federal, State, and local regulations for decommissioning and reclamation will be applied.

7.6.1 ONSITE FACILITIES

The reclamation plan for onsite surface facilities includes the following elements:

1. Buildings will be emptied of their contents, disassembled, and transported off the site and salvaged.

2. Most equipment (e.g., items required for mine ventilation, pumps, electrical generators, storage tanks) will probably be removed from the site and salvaged. Equipment not removed will be placed in a condition that will ensure it will not compromise repository performance.

3. The shaft collars and other foundations will be cut or broken into manageable pieces and moved to acceptable disposal sites.

4. Septic tanks and similar facilities will be abandoned in place.

5. Fluid impoundments (e.g., mud pits) will be backfilled after the removal of contaminated materials.

6. Chemical wastes will be disposed of in accordance with acceptable standards.

7. The site will be backfilled and graded to a final contour consistent with existing land-use patterns or plans and revegetated.

8. Qualified soil scientists will monitor compliance with site-specific reclamation plans.

The disposition of the exploratory shafts will depend on the shaft-abandonment practices routinely followed in a State and, in the case of Federal sites, on cooperative Federal-State agreements.

Most likely, the shafts will be backfilled with material excavated during its construction and sealed with a grout. Details of techniques will be determined by the geologic conditions at the site, but might involve the installation of concrete or chemical plugs and the replacement of excavated muck with compacting additives under high pressure. After the shafts have been sealed and the surface of the site has been restored, a marker explaining the history of the shafts might be emplaced.

Details for the decommissioning of deep exploratory boreholes also vary from site to site. All boreholes will be sealed at or before decommissioning. In general, the boreholes will be sealed with a grout formulation that is compatible with the geologic conditions at the site (e.g., with a grout whose density roughly matches that of the surrounding rock). The surfaces of borehole drill sites will also be graded and stabilized to a condition consistent with the surrounding terrain.

7.6.2 OFFSITE FACILITIES

The reclamation of the offsite surface facilities will be similar to that of onsite facilities, though less extensive. Such facilities include the sites of boreholes, the sites of environmental and geophysical surveys, access roads, and utility corridors. Some of these (e.g., roadways) might not require any restoration and will probably be left in their improved condition. Reclamation of specific equipment having monitoring functions (such as meteorological towers) will be carried out after consultation with the State.

Boreholes and trenches are the two most important examples of offsite subsurface work that will require some reclamation. Boreholes will be sealed according to accepted practice with materials appropriate to the particular site, and the surface of the drill site will be revegetated. Trenched areas will be regraded to a final contour and revegetated in a manner consistent with land-use patterns before the start of site characterization.

Chapter 8

WASTE SOLIDIFICATION AND PACKAGING

An identification of the process for solidifying high-level radioactive waste or packaging spent nuclear fuel, including a summary and analysis of the data to support the selection of the solidification process and packaging techniques, an analysis of the requirements for the number of solidification (or) packaging facilities needed, a description of the state of the art for the materials proposed to be used in packaging such waste or spent fuel and the availability of such materials including impacts on strategic supplies and any requirements for new or reactivated facilities to produce any such materials needed, and a description of a plan, and the schedule for implementing such plan, for an aggressive research and development program to provide when needed a high-integrity disposal package at a reasonable price

--Nuclear Waste Policy Act, Section 301(a)(8)

As explained in Part I, most of the commercial waste to be accepted for disposal in the first repository is expected to be spent reactor fuel. The first repository will, however, accept a small quantity of solidified commercial high-level waste from the West Valley Demonstration Project. It will also accept solidified defense high-level waste. This chapter therefore begins with a brief discussion of current packaging concepts for spent fuel. It then describes the solidification of high-level waste.

The rest of the chapter is concerned mainly with the materials to be used for various components of the waste package, especially the metal containers that will contain the waste. The waste package is defined as the waste form (i.e., spent fuel or solidified high-level waste) and any container, shielding, packing, and other absorbent materials immediately surrounding an individual waste container. Because detailed plans for research and development are presented in Section 2.5 of Part II, their discussion here is limited to a brief summary.

8.1 PACKAGING OF SPENT FUEL

The reference plan for the first repository calls for the packaging of spent fuel at the repository. During the first years of repository operation (i.e., phase 1--see Section 3.1 of Part I), the spent fuel will be received in shipping casks and transferred into metal containers for underground emplacement. When phase 2 of the repository begins operating, the spent fuel will be disassembled and consolidated, as well as encapsulated in containers. The spent-fuel assemblies will be taken apart and the fuel rods rearranged to accommodate the rods from two or more assemblies in the space of one assembly. The non-fuel-bearing skeletons of the assembly will be disposed of in accordance with applicable regulatory requirements. The DOE is currently evaluating the need for, and the implication of, disposing of these wastes in a repository.

The disassembly of spent-fuel assemblies has been demonstrated during the past several years. It has been performed in conjunction with fuel inspections, research and development programs, and the recovery of damaged fuel rods.

The consolidation and encapsulation operation may not be performed at the repository. It could be performed at the nuclear power plant or at a facility for monitored retrievable storage (MRS). The final decision on the location of this operation has not yet been made, but evaluation is underway to allow for this decision to be made in the near future. If rod consolidation occurs at the repository, then encapsulation of the spent fuel occurs as described above. If the consolidation is performed elsewhere, then these stainless-steel canisters will be used for transport and handling, and the metal container overpack will be added at the repository.

If a decision is made at a later date to emplace a universal cask (i.e., a cask that is storable, transportable, and disposable), no repackaging would be required at the repository.

8.2 WASTE SOLIDIFICATION

When spent fuel from either commercial or defense reactors is reprocessed, it is separated into three major fractions, two of which are wastes that would be disposed of in a geologic repository. The first fraction is a liquid called "high-level waste" because it contains more than 99 percent of the radioactivity. The second fraction consists of the metallic fuel-assembly components and other solid materials used in the process; it is a special kind of transuranic (TRU) waste. The third fraction consists of the uranium and plutonium extracted from the spent fuel, which can be recycled through a fuel-fabrication step to fuel other nuclear reactors. During fuel fabrication, additional TRU waste is generated. Before disposal in a geologic repository, high-level waste must be solidified. TRU waste may also require some treatment, such as compaction.*

Both reprocessing and plutonium-fuel fabrication, though not now used in the U.S. commercial fuel cycle, have been conducted at commercial U.S. facilities, and some wastes from these operations remain to be disposed of, particularly the high-level waste produced at West Valley, New York. The latter can be solidified (converted to glass) by techniques that are currently available and are being demonstrated in the West Valley Demonstration Project. The spent fuel that is removed from defense reactors and naval reactors is routinely reprocessed.

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*Present plans do not provide for repository disposal of TRU wastes from reprocessing.

Although much of the work on the conversion of high-level waste to solid waste forms was based on defense waste, the results and technology will be transferable, in large part, to commercial waste. Data developed in work with defense waste indicate that borosilicate glass is the leading candidate waste form for existing commercial high-level waste.

During solidification, high-level waste is mixed with glass frit and fed into a melter, where heat causes the high-level waste to be incorporated chemically into a borosilicate glass. The glass waste form is then cast into canisters, where the molten glass solidifies into a chemically inert, highly insoluble, nondispersible, nonvolatile solid with a very low potential for leaching in water of the type likely to be found in geologic repositories. The structural resistance of the glass form to heat and self-irradiation effects should be sufficient to maintain the structural integrity of the waste form for the containment period, although a container will still be required to ensure compliance with the waste package containment performance objective of 10 CFR 60.113. Moreover, the borosilicate glass has sufficient mechanical strength and impact resistance to withstand the stresses of repository emplacement and retrieval during a specified retrieval period. It is expected to be compatible with a full range of the geologic conditions expected in a repository and is undergoing performance test and analysis as described in Section 2.5.

Several processes are available for the treatment of TRU metallic waste, and each process offers several options. These include induction melting, electric-air melting, hot pressing, and compaction. Also under consideration or development are processes for removing TRU surface contamination to the extent required for the disposal of the base material as low-level waste.

The DOE will continue the development and demonstration of high-level-waste and TRU-waste treatment processes to ensure that acceptable waste forms will be available when necessary. The DOE has selected borosilicate glass as the waste form for Savannah River Plant defense high-level waste and for commercial high-level waste from the West Valley Demonstration Project (WVDP). Justification for the selection of borosilicate glass is contained in the Environmental Assessment--Waste Form Selection for Savannah River Plan HLW (DOE-EA-0179, July 1983) and in the Action Description Memorandum for the Selection for the Waste Form for WVDP (March 1983). Future development will focus on borosilicate glass and on second-generation (alternative) waste forms that have a high potential for reducing treatment requirements or overall disposal-system costs or on forms that will more easily accommodate higher internal temperatures at high waste loadings.

The number of waste-treatment facilities required cannot be determined at this time. However, in addition to the waste-treatment facilities required for defense waste and the West Valley Demonstration Project, at least one waste-treatment facility would be required for each spent-fuel-reprocessing plant. The number of reprocessing plants will be determined by the commercial nuclear industry and will depend on the need for reprocessing and its economics. No difficult technical problems are expected for the construction and operation of waste-treatment facilities.

8.3 CHOICE OF MATERIALS

Each host rock under consideration for the first repository has different requirements for the waste package. The paragraphs that follow discuss the reference container for spent-fuel disposal in each of the three host rocks and the packaging that will be used for solidified high-level waste. The choice of materials depends on detailed evaluations of the geochemical environment into which the package would be placed. Materials other than the reference ones could be chosen for any of the sites.

For basalt, the reference container for the waste package is made of low-carbon steel with an iron-chrome-molybdenum steel and cupronickel as alternatives. The thickness of the reference material is approximately 5 to 6 centimeters. This material is readily available, has been used widely in engineering structures, and should present no great difficulties in fabrication. The waste package for basalt also includes a packing material which is 15 centimeters thick, between the container and the host rock. It consists of a mixture of crushed basalt (75 percent) and fine-grained sodium bentonite clay (25 percent). Pneumatic emplacement and the use of precompressed annular rings are two methods being considered for the emplacement of this material. Both the basalt and the clay are readily available. The pneumatic-emplacement technology has been developed and demonstrated on the scale of full-size waste packages.

For salt, the reference container is made of low-carbon steel. The thickness of the material ranges up to 10 centimeters. Techniques for remote welding and inspection of welds will be developed, beginning in FY85, as well as procedures for weld acceptance and tests to identify corrosion effects. The designs for salt use crushed salt as a packing material. No difficulties are foreseen with the fabrication of the container. An alternative design concept employs a thin layer of the alloy Ticode-12 over a carbon-steel container.

For tuff, the reference container is made from austenitic stainless steel that is about 1 centimeter thick. This material is readily available and has a long history of use in engineering structures. No particular difficulties are foreseen with respect to fabrication. No packing material is used in the reference designs, although a tuff packing backfill is being considered in an alternative design for spent-fuel packages.

All reprocessed high-level waste currently included in the repository planning base will use a stainless-steel production canister, in which the waste is solidified. The production canister will be enclosed in an appropriate container of the material selected for repository disposal.

Evaluations of copper and selected copper alloys as potential container materials for basalt and tuff are also under way. These evaluations are considering corrosion resistance, structural stability, cost, availability, and fabrication requirements. In addition, the second-repository program (currently concentrating on crystalline host rocks) will initiate research during FY86-87 on the potential use of copper and copper alloys in the waste package. The evaluations will use data from completed and ongoing international copper studies, such as the Swedish and Canadian work, to the extent appropriate.

8.4 AVAILABILITY OF MATERIALS

As work in the waste-package area is directed toward detailed design, planning for materials acquisition and fabrication facilities assumes importance. As discussed in Section 2.5.2.2, the reference materials for waste containers are low-carbon steel and stainless steel. Two alternative designs also receiving attention consist of a carbon-steel container overpacked by a thin outer shell of titanium alloy (Ticode 12) and a container made from steel alloyed with 9 percent chromium and 1 percent molybdenum. The use of copper and copper alloys is also being considered for host rocks other than salt.

None of the aforementioned materials is presently considered strategically critical or in short supply, though chromium, an essential element in both the stainless and the alloy steel, is of limited availability in the United States.

The reference salt and basalt container as presently conceived will be made from a carbon-steel casting. Assuming carbon steel is shown to exhibit acceptable corrosion resistance, a carbon-steel casting is ideally suited for the waste package because of its reasonable cost, ease of manufacture, and excellent characteristics for welding. The number of foundries capable of producing the carbon-steel castings intended for containers is more than adequate to satisfy the requirements of the geologic repository program.

The reference tuff stainless-steel containers as presently conceived will be fabricated by welding rolled plate or possibly from extruded seamless pipe or centrifugal castings. No problems with suppliers or fabricators are expected with regard to producing rolled and welded containers. Only two suppliers, however, are at present capable of producing extruded pipe for containers.

Neither the titanium alloy (the alternative salt container material) nor the iron-chromium-molybdenum alloy (the alternative basalt container material) should be difficult to deliver or fabricate, although fabrication experience with the iron-molybdenum alloy steel is limited. Chromium, an essential element in both the stainless steel and the chromium-molybdenum alloy, is imported mainly from South Africa, although there are U.S. chromite mines that could be reactivated at substantially higher chromium costs than those via importation. The consumption of chromium in producing overpacks made of either stainless steel (for tuff) or iron-chromium-molybdenum (for basalt) would be insignificant compared to U.S. production of these alloys.

Data from the American Iron and Steel Institute and the U.S. Department of Commerce indicate that the annual U.S. production rates projected to the year 2025 for carbon steel, stainless steel, and titanium mill products (plate, pipe, and castings) far exceed the estimated material requirements for the packages needed through the year 2025. The supply of copper is also expected to exceed significantly the quantities needed for waste containers if copper or an alloy is selected. The table on the next page illustrates the domestic industrial output versus the first repository's needs for reference container material over its operating lifetime.

Material	Industry output[a] (thousands of tons) Yearly	From 1985 to 2025	Quantity needed for first repository[b] (thousands of tons) Salt	Tuff	Basalt
Carbon steel	4738	189,520	185		181
Stainless steel	240	9,600		75	

[a]1982 and 1981 American Iron and Steel Institute and 1981 U.S. Department of Commerce statistics.

[b]Weight of the total number of reference containers for the first repository (emplacement to the year 2025).

This tabulation shows that, for the current reference waste-package designs, the metal required for the first repository's containers will be less than 1 percent of the projected total U.S. industrial output of the particular metal. The use of these comparatively small amounts will not affect strategic supplies nor require production from new or reactivated facilities.

8.5 RESEARCH AND DEVELOPMENT PLANS FOR WASTE PACKAGES

Research and development plans for the reference waste packages in each of the repository host rocks under consideration are described in Chapter 2. The plans are divided into four principal tasks: (1) the definition of the waste package environment; (2) waste-form and materials testing, (3) design, fabrication and prototype testing; and (4) assessment of waste-package performance.

The definition of the waste-package environment requires the geologic, hydrologic, and geochemical data that define the ambient conditions of the underground repository and an evaluation of the effects resulting from the construction of the repository and the emplacement of the waste.

The waste-form tests are directed at estimating the rates of radionuclide release from the waste package over the long term. They are based on the interactions among the waste form, other engineered barriers, ground water, and the host rock. Covering the temperature range expected in the repository, the tests vary from simple tests of interactions between the waste form and ground water to multicomponent tests. The materials testing is concerned with obtaining sufficient data on the behavior of reference and alternative materials in the expected environment of a repository in a particular host rock to ensure that the performance of the waste package will be adequate.

The task of design, fabrication, and prototype testing is divided into several steps: conceptual design, advanced conceptual design, license-application design, and final procurement and construction design. These designs will be based on increasingly sophisticated engineering analyses, test data, and design configuration evaluations. These designs will be developed in conjunction with the corresponding design phases of the repository.

The performance analysis will be made with predictive site-specific models based on data obtained from tests with waste-package materials, site characterization, and waste-package and repository designs. They will predict (1) the time at which containment is lost and (2) the long-term release of radionuclides from the waste package.

Chapter 9

WASTE-GENERATION RATES, REQUIREMENTS FOR DISPOSAL CAPACITY, AND REPOSITORY SCHEDULES

An estimate of (A) the total repository capacity required to safely accommodate the disposal of all high-level radioactive waste and spent nuclear fuel expected to be generated through December 31, 2020, in the event that no commercial reprocessing of spent nuclear fuel occurs, as well as the repository capacity that will be required if such reprocessing does occur; (B) the number and type of repositories required to be constructed to provide such disposal capacity; (C) a schedule for the construction of such repositories; and (D) an estimate of the period during which each repository listed in such schedule will be accepting high-level radioactive waste or spent nuclear fuel for disposal

--Nuclear Waste Policy Act, Section 301(a)(9)

This chapter presents forecasts of nuclear electricity-generating capacity and the amounts of spent fuel requiring disposal as well as the factors that might affect the number and the capacities of repositories. The latter include (1) differences between the once-through fuel cycle (no reprocessing of spent fuel) and a fuel cycle that is based on reprocessing, (2) the disposal of defense waste, and (3) site limitations. Also presented are the waste-acceptance schedules for the authorized plan and the improved-performance plan discussed in Chapter 2 of Part I.

9.1 FORECASTS OF NUCLEAR ELECTRICITY-GENERATING CAPACITY AND SPENT-FUEL ACCUMULATION THROUGH THE YEAR 2020

The Energy Information Administration (EIA) of the DOE is responsible for making forecasts of the installed capacity of nuclear power plants in the future. Its forecasts are made for four different assumptions about the growth of the nuclear electricity-generating capacity: no new orders, low, middle, and high. For waste-disposal planning, the DOE is using the November 1984 EIA middle-case forecast.* According to this forecast, the installed capacity will reach 123 gigawatts electrical by the year 2000 and 212 gigawatts by 2020, growing at a rate slightly below 3 percent per year between these years.

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*U.S. Department of Energy, Commercial Power 1984: Prospects for the United States and the World, DOE/EIA-0438(84), Energy Information Administration, November 1984.

The total quantity of spent fuel discharged from nuclear power reactors is estimated to be about 130,000 metric tons of uranium (MTU) by 2020. The actual spent-fuel discharges will probably decline somewhat because it is expected that in the future the fuel will be kept in the reactors for longer periods. The EIA annual middle-case forecast for nuclear capacity and spent-fuel discharges from 1983 through 2020 are presented in Table 9-1.

To accommodate the total spent-fuel inventory of 130,000 MTU that will have accumulated by the year 2020, it will be necessary to construct two repositories. Two repositories will be needed because Section 114(d) of the Act stipulates that the DOE may emplace no more than 70,000 MTU in the first repository until such time as a second repository is in operation.

Spent fuel will, of course, continue to be discharged beyond 2020 if reactors continue to operate. However, it is not necessary to plan for a third repository at present. Under current plans, second-repository emplacement will not reach 70,000 MTU until about 2030. If current estimates hold, planning for a third repository can be done at the turn of the century.

Since long-range energy forecasts tend to change with time, it is necessary to examine the assumptions on which they are based. Recent trends indicate that a nuclear electricity-generating capacity exceeding 212 gigawatts electrical by 2020 is unlikely. Indeed, the capacity could be less than 212 gigawatts. To establish the lower bound, the EIA no-new-orders case was examined with respect to the need for two repositories. Under the assumptions of this case, installed capacity grows to 109 gigawatts by 1993, but decreases to 49 gigawatts by 2020. For the no-new-orders forecast, the total spent-fuel inventory would reach approximately 98,000 MTU by 2020, which would require two repositories to meet the requirements of the Act (i.e., the first repository is limited to 70,000 MTU until the second repository begins operations). Thus, even with a substantial reduction in the middle-case forecast for nuclear generating capacity by 2020, two repositories remain necessary.

9.2 FACTORS AFFECTING THE NUMBER OR CAPACITY OF REPOSITORIES

9.2.1 REPOSITORY REQUIREMENTS FOR THE ONCE-THROUGH FUEL CYCLE AND THE REPROCESSING FUEL CYCLE

In the once-through fuel cycle, which is currently used by the commercial nuclear industry in the United States, spent fuel is discharged from a reactor, cooled for some period of time in storage, and ultimately disposed of as waste. The waste requiring disposal in a repository is in the form of packages of intact fuel assemblies or packages of fuel rods consolidated from several assemblies. In the reprocessing fuel cycle, on the other hand, the spent fuel would be discharged, cooled, and reprocessed to recover uranium and/or plutonium. The high-level waste resulting from the reprocessing would be solidified and disposed of in a repository. The transuranic waste produced in reprocessing may also be disposed of in a repository; however, this decision has not been made at this time.

Table 9-1. 1984 EIA Middle-Case Forecast of Nuclear Electricity-Generating Capacity[a]

Year	Installed Capacity (GWe)	Spent-Fuel Generation (MTU)	
		Annual	Cumulative
1983	64	1400	9,900
1984	74	1200	11,100
1985	85	1300	12,400
1986	94	1400	13,800
1987	104	1700	15,500
1988	105	2000	17,500
1989	107	2100	19,600
1990	111	2300	21,900
1991	113	2300	24,200
1992	117	2500	26,700
1993	119	2600	29,300
1994	119	2600	31,900
1995	119	2700	34,600
1996	122	2700	37,300
1997	123	2800	40,100
1998	123	2900	43,000
1999	123	3000	46,000
2000	123	3000	49,000
2001	127	3000	52,000
2002	132	3000	55,000
2003	138	3100	58,100
2004	143	3300	61,400
2005	148	3400	64,800
2006	152	3800	68,600
2007	155	4100	72,700
2008	159	4700	77,400
2009	162	4500	81,900
2010	166	4500	86,400
2011	171	4000	90,400
2012	175	4100	94,500
2013	180	4200	98,700
2014	184	4200	102,900
2015	189	4300	107,200
2016	194	4300	111,500
2017	198	4500	116,000
2018	203	4700	120,700
2019	207	4700	125,400
2020	212	4900	130,300

[a]Source: U.S. Department of Energy, Commercial Power 1984: Prospects for the United States and the World, DOE/EIA-0438(84), Energy Information Administration, November 1984.

Section 114(d) of the Act specifies that the DOE may emplace no more than 70,000 MTU of spent fuel (once-through fuel cycle) or the high-level waste resulting from the reprocessing of 70,000 MTU in the first repository until such time as a second repository is in operation. Therefore, even though the waste-emplacement configuration for spent fuel and high-level waste may differ, the type of fuel cycle will not affect repository capacity as defined in the Act. To be sure, transportation requirements, waste-handling equipment, and repository layout would be somewhat different for a repository handling high-level waste rather than spent fuel.

The extent of the repository underground area required to accommodate spent fuel does not differ much from that required for high-level waste. (The size of underground disposal areas may depend more on the host rock and site-specific conditions.) Transuranic waste, because of its low heat output, can be densely packed into a repository and would not greatly affect the requirements for the underground disposal area, if this waste is disposed of in a repository. The waste-receiving and waste-handling facilities and operations of a repository would be different for spent fuel and high-level waste, but these differences would not affect the waste-acceptance rate or the waste-emplacement rate.

9.2.2 DEFENSE WASTE

Sections 8(b)(1) and (2) of the Act required the President to evaluate the use of one or more civilian repositories for the disposal of defense high-level waste. As explained in Chapter 2 of Part I, this evaluation concluded that there is no compelling reason for a defense-waste-only repository, and therefore the DOE is planning to emplace the defense waste in the civilian repositories.

The defense waste that would be disposed of in a geologic repository is solidified high-level waste from reprocessing. This waste has different thermal characteristics than commercial spent fuel or commercial high-level waste: it is a less concentrated source of radiation and heat. According to current estimates, about 8000 MTU, on a curie-equivalent basis, of defense high-level waste could be emplaced in a repository by the year 2020. When such a quantity of defense waste is added to the quantity of spent fuel estimated to require disposal, it appears that two 70,000-MTU repositories will be able to accommo- date the combined total--even for the EIA middle-case forecast (130,000 MTU of spent fuel).

Defense waste will be accepted on a schedule that will not adversely affect the rate of receipt for civilian wastes.

9.2.3 SITE LIMITATIONS

As already mentioned, the Act requires the first repository to accept no more than 70,000 MTU until the second repository is operational. However, the 70,000-MTU limit is not a minimum or maximum capacity requirement. A suitable site for the first or the second repository may be able to accommodate less or more than 70,000 MTU of spent fuel or the high-level waste resulting from reprocessing such an amount of spent fuel. From the information available for the sites currently under review, it does not appear that more than two repositories would be required to accommodate the projected volume of waste if one of the repositories would be able to accept less than 70,000 MTU.

9.3 CONSTRUCTION SCHEDULE

The construction schedule for the first repository is discussed in detail in Section 3.1.7 of Part I.

9.4 WASTE-ACCEPTANCE SCHEDULE AND THE NEED FOR INTERIM STORAGE

As described in Chapter 2 of Part I, two alternative waste-acceptance schedules are presented. The first (shown in Table 9-2) is based on the DOE's reference waste-management plan (i.e., the emplacement capability of two geologic repositories). In this case, waste acceptance at the first repository is scheduled to start in 1998.

The second schedule (shown in Table 9-3) is based on the improved-performance plan (i.e., the operating characteristics of the integrated waste-management system); it reflects not only the repository emplacement capability but also the acceptance capability of the monitored retrievable storage (MRS) facility. The primary functions of the MRS facility are to accept waste from reactors, prepare it for disposal, and provide temporary storage, if necessary. If Congress approves the DOE's proposal for the integrated waste-management system, then the second waste-acceptance schedule will be applicable. In this case, waste acceptance at the MRS facility will begin in 1996.

The at-reactor storage capacity required by these waste-acceptance schedules will have to be provided by the electric utilities that own the spent fuel. However, if the DOE fails to meet the schedule shown in Table 9-2 or 9-3, then the additional storage capacity needed to accommodate the delay in schedule will be provided by the DOE, possibly at reactor sites.

Table 9-2. Waste-Acceptance Schedule for the Authorized System
(Metric tons of uranium (MTU) per year)

Year	Spent-Fuel Generation[A]		First Repository				Second Repository		Cumulative Spent-Fuel Acceptance	Spent-Fuel Backlog
	Annual	Cumulative	Spent Fuel	High-Level Waste[B,C]	Total	Cumulative	Spent Fuel	Cumulative		
Pre 1998		40,100								40,100
1998	2900	43,000	400		400	400			400	42,600
1999	3000	46,000	400		400	800			800	45,200
2000	3000	49,000	400		400	1,200			1,200	47,800
2001	3000	52,000	900		900	2,100			2,100	49,900
2002	3000	55,000	1800		1800	3,900			3,900	51,100
2003	3100	58,100	3000	400	3400	7,300			6,900	51,200
2004	3300	61,400	3000	400	3400	10,700			9,900	51,500
2005	[illegible]	64,600	3000	400	3400	14,100			12,900	51,900
2006	3800	68,600	3000	400	3400	17,500	900	900	16,800	51,800
2007	4100	72,700	3000	400	3400	20,900	1800	2,700	21,600	51,100
2008	4700	77,400	3000	400	3400	24,300	1800	4,500	26,400	51,000
2009	4500	81,900	3000	400	3400	27,700	1800	6,300	31,200	50,700
2010	4500	86,400	3000	400	3400	31,100	1800	8,100	36,000	50,400
2011	4000	90,400	3000	400	3400	34,500	2400	10,500	41,400	49,000
2012	4100	94,500	3000	400	3400	37,900	3000	13,500	47,400	47,100
2013	4200	98,700	3000	400	3400	41,300	3000	16,500	53,400	45,300
2014	4200	102,900	3000	400	3400	44,700	3000	19,500	59,400	43,500
2015	4300	107,200	3000	400	3400	48,100	3000	22,500	65,400	41,800
2016	4300	111,500	3000	400	3400	51,500	3000	25,500	71,400	40,100
2017	4500	116,000	3000	400	3400	54,900	3000	28,500	77,400	38,600
2018	4700	120,700	3000	400	3400	58,300	3000	31,500	83,400	37,300
2019	4700	125,400	3000	400	3400	61,700	3000	34,500	89,400	36,000
2020	4900	130,300	3000	400	3400	65,100	3000	37,500	95,400	34,900
2021[D]			3000	400	3400	68,500	3000	40,500	101,400	28,900
2022			1100	400	1500	70,000	3000	43,500	105,500	24,800
2023							3000	46,500	108,500	21,800
2024							3000	49,500	111,500	18,800
2025							3000	52,500	114,500	15,800
2026				8000[E]			3000	55,500	117,500	12,800
2027							3000	58,500	120,500	9,800
2028							3000	61,500	123,500	6,800
2029							3000	64,500	126,500	3,800
2030							3000	67,500	129,500	800
2031							800	68,300	130,300	

[A]Data from Commercial Nuclear Power 1984: Prospects for the United States and the World, DOE/EIA 0438(84), November 1984. Includes discharge from decommissioned reactors.

[B]Approximate waste-acceptance rates for high-level waste from atomic energy defense activities and commercial high-level waste from the West Valley Demonstration Project. Quantities have been "normalized" to metric tons of uranium (MTUs) on a curie-equivalent basis. Direct comparison with spent fuel is not equivalent, because defense high-level waste (DHLW) and commercial high-level waste (CHLW) resulted from the reprocessing of spent fuel. In the example, 400 MTU of defense waste equals 800 canisters. Actual acceptance rates are to be negotiated between Defense Programs and the Office of Civilian Radioactive Waste Management in the DOE.

[C]The first repository currently is designed to begin operation in two phases. This example shows the acceptance of DHLW and CHLW in the first phase when the second phase reaches its maximum receipt rate.

[D]The Energy Information Administration projects spent-fuel generation only through the year 2020. For waste created after 2020, either the capacity of the first two repositories could be increased or additional repositories could be built.

[E]The example shows a total of 8000 MTU of DHLW and CHLW emplaced by the year 2022. Additional DHLW can be accommodated by extending the operation of the first repository, emplacing DHLW in the second repository, or constructing additional repositories, as indicated in footnote D.

Table 9-3. Waste-Acceptance Schedule for the Improved-Performance System
(Metric tons of uranium (MTU) per year)

Year	Spent-Fuel Generation[A]		MRS Acceptance[B]	MRS Inventory	First Repository				Second Repository		Cumulative Spent-Fuel Acceptance	Spent-Fuel Backlog
	Annual	Cumulative			SF from MRS	High-Level Waste[C]	Total	Cumulative Total Waste	Spent Fuel	Cumulative		
Pre 1998		40,100	2200	2,200							2,200	37,900
1998	2900	43,000	3000	4,800	400		400	400			5,200	37,800
1999	3000	46,000	3000	7,400	400		400	800			8,200	37,800
2000	3000	49,000	3000	10,000	400		400	1,200			11,200	37,800
2001	3000	52,000	3000	12,100	900		900	2,100			14,200	37,800
2002	3000	55,000	3000	13,300	1800		1800	3,900			17,200	37,800
2003	3100	58,100	3000	13,300	3000	400	3400	7,300			20,200	37,900
[illegible]	[illegible]	61,400	3000	13,300	3000	400	3400	10,700			23,200	38,200
2005	3400	64,800	3000	13,300	3000	400	3400	14,100			26,200	38,600
2006	3800	68,600	3000	13,300	3000	400	3400	17,500	900	900	30,100	38,500
2007	4100	72,700	3000	13,300	3000	400	3400	20,900	1800	2,700	34,900	37,800
2008	4700	77,400	3000	13,300	3000	400	3400	24,300	1800	4,500	39,700	37,700
2009	4500	81,900	3000	13,300	3000	400	3400	27,700	1800	6,300	44,500	37,400
2010	4500	86,400	3000	13,300	3000	400	3400	31,100	1800	8,100	49,300	37,100
2011	4000	90,400	3000	13,300	3000	400	3400	34,500	2400	10,500	54,700	35,700
2012	4100	94,500	3000	13,300	3000	400	3400	37,900	3000	13,500	60,700	33,800
2013	4200	98,700	3000	13,300	3000	400	3400	41,300	3000	16,500	66,700	32,000
2014	4200	102,900	3000	13,300	3000	400	3400	44,700	3000	19,500	72,700	30,200
2015	4300	107,200	3000	13,300	3000	400	3400	48,100	3000	22,500	78,700	28,500
2016	4300	111,500	3000	13,300	3000	400	3400	51,500	3000	25,500	84,700	26,800
2017	4500	116,000	2800	13,100	3000	400	3400	54,900	3000	28,500	90,500	25,500
2018	4700	120,700		10,100	3000	400	3400	58,300	3000	31,500	93,500	27,200
2019	4700	125,400		7,100	3000	400	3400	61,700	3000	34,500	96,500	28,900
2020	4900	130,300		4,100	3000	400	3400	65,100	3000	37,500	99,500	30,800
2021				1,100	3000	400	3400	68,500	3000	40,500	102,500	27,800
2022					1100	400	1500	70,000	3000	43,500	105,500	24,800
2023									3000	46,500	108,500	21,800
2024									3000	49,500	111,500	18,800
2025									3000	52,500	114,500	15,800
2026						8000			3000	55,500	117,500	12,800
2027									3000	58,500	120,500	9,800
2028									3000	61,500	123,500	6,800
2029									3000	64,500	126,500	3,800
2030									3000	67,500	129,500	800
2031									800	68,300	130,300	

[A]Data from Commercial Nuclear Power 1984: Prospects for the United States and the World, DOE/EIA 0438(84), November 1984. Includes discharge from decommissioned reactors.
[B]The MRS facility is assumed to reach a constant acceptance rate and discharge to the first repository as fast as the first repository can accept spent fuel. The MRS facility will stop accepting spent fuel when its inventory will fill the first repository.
[C]See footnotes B and C in Table 2-2.

Chapter 10

COSTS OF MANAGING COMMERCIAL RADIOACTIVE WASTE

An estimate, on an annual basis, of the costs required (A) to construct and operate the repositories anticipated to be needed under paragraph (9) based on each of the assumptions referred to in such paragraph; (B) to construct and operate a test and evaluation facility, or any other facilities, other than repositories described in subparagraph (A), determined to be necessary; and (C) to carry out any other activities under this Act

--Nuclear Waste Policy Act, Section 301(a)(10)

This chapter presents cost estimates for a number of reference and sensitivity cases. After briefly describing the framework for the analysis of costs, it discusses key assumptions, explains the method of cost estimation and presents the results for the major cost categories (development and evaluation, transportation, repository, and storage), and summarizes the principal findings.

10.1 INTRODUCTION

As part of its continuing evaluation of the adequacy of the revenues raised by the Nuclear Waste Fund against the expenses of the waste-management program, the DOE maintains a cost-estimating capability. The most recent cost estimates for the entire program are contained in a January 1985 report, Analysis of the Total System Life Cycle Cost for the Civilian Radioactive Waste Management Program (Roy F. Weston, Inc., 1985). The costs presented in this report were estimated for a set of reference cases that are consistent with the DOE's FY86 budget submittal to Congress in terms of program strategy and schedule. The reference cases differ by repository location only; all other assumptions are identical for all reference cases. In addition, this report provides cost estimates for a limited number of sensitivity cases that were analyzed to determine the effects of variations in a few major program assumptions. This chapter summarizes the estimating methods and results from the January 1985 study. It does not attempt to analyze the cost implications of changes in the program occurring after January 1985.

Total-system costs for the reference cases were calculated by summing the annual costs (expressed in constant 1984 dollars) estimated for each major cost category: development and evaluation (D&E), transportation, and repository construction, operation, and closure and decommissioning. For two of the sensitivity cases, the costs of monitored retrievable storage (MRS) were also included. In order to estimate the costs, an estimation method must be established. The first step in this procedure was to define a reference case by determining the components of the waste-management system and the path of waste material flows. The next step was to develop assumptions that characterize the facilities and processes in the system in sufficient detail for the derivation of engineering cost estimates. These assumptions also establish the scope of the system by specifying the quantity and the schedule of waste acceptance. The assumptions for the waste-generation rate, the minimum "age" at which spent fuel will be accepted by the DOE, and the waste-acceptance rate can be used to estimate the annual flows of waste that will occur once the system is operational. The waste flows determine both transportation and repository costs because they determine how much and when waste has to be transported and how long the repository will operate before it is filled to capacity. By using a series of estimating techniques, the total-system cost for the reference cases is then calculated.

By changing the assumptions about any of the reference-case characteristics, an endless number of additional cases could be analyzed. In light of the many different assumptions that could be made, a substantial number of cases would, in fact, be required to account for the entire spectrum of potential contingencies. However, this analysis is not intended to represent such a broad effort. Instead, a few major characteristics were chosen to derive a set of alternative cases for which total-system costs were estimated.

For the reference cases, seven combinations of host rocks were assumed for the first and the second repositories:

First Repository	Second Repository
Tuff	Crystalline rock
Basalt	Crystalline rock
Salt	Crystalline rock
Tuff	Salt
Basalt	Salt
Salt	Salt
Basalt	Tuff

Three sets of sensitivity cases were developed. These cases differ from the reference cases in (1) the waste-generation rate, which is assumed to be lower; (2) transportation-cask technology, which is assumed to be improved; and (3) the repository-startup dates, which are assumed to be delayed. Ten such sensitivity cases were analyzed.

10.2 ASSUMPTIONS

10.2.1 REFERENCE CASES

The reference waste-management system for this analysis assumes that, after spent fuel has cooled sufficiently for DOE acceptance at reactor sites throughout the country, the fuel will be transported directly to the repository for preparation (i.e., rod consolidation and loading into disposal containers) and disposal. Therefore, the only facilities in the reference system are the repository and the required transportation network. The key assumptions for the reference cases are given in Table 10-1.

Table 10-1. Key Assumptions for the Reference Cases

Parameter	Assumptions
Waste type	Spent fuel, commercial high-level waste from West Valley, New York, and low-level waste generated at the repository during spent-fuel consolidation and handling (defense waste is not included)
Waste quantity	130,300 MTU, based on the November 1984 middle-case forecast (DOE, 1984a) by the Energy Information Administration (EIA) of the cumulative spent-fuel generation through the year 2020
Minimum waste age for acceptance	5 years
Number of repositories	Two
Design capacity for each repository	70,000 MTU for the first repository and 60,300 MTU for the second repository (the difference between the cumulative spent fuel generation through the year 2020 and the first-repository capacity)
Repository design receipt rate[a]	First repository: 400 MTU per year for the first 3 years, 900 MTU for the fourth year, 1800 MTU for the fifth year, and 3000 MTU per year thereafter to closure Second repository: 1800 MTU per year for the first 5 years and 3000 MTU per year thereafter to closure
Repository-startup dates	1998 for the first repository and 2006 for the second repository
Host-rock type	Basalt, crystalline rock, salt, and tuff
Transportation-cask technology	Currently licensed transportation casks
Cost basis	All costs are expressed in terms of constant 1984 dollars

[a]This repository-design receipt rate was used to develop the January 1985 program-cost estimates, which in turn were used for the February 1985 report on fee adequacy (DOE, 1985). It is not equivalent to the design receipt rates used elsewhere in the Mission Plan.

The host rock and the site of the repository are two related parameters that must be defined before the estimates can be made. The nine potentially acceptable sites for the first repository consist of one site in a tuff formation in Nevada, one site in basalt at the Hanford Site in the State of Washington, and seven sites in salt formations in Louisiana Mississippi, Texas, and Utah. Since only one site is being considered in both tuff and basalt, the site is designated by the rock type. For the seven salt sites, a single site was assumed in order to estimate the transportation costs for this host rock. A site in the Permian Basin of Texas was selected because it represents the middle range for the average distance traveled from most of the reactors in the eastern half of the country. Also, the recently issued draft environmental assessments (DOE, 1984b) concluded that the site in Deaf Smith County, Texas, is one of the three preferred sites (together with the sites in basalt and tuff) for recommendation to the President as candidates for characterization. However, the choice of sites in this analysis does not represent the DOE's final decision on the sites to be recommended for characterization or development of a repository.

For the second repository, the DOE is evaluating crystalline-rock (granite) formations in 17 States. These States are located in the midwestern, northeastern, and southeastern regions of the country. The estimated geographic centroid for these regions was assumed for the location of the crystalline-rock repository. This centroid was used only as the basis for estimating the average reactor-to-repository distance in calculating transportation costs; the assumption does not represent the DOE's policy for the selection of crystalline-rock sites.

From the four alternative rock types and sites for repositories, combinations of sites for the first and the second repository were developed for the reference cases. The DOE's current budget-planning assumption is that two of the three candidate sites for the second repository will be in crystalline rock. Since crystalline rock is not under consideration for the first-repository site, a second repository in crystalline rock was alternatively combined with each of the other three rock types as first-repository sites. Also, since multiple salt sites currently exist, a second repository in salt was combined with first-repository sites in tuff, basalt, and also salt. Finally, a basalt site for the first repository and a tuff site for the second were combined because these two sites represent the longest distances from most of the reactors and hence are expected to incur the maximum transportation costs. The shortest transportation distance is associated with the combination of salt and crystalline rock.

As already mentioned, the seven reference cases differ only by the location of the repository sites. Each of the cases is based on identical assumptions about the amount of fuel, the design of the repositories (two phases for the first repository and one phase for the second repository), repository-startup dates, and transportation casks.

10.2.2 SENSITIVITY CASES

Three categories of sensitivity cases were derived: (1) low waste generation, (2) improved transportation-cask technology, and (3) repository delay. Within each category, a few different cases were included. The complete case structure--7 reference cases and 10 sensitivity cases--is described in Table 10-2 by its distinguishing features.

To represent a low-waste-generation case, the EIA "no-new-orders" forecast of November 1984 was assumed (DOE, 1984a). The cumulative amount of spent fuel generated in this case is 97,700 MTU, or 25 percent less than the amount projected in the reference cases. The repository waste-acceptance rate and startup schedule remain the same as in the reference cases. Four combinations of first- and second-repository locations were assumed for this case: (1) basalt and tuff, the reference-case combination with the highest total-system cost; (2) salt and crystalline rock, the reference-case combination with the lowest total-system cost; (3) basalt and salt; and (4) tuff and crystalline rock. These combinations provide a broad-band assessment of the cost impacts associated with less waste in the system.

The currently licensed spent-fuel transportation casks assumed for the reference case are relatively inefficient in comparison with the cask designs that are expected to be developed. The new casks will be able to carry more spent-fuel assemblies, thereby reducing the number of shipments necessary and, in turn, the cost of transportation. Current casks are designed to transport spent fuel that has a minimum age of only 120 days (i.e., the time of discharge from the reactor). The fuel to be accepted by the reference waste-management system is to be aged at least 5 years, and the greater capacity of the new casks can be realized because less shielding will be required for this fuel . An alternative, more efficient, set of transportation casks was therefore included in this analysis as a sensitivity case to determine the effect on the total-system cost. The cost estimates were calculated for two repository-site combinations that represent the greatest distance traveled (basalt/tuff) and the smallest distance traveled (salt/crystalline rock) from among the seven reference-case combinations.

Although the DOE is committed to start accepting spent fuel from utilities by January 31, 1998, two sensitivity cases were developed to determine the effect on total-system costs of delays in the startup of the repositories. Two alternative cases were examined: a delay of 5 and 10 years in the opening of both the first and the second repository.

Costs for each of the repository-delay cases were estimated for the reference-case repository-site combinations that yield the highest (basalt/tuff) and the lowest (salt/crystalline rock) total-system cost.

10.3 DEVELOPMENT AND EVALUATION COSTS

The development and evaluation (D&E) cost category covers all the siting, design development, testing, regulatory, and institutional activities associated with the repositories and the required transportation network; it also covers the D&E activities associated with monitored retrievable storage. Most of the D&E activities will take place before the construction of waste-receiving facilities and the fabrication of waste packages and transportation casks, but some efforts, such as regulatory activities, will continue during the facility-construction period. Included in the D&E category is the mitigation of socioeconomic impacts, which is assumed to occur throughout repository

Table 10-2. Case Structure for the Total-System Cost Analysis[A]

Case	Repository Host Rock First	Repository Host Rock Second	Cumulative Spent-Fuel Generation (MTU)	Repository Startup Date First	Repository Startup Date Second	Additional Storage Facilities
Reference cases						
	Salt	Crystalline	130,300	1998	2006	None
	Tuff	Crystalline	130,300	1998	2006	None
	Basalt	Crystalline	130,300	1998	2006	None
	Salt	Salt	130,300	1998	2006	None
	Tuff	Salt	130,300	1998	2006	None
	Basalt	Salt	130,300	1998	2006	None
	Basalt	Tuff	130,300	1998	2006	None
Sensitivity cases						
Low waste generation	Basalt	Salt	97,700	1998	2006	None
	Basalt	Tuff	97,700	1998	2006	None
	Salt	Crystalline	97,700	1998	2006	None
	Tuff	Crystalline	97,700	1998	2006	None
Improved cask technology	Basalt	Tuff	130,300	1998	2006	None
	Salt	Crystalline	130,300	1998	2006	None
Repository delay 5-year	Basalt	Tuff	130,300	2003	2011	MRS
	Salt	Crystalline	130,300	2003	2011	MRS
10-year[B]	Basalt	Tuff	130,300	2008	2016	MRS
	Salt	Crystalline	130,300	2008	2016	MRS

[A]The waste-receipt rate for the two-phase first repository is 400 MTU/yr for the first 3 years of operation, 900 MTU in the fourth year, 1800 MTU in the fifth year, and 3000 MTU/yr thereafter. The rate for the single-phase second repository is 1800 MTU/yr for the first 5 years of operation and 3000 MTU/yr thereafter.

[B]The first repository is assumed to be a single-phase facility.

construction. Also included in this category is the cost of Federal Government administration of the entire waste-disposal program. As so defined, D&E encompasses all program expenditures both at the present time and for the next several years.

The starting point for estimating D&E costs is a schedule of overall program milestones. Having established a milestone schedule, the activities currently under way to accomplish these milestones must be determined along with the current costs for these activities. Next, activities in the future that must be either continued or initiated to accomplish the entire schedule of milestones are determined, and the time periods over which these future activities must take place are estimated. Finally, the costs of performing each of these activities are estimated, drawing on the cost-activity relationships of the current and near-term activities and independent cost estimates of future activities, where available.

The schedule of milestones for the reference-case D&E cost estimates is based on the program schedule as of January 1985, which is consistent with the FY86 budget submittal to Congress. Compared with the schedule in the April 1984 draft Mission Plan, this schedule represents later dates for near-term first-repository milestones, but still retains the January 1998 date for the start of repository operations. For the second repository, the start of operations has been delayed 17 months from the draft Mission Plan schedule. Table 10-3 presents the specific milestones that were used in developing the D&E costs.

The D&E cost estimates assume only the activities that are covered by the Nuclear Waste Fund and are categorized into five major areas: first repository; second repository; monitored retrievable storage; transportation and systems integration; and socioeconomic impact mitigation. Government administration is added as the sixth cost category.

The primary data source for the cost of current program activities is the budget developed for the Nuclear Waste Fund. For all of the D&E cost categories, the FY86 budget submitted to Congress in January 1985 served as the numerical basis through the year 1990. The D&E estimates are expressed in terms of constant 1984 dollars for consistency with the other cost categories.

This reference-case D&E cost estimate pertains to all the cases in which the repositories are assumed to start operating according to the program schedule and is essentially the same across all host rocks and spent-fuel generation scenarios. In addition to the reference-case estimates, there are two sensitivity cases that require alternative D&E cost estimates: the 5- and 10-year repository delays. The D&E costs for the reference and the sensitivity cases are summarized in Table 10-4.

Table 10-3. Schedule of Program Milestones

Program Milestone	First Repository[A]	Second Repository
Identify potentially acceptable sites	Completed	6/86
Complete draft environmental assessments	12/84	12/90
Complete final environmental assessments	6/85	6/91
Nominate sites	6/85	6/91
Recommend candidate sites	7/85	7/91
Presidential approval of candidate sites	9/85	9/91
Start preparation of exploratory-shaft site	12/85-10/86[B]	9/91
Start exploratory-shaft construction	3/86-2/87[C]	2/92
Start preliminary waste-package design	6/87	6/93
Complete exploratory-shaft construction	3/88-9/88[D]	8/94
Start Title I repository design	2/88	1/94
Complete exploratory-shaft testing for DEIS and recommendation	12/89	12/95
Issue draft environmental impact statement (DEIS)	6/90	6/96
Issue final environmental impact statement	12/90	12/96
Recommend to President	1/91	1/97
Complete exploratory-shaft testing for license application to the NRC	11/90	11/96
Complete Title I repository design	5/90	1/96
Site designation effective, submit license application	5/91	5/97
NRC grants license, start operations	1/98	2/2006

[A]The dates given here are the program-milestone dates used for the most recent analysis of total-system costs (Roy F. Weston, Inc., 1985). They are not the same as the revised dates presented elsewhere in this plan.

[B]Earlier date is for basalt and tuff, and the later date is for salt.

[C]Earlier date is for basalt, and the later date is for salt. The date for tuff is between these two dates.

[D]Earlier date is for tuff, and the later date is for salt. The date for basalt is between these two dates.

Table 10-4. Summary of Total D&E Costs
(Millions of 1984 Dollars)

Cost Category	Reference Case	5-Year Delay Case	10-Year Delay Case
First repository	3200	3400	3500
Second repository	2100	2200	2300
Monitored retrievable storage	100	100	100
Transportation and systems integration	200	300	400
Socioeconomic impact mitigation	600	700	1000
Government administration[A]	1600	1700	1800
Total	7800	8400	9100

[A]Assumes crystalline rock or tuff for the second repository. If the host rock is salt, then the costs of Government administration and therefore the total D&E costs will be $50 million less.

10.4 TRANSPORTATION COSTS

The Act directed the DOE to develop the transportation capability necessary to support the waste-management system. The Act requires the DOE to take title to the spent fuel at the reactors and to arrange for transportation to storage or disposal facilities. The Act also requires that private industry be involved in developing and providing the necessary transportation services to the fullest extent possible.

The method for estimating transportation costs derives a unit charge for transportation-cask use, shipping, and security for each potential transportation pathway; this unit charge is applied to the annual waste material flows to arrive at the total transportation cost. The pathways considered include transportation from the reactors to each repository loca- tion, from reactors to an MRS facility (which is assumed to be used only in the repository-delay cases), and from the MRS facility to each repository. The total unit transportation cost is the sum of these three unit costs. Each of these estimations is performed for two modes of transportation: rail and truck transportation. A split between the two modes is assumed in order to calculate the total cost.

Before any of these unit costs can be derived, the transportation distance for each pathway must be estimated. The distances were estimated in two steps. First, average distances were estimated from reactors to each of the four repository sites and to the MRS site and from the MRS site to each of the repository sites. These distances are pertinent only when one repository is in operation. Second, a reduction in these distances was calculated to account for the potential savings of optimized routing for the years when two repositories are in operation. Unit costs were estimated for each set of distances and are appropriately applied to the annual waste material flows, depending on whether in a specific year one or two repositories are in operation.

Table 10-5 presents a summary of the transportation costs estimated for each reference and sensitivity case, detailed by individual pathway.

10.5 REPOSITORY COSTS

The construction, operation, and closure and decommissioning costs for the two repositories represent the largest component of total-system costs. By virtue of their relative importance, the repository costs have undergone substantial review and reestimation since the previous set of costs was calculated for the draft Mission Plan. The cornerstone of this process was a new engineering feasibility study developed in response to a change in the program strategy. The design concept for the first repository was changed from a one-phase facility to a two-phase facility that allowed waste acceptance by January 1998. This feasibility study included a cost analysis of the new repository design. However, the estimates should be recognized to have substantial uncertainty because of possible future changes in the design of the repositories. As designs become more advanced and the facility characteristics become fixed, the cost estimates will become more meaningful.

The method used in estimating the repository costs was a three-step procedure. First, costs were developed for standard-size facilities (70,000 MTU) for each of the alternative host rocks. Second, a scaling technique was applied to the costs of a standard-size facility to derive costs for the facility capacities that are required by the waste material flows for each case in the analysis. Third, the total construction, operation, and closure and decommissioning costs were annualized for inclusion with the other cost components.

In developing the standard-size-facility costs for tuff, basalt, salt, and crystalline-rock repositories, a parametric approach was used. It assumes that many features of the surface facilities and underground layout are generic for all rock types. In general, the surface and underground design of the tuff repository was used for the other host rocks. However, certain aspects of the tuff design have been adjusted for salt, basalt, and crystalline rock to allow for differences between these host rocks. The costs of a two-phase repository for the three first-repository host rocks were first developed according to the parametric analysis approach. Then these costs were used to develop the costs of a one-phase repository for all four rock types since each could potentially be used for the second repository, which is a one-phase facility. The costs for the standard-size repositories are presented in Table 10-6.

Table 10-6. Summary of Cost Estimates for the Standard-Size Repository by Host Rock (Billions of 1984 Dollars)

	First Repository (Two Phases)		
Cost Category	Tuff	Basalt	Salt
Construction	1.1	2.3	1.6
Operation	5.8	8.3	4.9
Closure and decommissioning	0.1	0.1	0.3
Total	7.0	10.7	6.8

	Second Repository (One Phase)			
Cost Category	Tuff	Basalt	Salt	Crystalline
Construction	1.0	2.2	1.4	0.9
Operation	5.7	8.2	4.7	5.7
Closure and decommissioning	0.1	0.1	0.2	0.1
Total	6.8	10.5	6.3	6.7

In all cases but the low-waste-generation case, the first-repository capacity is identical with that of the standard-size facility, or 70,000 MTU. Therefore, no adjustment in the costs of the standard-size costs is required. The second-repository capacity, though, is 63,300 MTU, so that the costs of the standard-size facility must be scaled down to estimate the second-repository costs. In the low-waste-generation case, both the first and the second repositories are sized below design capacity, and the scaling technique is applied to each. A summary of the repository-cost estimates for all cases is shown in Table 10-7.

10.6 STORAGE COSTS

This section presents the cost estimates for the storage activities required in the 5- and 10-year repository-delay cases. It was assumed that such delays would require an MRS facility. These assumptions were made for the sole purpose of performing the cost estimation and may not represent the final assumptions for the integrated waste-management system.

The costs for each of the delay cases were estimated by first determining the amount of fuel that needs to be stored in each case. This was accomplished by assuming that even with a delay in the start of repository operation, the DOE would accept fuel at the reference-case rate. Therefore, the storage requirements were determined by calculating the difference between the reference-case acceptance schedule and the repository acceptance schedule in each delay case. Having made this determination and after deciding on the preferred engineered concept for providing the required storage at an MRS facility, the cost estimates were then developed by using the best information available on the costs of constructing and operating the required storage facilities.

The Act identifies monitored retrievable storage as an option for the long-term storage of waste. The Act directs the DOE to submit to Congress by June 1, 1985, a proposal to construct one or more MRS facilities. The Act further specifies that this proposal should include at least three alternative sites and a minimum of five alternative combinations of sites and facility designs. To develop these designs, at least two concepts must be selected for further design. To do this, eight previously studied concepts were evaluated. From these alternative concepts, the concrete-cask design was selected as the primary concept because of its demonstration experience, simple and flexible design, and low estimated cost in comparison with the other concepts. On the basis of this evaluation study, the concrete-cask concept was assumed for estimating the MRS cost. Table 10-8 presents the MRS cost estimates for both the 5- and the 10-year repository-delay cases. In the 5-year case, a storage capacity of 30,000 MTU is required, while in the 10-year case a capacity of nearly 55,000 MTU is needed. The total costs for each case are $2.0 and $2.4 billion, respectively. It should be noted, how- ever, that these cost and storage capacities are based on the previous MRS mission of providing backup storage for a repository. The costs and capa- cities for an integral MRS facility would be different.

Table 10-7. Summary of Repository-Cost Estimates
(Billions of 1984 Dollars)

Case	First Repository				Second Repository			
	Construction	Operation	Decommissioning	Total	Construction	Operation	Decommissioning	Total
Reference cases								
Tuff/crystalline	1.1	5.8	0.1	7.0	0.9	5.1	0.1	6.1
Basalt/crystalline	2.3	8.3	0.1	10.7	0.9	5.1	0.1	6.1
Salt/crystalline	1.6	4.9	0.3	6.8	0.9	5.1	0.1	6.1
Tuff/salt	1.1	5.8	0.1	7.0	1.4	4.2	0.2	5.8
Basalt/salt	2.3	8.3	0.1	10.7	1.4	4.2	0.2	5.8
Salt/salt	1.6	4.9	0.3	6.8	1.4	4.2	0.2	5.8
Basalt/tuff	2.3	8.3	0.1	10.7	0.9	5.0	0.1	6.0
Sensitivity cases								
Low waste generation								
Basalt/salt	2.2	8.1	0.1	10.4	1.3	2.7	0.2	4.2
Tuff/crystalline	1.0	5.6	0.1	6.7	0.7	3.2	0.1	4.0
Basalt/tuff	2.2	8.1	0.1	10.4	0.8	3.1	0.1	4.0
Salt/crystalline	1.5	4.8	0.3	6.6	0.7	3.2	0.1	4.0
Improved cask technology								
Basalt/tuff	2.3	8.3	0.1	10.7	0.9	5.0	0.1	6.0
Salt/crystalline	1.6	4.9	0.3	6.8	0.9	5.1	0.1	6.1
5-year delay								
Basalt/tuff	2.3	8.3	0.1	10.7	0.9	5.0	0.1	6.0
Salt/crystalline	1.6	4.9	0.3	6.8	0.9	5.1	0.1	6.1
10-year delay								
Basalt/tuff	2.7	8.2	0.1	11.0	1.1	5.0	0.1	6.2
Salt/crystalline	1.8	4.7	0.2	6.7	1.1	5.1	0.1	6.3

Table 10-8. MRS Requirements, Operating Lifetime, and Costs[a]

Category	5-Year Delay	10-Year Delay
Storage requirements (MTU)	30,000	54,900
Operating lifetime (years)	36	41
Costs[a]		
Construction	300	300
Operations	1,600	2,000
Closure and decommissioning	60	60
Total cost	1,960	2,360

[a]It should be noted that these costs and storage capacities are based on the previous MRS mission of providing backup storage for the repository. The numbers for the integral MRS facility included in the improved-performance plan (see Chapter 2 of Part I) would be different.

10.7 SUMMARY OF TOTAL SYSTEM COSTS

The cost of the repository is the largest component of the total-system costs for all cases. For the reference cases, the costs for both repositories represent 51 to 59 percent of the total. The development and evaluation costs are the next largest component, accounting for 26 to 33 percent of the total, and transportation represents 14 to 18 percent. The relative importance of each of these components is decreased in the repository-delay sensitivity cases because of the inclusion of storage costs in the total-system costs. Storage costs may be as high as 8 percent of the total in the 10-year-delay case. The total-system costs are summarized in Table 10-9 for the 7 reference cases and 10 sensitivity cases.

The principal findings of this analysis are as follows:

1. The total-system costs for the reference program, expressed in constant 1984 dollars, range from $23.8 to $29.7 billion, depending on the host rocks and sites of the two repositories. For the sensitivity cases analyzed in this report, the total-system costs may be as high as $35.3 billion (10-year repository delay) or as low as $20.9 billion (low waste generation), representing a range in potential costs of 69 percent.

2. The host rocks and sites of the two repositories have a significant effect on total system costs; the total costs for the host-rock combination with the highest reference-case cost (basalt/tuff) is 25 percent higher than the cost for the combination with the lowest reference-case cost (salt/crystalline rock).

3. The waste-generation rate also has a significant effect on total-system costs. The cost for the low-waste-generation case is $2.9 to $3.6 billion less than that for the reference case, depending on the repository site. However, on an average unit-cost basis, the low-waste-generation case is 17 percent more expensive than the reference case because of economies of scale.

4. The use of improved transportation-cask technology reduces transportation costs by 50 percent and decreases the total-system costs for the reference case by $1.7 to $2.5 billion, or 7 to 8 percent, depending on the site of the repository.

5. Delays of 5 or 10 years in the opening of the repositories increase the total-system costs by $3.3 to $3.5 billion and $5.1 to $5.6 billion, respectively, depending on the host-rock combination. These additional costs are due to extended development and evaluation activities, to storage facilities that would otherwise not be required, and increased transportation requirements for shipments to and from an MRS facility. (In the 10-year delay, repository-construction costs are also increased because, by definition, the delay is partially due to problems experienced in construction.) Both repositories receive 100 percent of the design receipt rate throughout their operating period in the reference cases; thus delaying the start of repository operation does not affect repository-operation costs because in this delay case the system also operates at maximum efficiency.

6. Because of the sizable cost impacts of repository sites, waste-generation rate, transportation-cask technology, and repository-startup dates, the effects of one parameter may be partially or wholly offset by the effects of another parameter. For example, the total-system costs for the 5-year delay with repositories in salt and crystalline rock are lower than those for repositories in basalt and tuff.

Figure 10-1 shows the annual total-system costs for all years in the life cycle, detailed by major cost category, for the highest-cost reference case (basalt/tuff). As the figure shows, total-system costs from 1983 through 1990 consist exclusively of development and evaluation costs. Construction costs (advanced design work) for the first repository start in 1991. The total-system costs peak in 1995, when both the costs of first-repository construction and the costs of development and evaluation for the second repository are at their highest levels. A high plateau for total-system costs--only 14 percent lower than the 1995 peak value--starts in 2011, when both repositories

Table 10-9. Summary of Total-System Life-Cycle Cost Estimates (Billions of 1984 Dollars)

Case	D&E	Transportation	Repository First	Repository Second	Repository Total	Storage	Grand Total[a]
Reference cases							
Tuff/crystalline rock	7.8	3.8	7.0	6.1	13.1	-	24.7
Basalt/crystalline rock	7.8	3.9	10.7	6.1	16.9	-	28.5
Salt/crystalline	7.8	3.3	6.8	6.1	12.8	-	23.8
Tuff/salt	7.8	4.5	7.0	5.8	12.8	-	25.0
Basalt/salt	7.8	4.4	10.7	5.8	16.6	-	28.8
Salt/salt	7.8	3.9	6.8	5.8	12.5	-	24.2
Basalt/tuff	7.8	5.1	10.7	6.0	16.9	-	29.7
Sensitivity cases							
Low waste generation							
Basalt/salt	7.8	3.5	10.4	4.2	10.6	-	25.9
Tuff/crystalline rock	7.8	3.2	6.7	4.0	10.7	-	21.6
Basalt/tuff	7.8	3.8	10.4	4.0	14.4	-	26.1
Salt/crystalline rock	7.8	2.6	6.6	4.0	10.5	-	20.9
Improved cask technology							
Basalt/tuff	7.8	2.6	10.7	6.0	16.9	-	27.2
Salt/crystalline rock	7.8	1.6	6.8	6.1	12.8	-	22.2
Repository delay							
5-year							
Basalt/tuff	8.4	5.9	10.7	6.0	16.9	2.0	33.2
Salt/crystalline rock	8.4	4.0	6.8	6.1	12.8	2.0	27.1
10-year							
Basalt/tuff	9.1	6.5	11.0	6.2	17.4	2.4	35.3
Salt/crystalline rock	9.1	4.7	6.7	6.3	13.0	2.4	28.9

[a]The costs in any particular category may not add to the total because of independent rounding.

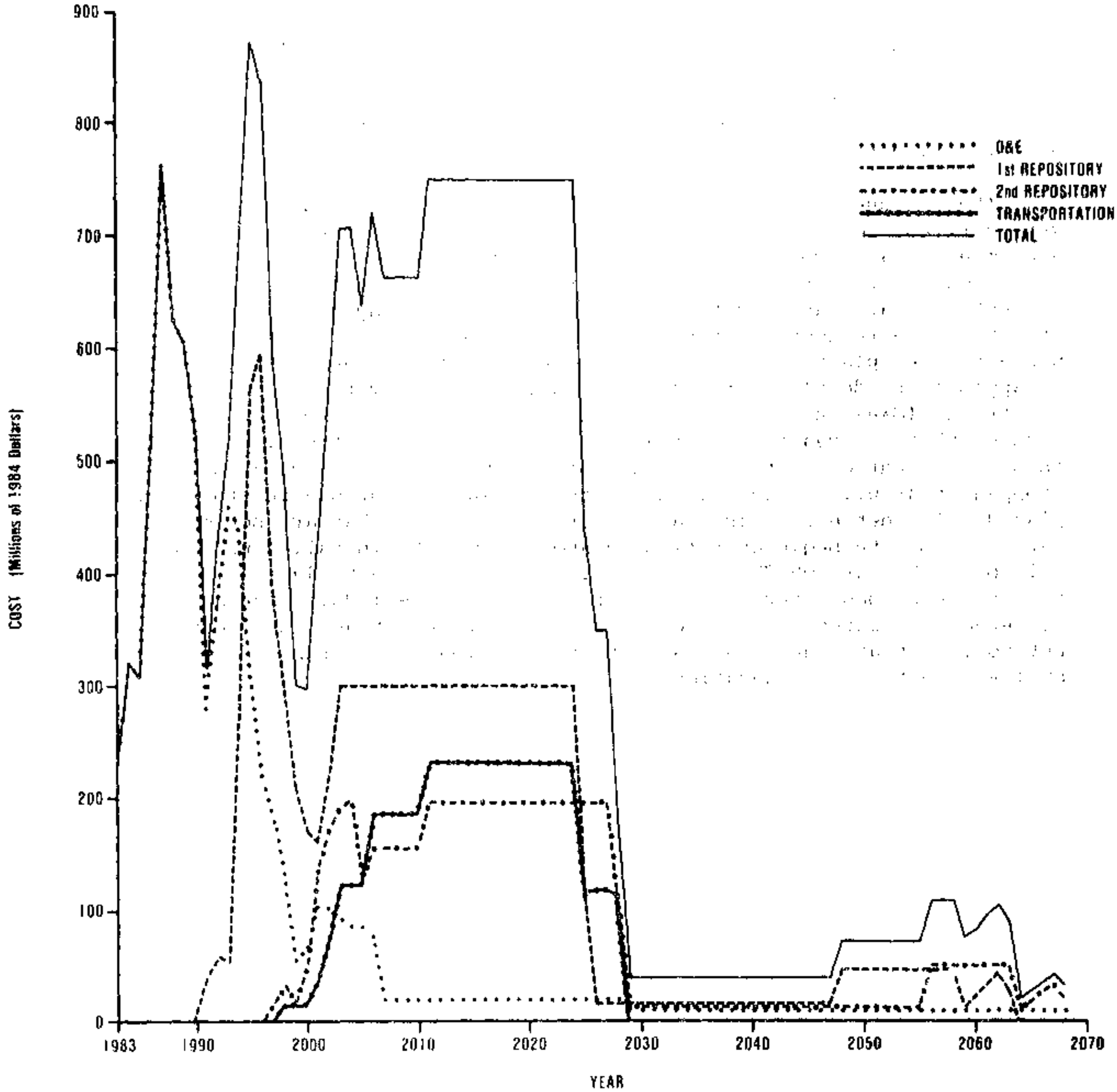

Figure 10-1. Annual total-system costs for the reference case, 1983-2086.

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are operating at their maximum receipt rates and continues through 2024, the last year of first-repository operation at a rate of 3000 MTU per year. Total-system costs drop very rapidly after this year as both repositories enter the caretaker period by the year 2029.

The adequacy of the waste-disposal fees for the costs for the disposal of commercial spent nuclear fuel and high-level waste has been examined annually since 1983. These fees, established by the Act, consist of a one-time fee assessed on waste existing on April 7, 1983, and an ongoing fee assessed on electricity generated in nuclear power plants after April 7, 1983.

The revenue projections used in the February 1985 analysis (DOE, 1985) were derived from EIA forecasts of gross electricity generation prepared in September 1984. Two forecasts of the growth of nuclear power were used. The middle-case forecast assumes that there will be no net future cancellations of present nuclear-plant construction projects (i.e., any cancellations will be offset by the resumption of previously deferred plants, and that the number of nuclear power plants will grow at a moderate rate between 1990 and 2020, with an approximate doubling of installed nuclear capacity from 107 gigawatts electrical (GWe) in 1990 to 212 GWe in 2020. The no-new-orders forecast assumes that all reactors that are currently under construction but are less than 30 percent complete, are indefinitely deferred, or have a current work stoppage that will be cancelled and that no orders for new reactors will be placed. The net effect is that, after the reactors that are now more than 30 percent complete begin operation by about 1990, the installed nuclear capacity will be stable at 109 GWe for about 10 years, decline to 49 GWe in 2020, and fall to zero soon after as plants are retired. The middle-case and the no-new-orders forecasts are not intended to represent absolute bounding cases, but to illustrate the potential effects of a reasonable range of forecasts for nuclear electricity generation.

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Chapter 11

SOCIOECONOMIC IMPACTS

> *An identification of the possible adverse economic and other impacts to the State or Indian tribe involved that may arise from the development of a repository or test and evaluation facility at a site.*
>
> --Nuclear Waste Policy Act, Section 301(a)(11)

This chapter identifies a range of generic socioeconomic impacts that may be associated with the siting, development, and operation of a geologic repository. The DOE does not expect that the full range of impacts discussed here would occur at every potential site. In accordance with the Act, the site-specific impacts of both site characterization and a repository are assessed in the socioeconomic-impact sections of the draft environmental assessments and will be assessed in the environmental impact statement. Both the States and the DOE will be conducting impact-assessment studies during the site characterization phase of the program.

Experience with large energy-development projects in rural areas indicates that impact assessments will be more accurate if the residents of affected communities take part in the process. The DOE will work closely with States, affected Indian tribes, and local communities to identify and avoid or mitigate significant adverse impacts caused by a repository. Furthermore, the Act provides States and affected Indian tribes with grant funds to conduct their own independent assessments of socioeconomic impacts and to request impact-mitigation funds from the DOE if a site within their boundaries or on their reservation is selected for a repository.

An accurate assessment of all potential impacts may prove difficult because the schedule for constructing, operating, closure, decommissioning, and covers 90 years. Socioeconomists find it more difficult to make forecasts as the planning period increases and must revise and update their predictions to reflect changing conditions in a given study area.

The socioeconomic impacts of a repository can be grouped into two major categories:

1. Impacts that result from development-related growth.

2. Impacts that result from the unique features and public perceptions of a repository.

Several types of impacts are discussed in this chapter: demographic, economic, community service, social, and fiscal. The discussion covers both the impacts stemming from development-related growth and the impacts related to the characteristics and perceptions of a repository. These and other impacts have been being studied for the environmental assessments and will be further studied, as needed, for the preparation of the environmental impact statement.

11.1 DEMOGRAPHIC CHANGES

Demographic changes include population inmigration resulting from increased employment opportunities and outmigration resulting from the termination of temporary jobs. Some residents might also leave the area if they are reluctant to live near a repository.

The development of a repository will create demands for workers to construct and operate the facility. Workers and their families will move into the affected area if enough workers who have the needed job skills do not already live in the area. The expanded population will demand more goods and services, thereby creating new business opportunities that could encourage others to move into the area. This secondary population increase may be larger than the increase that can be attributed directly to the repository (see Section 11.2).

Four major factors influence the extent to which these demographic changes could affect surrounding communities: (1) the total number of inmigrants and outmigrants, (2) the rate of population growth, (3) where the inmigrants choose to live, and (4) the demographic characteristics of the inmigrants and the host population.

The total number of inmigrants will depend on the number of workers needed to construct and operate the repository, the availability of local labor, and the number of family members who accompany incoming workers. Therefore, when estimating the number of inmigrants into an area, assumptions must be made regarding the percentage of available jobs that can be filled by local residents and the family size of incoming workers.

Some residents may move out of the affected area if they believe their health or safety is threatened by a repository, but it is difficult to predict how many people might leave for this reason. Other residents living along roads designated as waste-transportation corridors may also move because they are concerned about the hazards of waste transportation. If outmigration occurs for these two reasons, it would probably occur during the early phases of repository development and operation and would cease if the repository operates without incident.

The rate of population growth is important, as is the total number of inmigrants. The schedule of repository construction and the availability of workers in the affected area determine the rate at which workers move into an area. Inmigration could begin before the final site selection decision is announced. For example, unemployed construction workers may move into the area in anticipation of future job opportunities.

Where the inmigrants choose to live makes a difference in the kinds of impacts associated with population increases. Workers are more likely to choose communities where housing and services are already available, although some may choose to live in smaller communities with fewer services if they are closer to the repository. The changes associated with the immigration--changes in age distributions, the ratio of males to females, income and educational levels, and the ethnic composition of a community--will affect the types of services and housing that are needed and the way of life in the community. These impacts are discussed in Sections 11.3 and 11.4.

11.2 ECONOMIC IMPACTS

Economic impacts may be positive for some groups and negative for others. Increased demand for goods and services can promote new business and employment opportunities. On the other hand, higher wages may drive up the cost of living, causing hardships to some businesses, people whose wages do not increase, and people on fixed incomes. Moreover, some economic activities, such as agriculture or tourism, could be affected.

The development and operation of a repository will infuse money into the economies of surrounding communities and provide new jobs, some of which will be filled by local residents. Repository workers may receive higher wages than those paid in these communities. This difference in wages may encourage residents to leave their jobs and seek employment at the repository. Established local businesses may find it necessary to raise wages in order to retain their employees. One result of this competition for workers could be a rise in the average per capita income, which could lead to increased demands for a wider variety of goods and services.

The combination of a larger population, increased consumer demands, and higher wages may drive up the general cost of living in affected communities. Residents whose incomes do not grow at the same rate as the general cost of living may find that their purchasing power is reduced. In particular, people on fixed incomes, such as the elderly, may have difficulty paying for housing and other needed services.

Local purchases of materials used in constructing and operating the repository and increased consumer spending will stimulate secondary economic development in the area. New businesses will open and some existing ones will expand, which will provide more choices to consumers. The extent of this secondary economic development will largely depend on how much of the wages of repository workers is spent within the community and what portion of the materials needed for the repository is purchased locally. It is likely that the secondary economic growth will exceed the primary economic growth.

Economic growth may affect the market shares of existing businesses, depending on their abilities to expand and to compete with new enterprises. For example, some businesses may have difficulty paying higher wages and obtaining the financing to expand their operations.

The number of workers employed at the repository will fluctuate throughout the various phases of the repository. The number of construction workers will reach a maximum between the third and the fifth year of construction and then gradually decline. The number of jobs during the period of repository operations will increase from the first year until reaching a peak between the 14th and the 18th years, after which the number of jobs will decline for the remainder of the operations phase. There will be a slight increase in employment opportunities during decommissioning and closure, after which very few persons, if any, will be employed at the repository.

It is possible that affected communities may experience an economic downturn with repository closure, and they may want to develop strategies for economic diversification in anticipation of the closing of the repository.

Several economic impacts may stem from public apprehension of a repository. First, some economic activities, such as tourism and agriculture, could be affected. Second, private-property values near the site of the repository and along major transportation corridors could fluctuate. Third, it may be difficult to attract major new industries into an area where a repository is located.

Activities like tourism and agriculture could be affected by the development of a repository if potential visitors to recreational, natural, or historical places in the affected area, believing that these places are less attractive because of their proximity to a repository, choose to stay away. This would hurt businesses in affected areas that depend on tourism. Similarly, if consumers believe that agricultural products grown near a repository are contaminated or otherwise undesirable, it may be difficult to sell those products, and farmers near the repository could conceivably experience losses. At this time, however, there is no direct evidence that either of these impacts would occur. The potential for these kinds of impacts will be investigated during the investigations to be conducted concurrently with site characterization.

Private-property values may fluctuate throughout the repository planning, construction, and operation phases. These fluctuations could occur near the site and along major transportation corridors in the vicinity of the repository. The initial phases of repository development may be accompanied by a decline in property values. However, it is likely that property values will increase again at some time during the operations phase when the safety of repository operations is accepted by the public.

It is possible that developers from outside the community will attempt to purchase large tracts of land in anticipation of future housing needs. This could result in a larger percentage of absentee landowners in affected communities and some loss of local property control.

Communities hosting a repository may initially have trouble attracting new commercial or industrial enterprises to their area in an attempt to diversify the local economy. However, any initial reluctance of businesses to locate in the vicinity of a repository should also subside after the repository has been operating for several years without incident.

11.3 COMMUNITY-SERVICES IMPACTS

As mentioned above, population increases will stem from the hiring of repository workers from outside the area (primary growth) and the expansion of business activity (secondary growth). This growth in population will place additional demands on existing housing, public facilities, and public services. One long-range effect of this increased demand could be more housing choices for residents and improved community facilities and services. However, if sufficient funds are not available to pay for the needed improvements, existing services would be strained, which would lower the overall quality of services in the community.

11.3.1 IMPACTS ON HOUSING

If a large proportion of repository-construction jobs are filled by inmigrants, new workers will be competing for available housing in affected communities. Demand for housing will accelerate quickly because peak employment will occur between the third and the fifth years of repository construction. The extent to which this housing demand can be met will depend mainly on the number of vacant housing units in affected communities and the extent of planned real-estate development.

A sizable population influx will also reduce vacancy rates in affected communities. It is possible that the repository-related population growth will result in increases in the price of housing. Since repository workers may receive higher wages, other members of the community could be at a competitive disadvantage in the housing market. In particular, residents on fixed incomes and those who rent housing may have difficulty adjusting to increases in housing prices.

Demands for new housing should stabilize during repository operation because additional housing will have been built during the construction phase. It is likely that repository-operations workers will also occupy housing vacated by the construction workers who will leave when construction is completed.

Experience with other large development projects in rural areas suggests that housing prices may remain at inflated levels even when the additional demand due to population growth subsides, especially if the wages of project-construction workers inflate the general cost of living.

11.3.2 IMPACTS ON COMMUNITY FACILITIES AND SERVICES

The population increases associated with the repository may create a need for additional facilities and services in surrounding communities, including roads, water and sewer lines, schools, health-care services, fire and police protection, traffic-control and mass-transit systems, and cultural and recreational facilities. The expanded population may also create demands for services not currently provided in the community, such as counseling centers and an emergency-response capability.

The extent to which public facilities must be expanded will depend, in part, on the number of additional housing units that are built. If a large number of housing units must be constructed, costly expansions of municipal facilities may be required. For example, the construction of new housing developments will require that access roads be improved and that utility runs to existing electrical power, water, and sewer lines be lengthened.

The effects of population growth on public services will vary. In some cases, a larger population will allow the community to provide more services. For example, a larger population will be able to support more specialized medical personnel, resulting in improved health care-services. On the other hand, if affected communities cannot fund specialized medical personnel, some new community members with health problems different from those of long-time residents may not get the health care they need.

A community's educational system will be immediately affected by a rapid population growth because workers will enroll their children in school as soon as they move into an area. Although communities may have to invest more money in their schools to accommodate these increases, a long-range effect of this investment could be an improved educational system. For example, more teachers could be hired, and a wider range of courses could be offered. However, if affected communities are not willing or able to pay for the needed improvements, schools could become overcrowded, and the quality of education would suffer.

The need for some services may increase beyond what would be expected solely on the basis of population growth. For example, when the selection of the repository site is announced, unemployed construction or mining workers may be attracted to communities near the site. If many of these workers do not find jobs but choose to remain in the area, local social service agencies may be excessively burdened. The need for services not presently provided in affected communities may also be created. For example, new residents may desire day-care centers or family-planning clinics in their community.

11.4 SOCIAL IMPACTS

Social impacts are related mainly to a community's social organization and with perceptions of group and personal well-being. These impacts can be important to community residents, yet they are most difficult to identify and measure. For example, there are no standard indicators of community characteristics like the quality of life or community satisfaction. This section lists some of the social changes that a repository may cause.

A large increase in the size of community may alter the age distribution of its residents, its ethnic composition, and the ratio of males to females. Furthermore, the values, lifestyles, cultural traditions, and political views of the immigrants may differ from those of long-time residents. These changes will affect the way residents interact with one another and may influence the quality of life in that area. In the case of a repository, whether these changes are positive or negative will depend on individual preferences and the extent of planning conducted jointly by the community, the State or Indian tribe, and the DOE. Some residents might view immigrants as good for the community because they bring new ideas and more varied activities with them. Others may view immigrants as being responsible for a loss of traditional values and ways of life. In these instances, newcomers may not be welcomed into the community and tensions could develop between the two groups. Some residents may view the increased levels of personal affluence and expanded business opportunities that accompany repository development as a positive effect. Others may believe that these changes threaten their traditional lifestyles. Some of the factors that may affect community attitudes toward newcomers are the size of the existing community, previous experiences with transient workers, and the ability of the community to provide services when they are needed.

A rapid growth in population may be associated with increases in social problems--crime, alcoholism, drug abuse, family conflicts and divorce--and mental illness. The ability of a community to absorb the additional population without greatly increasing the occurrences of these social disorders depends largely on the rate of growth.

Leadership requirements in these growing communities may also change. Small, informal governments may have to add staff and become more formal as demands for services increase. Communities that previously had few land-use controls may enact new zoning ordinances for residential and commercial development. If immigrants become active in community affairs, new leaders may emerge as candidates for elected office or advocates for various issues.

To develop a repository, the DOE may need to acquire privately owned land. Any residences or businesses located at the site of the repository will have to be moved to other locations, and those who have to be relocated may experience greater social impacts than the other residents of the areas. Under the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (Public Law 91-646), relocated residents must be moved to comparable dwelling units. If no such units are available in the immediate area, residents may have to be moved out of their neighborhoods. Relocated businesses may lose some of their customers, particularly if they are moved a considerable distance from their original location.

The degree of public concern over the safety of a repository will depend partly on the extent to which local residents trust government institutions to adequately protect the community. Studies have shown that the public's trust of Federal Government officials diminished during the 1970s. The DOE recognizes that the degree of trust community members have in public officials will depend on the amount and the quality of information provided to the public, and the opportunities for public involvement during the siting and development process.

Public opinion about a repository will vary. Some community members will oppose it because of concern for their safety, potential changes to their community and lifestyles, or their political beliefs. Others may support the repository because it will produce jobs and stimulate economic development or alter their community in ways they view as positive. These differing opinions could lead to the polarization of groups in affected communities. New community leaders representing the varying positions may emerge as a result of this controversy. This polarization may be most severe during the period when the selection of a site is still an open issue.

11.5 FISCAL IMPACTS

The fiscal impacts of repository construction and operation may include increased revenues from an expanded property or other tax base and increased expenditures resulting from requirements for additional services. At the local level, revenue sources could include ad valorem taxes, user fees, special assessments, and intergovernmental transfers. Local expenditures may be required to improve schools and hire teachers, build water and sewer systems, and provide law enforcement, fire protection, and social services. Fiscal burdens may also result from the need to develop emergency-response and radiation monitoring capabilities.

The fiscal impacts on repository host States and local communities will depend, in part, on the political jurisdictions affected by increased demands for services, their respective authorities for raising revenues, and the financial assistance available to them under the Act.

The primary sources of income for local governments are usually property taxes. Property-tax revenues will fluctuate throughout the life of the project, reflecting population changes that occur with construction, operation, decommissioning, and closure. Revenues will also fluctuate slightly in response to changes in property values.

Property-tax revenues will increase in communities where inmigrants choose to live and businesses expand. It is possible that the residential choices of inmigrants will lead to a distribution of revenues that is different from the distribution of required expenditures among affected jurisdictions. For example, a repository may be located in one jurisdiction while most of its workers live in adjoining jurisdictions. This is more likely to occur if there is an urban area near the repository, because inmigrants may tend to settle in an urban area that offers more housing choices and amenities. If this settlement pattern does occur, communities in adjoining jurisdictions may be disproportionately burdened with increased debts to pay for improvements in services while receiving relatively minor revenue increases.

Even if inmigrants living in one jurisdiction do not demand services in another, the tax structure of State and local governments may result in unequal geographic distribution of revenues and expenditures. For example, tax structures may distribute most project-related revenues to State or county governments, although most costs will be incurred at the municipal or school-district level.

Large construction projects in rural areas frequently result in requirements for increased expenditures (because of the need to expand public services) several years before revenues begin to increase. This gap between expenditures and revenues may also occur early in the construction of a repository. Local governments may find it difficult to provide financing for these improvements.

Section 11.2 noted that certain economic activities, such as agriculture and tourism, may decline as a result of public apprehension about a repository. If this occurs, any associated sales taxes or user fees received by State and local governments will also decrease.

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U.S. Department of Energy
Public Inquiries Room
Forrestal Building
Room 1E-206
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Persons interested in obtaining copies of these publications or in learning about their availability at other DOE facilities (e.g., DOE public reading rooms) should write to the following:

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Office of Policy, Integration and Outreach
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GLOSSARY

accessible environment - the atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere that is outside the controlled area.

Act - the Nuclear Waste Policy Act of 1982 (Public Law 97 425).

actinides - radioactive elements with atomic numbers beginning at 89 and continuing through 103.

affected area - either the area of socioeconomic impact or the area of environmental impact.

affected Indian tribe - any Indian tribe (1) within whose reservation boundaries a monitored retrievable storage facility, a test and evaluation facility, or a repository for high-level radioactive waste or spent fuel is proposed to be located or (2) whose federally defined possessory or usage rights to other lands outside the reservation's boundaries arising out of congressionally ratified treaties may be substantially and adversely affected by the locating of such a facility: provided that the Secretary of the Interior finds, upon the petition of the appropriate governmental officials of the tribe, that such effects are both substantial and adverse to the tribe.

alluvium - clay, silt, sand, gravel, or similar material deposited in fairly recent geologic time by streams or rivers.

alpha particle - a positively charged particle emitted in the radioactive decay of certain nuclides. Made up of two protons and two neutrons bound together, it is identical to the nucleus of a helium atom. It is the least penetrating of the three common types of radiation--alpha, beta, and gamma.

alternative sites - the sites referred to in Section 141(b)4 of the Act for a monitored retrievable storage facility which are to be used in development of designs and an environmental assessment for the proposal required in that Section, and from among which the Secretary is directed to recommend a preferred site/design combination.

anhydrite - a mineral, $CaSO_4$, consisting of anhydrous calcium sulfate, that is usually massive and white or slightly colored.

anion - a negatively charged ion.

anisotropic - exhibiting properties with different values when measured along different axes.

anticlines - ridges formed by the folding of strata; characteristic structures of basalt flows.

aquifer - a formation, a group of formations, or a part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

aquitard - a confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a storage unit for ground water.

argillaceous - applied to all rocks or substances composed of clay minerals or having a notable proportion of clay in their composition such as shale, slate, etc.

artesian wells - wells tapping ground water confined under hydrostatic pressure. The water level in an artesian well is above the top of the artesian water body it taps. If the water level in an artesian well stands above the land surface, the well is a flowing artesian well.

atomic energy defense activity (or program) - any activity of the Secretary of Energy performed in whole or in part in carrying out any of the following functions: naval reactors development; weapons activities including defense inertial confinement fusion; verification and control technology; defense nuclear materials production; defense nuclear waste and materials by-products management; defense nuclear materials security and safeguards and security investigations; and defense research and development.

backfilling - placement of originally removed or new materials into excavated areas of a repository, including holes drilled for waste canisters, tunnels, access ways, and shafts.

barrier - any material or structure that prevents or substantially delays movement of ground water and, hence, dissolved radionuclides.

basal colonnade - a subdivision of the dense interior of a basalt flow consisting of relatively well-formed columns typically with fewer primary fractures than in the entablature.

basalt - a fine-grained solidified lava, rich in iron and magnesium minerals. A dark- to medium-dark-colored, commonly extrusive, mafic igneous rock composed chiefly of calcic plagioclase and clinopyroxene in a glassy or fine-grained groundmass.

bentonite - a soft, plastic, light-colored clay formed by chemical alteration of volcanic ash.

beta particle - a charged particle that is emitted by certain radioactive materials and is physically identical with the electron.

biosphere - the part of the Earth in which life can exist, including the lithosphere, the hydrosphere, and the atmosphere.

boiling-water reactor (BWR) - a nuclear reactor that uses boiling water to generate electricity.

borehole - a hole drilled into the earth, often for exploratory purposes. A borehole is generally of such a small diameter that workers cannot work inside it. It is most often drilled into the ground vertically, or possibly on a small slant or horizontally. A borehole could be shallow or it could penetrate the repository formation or even deeper strata.

borosilicate glass - a silicate glass that contains at least 5 percent boric acid and is used to solidify commercial or defense high-level waste.

breccia - rock that is not waterworn, consisting of sharp fragments cemented together or embedded in a fine-grained matrix.

brine - water at or near saturation with salt.

brine migration - the movement of brine through interstices in rock.

burnup - a measure of reactor fuel consumption, expressed either as the percentage of fuel atoms that have undergone fission, or the amount of energy produced per unit weight of fuel in the reactor.

calcine - material heated to a temperature below the melting point to bring about a more chemically stable form through oxidation, reduction, or the loss of moisture.

caldera - a large, basin-shaped volcanic depression, more or less circular in form.

caliche - gravel, sand, or desert debris cemented by calcium carbonate; also the calcium carbonate itself.

canister - the first material envelope surrounding a waste form for handling purposes.

caprock - a comparatively impervious layer of rock immediately overlying a fluid-bearing reservoir.

cask - a container for shipping spent nuclear fuel or high-level radioactive waste which meets all applicable regulatory requirements.

cask-in-trench (or berm) - an adaptation of the basic above-ground silo design where earth is used in addition to concrete to provide radiation shielding and physical protection.

CASTOR cask - a prototype dry-storage cask designed to store 16 BWR fuel assemblies.

cation - a positively charged ion.

Cenozoic - the latest of the eras into which geologic time, as recorded by the stratified rocks of the earth's crust, is divided; it extends from the end of the Mesozoic Era up to and including the present.

central entablature - a subdivision of the dense interior of a basalt flow, composed of irregularly or regularly jointed rock with relatively small columnar structures.

characterization - the collecting of information necessary to evaluate suitability of a region, location, or site.

chemical resynthesis - the process whereby thermodynamic equilibrium between nuclear waste and its host rock is attempted in order to enhance waste form stability.

cladding - the outer jacket of spent fuel elements which contains and supports the fuel material, protects the fuel from interaction with the coolant, and prevents the release of fission products into the coolant.

colloid - a suspension of finely divided particles in a liquid, gaseous, or solid substance. Suspended particles are not easily filtered out.

commercial high-level radioactive waste - high-level radioactive waste produced in atomic-energy activities other than for defense purposes.

commercial nuclear reactor - a civilian nuclear power plant operated to produce heat for generating electricity. It is required to be licensed under Section 103 and 104b of the Atomic Energy Act of 1954 (42 U.S.C. 2133, 2134b).

Commission - the U.S. Nuclear Regulatory Commission.

consolidation - the operation performed on spent fuel assemblies during which the upper and lower fuel-assembly tie plates are removed, the assembly spacer grids and any other assembly structural members are removed, and the fuel tubes are collected and formed into a closely packed bundle for insertion into a canister. The nonfuel structural members of the fuel assemblies will be reduced in volume and placed in containers for shipment and disposal.

consultation-and-cooperation (C&C) agreement - the agreement required by the Nuclear Waste Policy Act. The Secretary of Energy is required to attempt to enter into a C&C agreement with a State that hosts a site approved for characterization or with an affected Indian tribe. Also, a State that has a potentially acceptable site for a repository may enter into a C&C agreement with the Department of Energy.

containment - the confinement of radioactive waste within a designated boundary or vessel.

contract - the "Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste" under which the Department of Energy will make available radioactive waste disposal services to the owners and generators of spent nuclear fuel and high-level radioactive waste.

cristobolite - a mineral (SiO_2) which is a high-temperature form of quartz and tridymite and occurs as white octahedrons in acidic volcanic rocks.

crystalline rock - a general term for igneous and metamorphic rocks as opposed to sedimentary rocks. Granite is one type of crystalline rock.

curie (Ci) - a unit of measurement of radioactivity. One curie equals that quantity of any nuclide which undergoes 3.7×10^{10} disintegrations per second.

decay - the process whereby radioactive particles undergo a change from one isotope or state to another at a geometric rate, releasing radioactive particles and/or energy in the process.

decommission - the permanent removal from service of surface facilities and components necessary for preclosure operations only, after repository closure, in accordance with regulatory requirements and environmental policies. Pertaining to an MRS facility, the permanent removal from service of facilities and components in accordance with regulatory requirements and environmental policies.

defense high-level waste - waste derived from atomic energy defense activities.

devitrification - the process by which glassy substances lose their vitreous (amorphous) nature and become crystalline.

disposal - the emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive waste with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste.

disposal package - the primary container that holds, and is in contact with, solidified high-level radioactive waste, spent nuclear fuel, or other radioactive materials, and any overpacks that are emplaced at a repository.

dissolution - a process of chemical weathering by which minerals and rocks are dissolved in water.

disturbed zone - that portion of the controlled area, excluding shafts, whose physical or chemical properties are predicted to change as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change of properties could have a significant effect on the performance of the geologic repository.

DOE - the U.S. Department of Energy.

drift - a horizontal opening excavated underground.

dry storage - cask, drywell, silo, and vault systems that are passive, modular, and low in maintenance and that provide an alternative for additional spent fuel storage at nuclear power plants that cannot accommodate reracking or rod compaction.

drywell - a cylindrical hole into which sealed metal canisters containing spent fuel or high-level waste are placed.

dual-purpose cask - a cask that could serve as a storage module as well as a transport cask.

ecology - the study of the relationships between living things and their environments.

ecosystem - an ecologic system composed of organisms and their environment.

effective porosity - the amount of interconnected pore space and fracture openings available for the transmission of fluids, expressed as a ratio of the volume of interconnected pores and openings to the volume of rock.

engineered barrier system - the manmade components of a disposal system designed to prevent the release of radionuclides from the underground facility into the geohydrologic setting. It includes the radioactive-waste form, radioactive-waste canisters, materials placed over and around such canisters, any other components of the waste package, and barriers used to seal penetrations in and to the underground facility.

environmental assessment (EA) - a concise public document for which a Federal agency is responsible that 1) serves to briefly provide sufficient evidence and analysis for determining whether to prepare an environmental impact statement or a finding of no significant impact; 2) serves to aid an agency's compliance with the National Environmental Policy Act of 1969 (NEPA) when an environmental impact statement is necessary; 3) serves to facilitate preparation of an environmental impact statement when necessary. The EA will include brief discussions of the need for the proposal, of alternatives as required by the NEPA, of the environmental impacts of the proposed action and alternatives and a listing of agencies and persons consulted; 4) a comparative analysis of the potential environmental and socioeconomic impacts of the six alternative combinations of reference sites and designs that will be developed for the MRS proposal.

environmental impact statement (EIS) - the document required by Section 102(2)(c) of the National Environmental Policy Act of 1969 (NEPA).

epicenter - the point on the earth's surface directly above the exact subsurface location of an earthquake.

erosion - the wearing-away of soil and rock by weathering, mass wasting, and the action of streams, glaciers, waves, wind, and ground water.

evaporation - conversion of a liquid to a vapor state by the addition of latent heat.

evaporites - sedimentary rocks which are deposited from aqueous solution as a result of extensive or total evaporation of the solvent. Rock salt and gypsum are examples of evaporites.

evapotranspiration - a term embracing that portion of the precipitation returned to the air through direct evaporation or by transpiration of vegetation.

exploratory shaft - a subsurface excavation composed of tunnels and rooms in the host rock in the immediate vicinity of the shafts and at the depth that a repository would be built. The shafts will be large enough to allow people and test equipment to be transported from the surface to the subsurface excavations and will allow detailed study of the host rock including lateral exploratory drilling.

extensometer - an instrument used in measuring strain.

facility - any structure, system, or element of a system, including engineered barriers, created by the DOE to meet performance or functional objectives.

fault - a fracture or a zone of fractures along which there has been displacement of the sides relative to one another, parallel to the fracture or zone of fractures.

fault block - a crustal unit formed by block faulting; it is bounded by faults, either completely or in part.

Federal interim storage (FIS) - see interim storage facility.

field drywell - an in-ground sealed metal enclosure for storing canisters of waste. The drywells can be bored to different sizes as required to accept different sizes of canisters.

fission - the splitting of a heavy nucleus into two or more radioactive nuclei, accompanied by emission of gamma rays, neutrons, and a significant amount of energy. Fission is usually initiated by neutron bombardment, but it can also occur spontaneously.

flow top - a vesicular or brecciated crust that grades into the dense flow interior of a basalt flow.

fluvial - of or pertaining to rivers; growing or living in a stream or river; produced by the action of a stream or river.

fold - a bend or flexure in bedding, foliation, cleavage, or other planar features in rock. A fold is usually a product of deformation.

fuel assembly - a grouping of fuel rods which is not taken apart during the charging and discharging of a reactor core.

fuel cycle - the processing steps that convert uranium ore to nuclear fuel and provide for its disposal, including mining, milling, conversion, enrichment, fuel element fabrication, irradiation in reactors, reprocessing (if desired), storage, and disposal.

full cost recovery - the recoupment by the DOE through purchaser fees, and any interest earned, of all direct costs, indirect costs, and all allocable overhead, consistent with generally accepted accounting principles consistently applied, of providing disposal services and conducting activities authorized by the Nuclear Waste Policy Act of 1982 (Public Law 97-425).

gamma ray - short-wavelength electromagnetic radiation emitted during the radioactive decay of certain nuclides. Gamma rays are highly penetrating.

geochemistry - the study of the distribution and amount of the chemical elements in minerals, ores, rocks, soils, water, and the atmosphere.

geodetic survey - survey in which account is taken of the shape and size of the earth and corrections are made for earth curvature.

geohydrologic - pertaining to ground water and its movements through the geologic environment.

geohydrologic setting - the system of geohydrologic units that is located within a given geologic setting.

geohydrologic system - the units within a geologic setting, including any recharge areas, discharge areas, interconnections between units, and any natural or man-induced processes or events that could affect ground-water flow within or among those units.

geohydrologic unit - an aquifer, a confining unit, or a combination of aquifers and confining units composing a reasonably distinct geohydrologic system.

geologic - in the Civilian Radioactive Waste Management Program, factors such as the depth, thickness, and lateral extent of the host rock; ground motion, faults, igneous activity, uplift and subsidence, and dissolution; rock structure and characteristics, ground-water flow and travel times; chemical interactions; resource potential; surface water bodies; and terrain.

geologic disposal - placement of radioactive waste in deep stable geologic formations.

geologic repository - a system which requires licensing by the NRC, that is intended to be used, or may be used, for the disposal of radioactive wastes in excavated geologic media. A geologic repository includes 1) the geologic repository-operations area and 2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.

geomechanics - that branch of geology dealing with the response of earth materials to the application of deformational forces and embracing the fundamentals of structural geology.

geomorphic - of or relating to the form of the earth or its surface features.

geophysical - pertaining to the properties of the earth related to its structure, composition, and development.

grants-equal-to-taxes (GETT) - as specified in the Act, an amount, each fiscal year, equal to the amount a State and a unit of local government, would receive were they authorized to tax site characterization activities at a potential repository site, and the development and operation of such a repository, just as a State and a unit of general local government tax other real property and industrial activities.

ground water - water that is below the ground surface in saturated soil and rock that supplies wells and springs.

half-life - the time required for half the nuclei in a sample of a specific isotope species to undergo radioactive decay.

high-level radioactive waste (HLW) - (1) the highly radioactive material resulting 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; and (2) other highly radioactive material that the Nuclear Regulatory Commission determines by rule, or the DOE determines by order, consistent with existing law, to require permanent isolation.

host rock - the geologic medium in which the waste is emplaced, specifically the geologic materials that directly encompass and are in close proximity to the underground facility.

hot cell - a compartment enclosed with thick concrete walls and with highly efficient filter systems that collect and capture any airborne radioactive particles that may be released during operations involving radioactive materials; a heavily shielded enclosure in which radioactive materials can be handled by persons using remote manipulators and viewed through shielded windows or periscopes.

hydraulic conductivity - the volume of water that will move through a medium in a unit time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow.

hydraulic gradient - a change in the static pressure of ground water, expressed in terms of the height of water above a datum, per unit of distance in a given direction.

hydraulics - an engineering discipline dealing with the statics and dynamics of fluids.

hydrofracture - a process of producing underground openings by injection of fluids (usually water) at pressures greater than the weight of the overlying rock and soil.

hydrologic properties - those properties of a rock that govern the capacity to hold, transmit, and deliver water, such as porosity, effective porosity, specific retention, permeability, and the directions of maximum and minimum permeabilities.

hydrology - the study of ground water and its properties, circulation, and distribution, from the time it falls as rainwater until it is returned to the atmosphere through evapotranspiration or flows into the ocean.

igneous activity - the emplacement (intrusion) of molton rock material (magma) into material in the earth's crust or the expulsion (extrusion) of such material onto the earth's surface or into its atmosphere or surface water.

igneous rock - a rock that solidified from molten or partly molten material, i.e., from a magma.

immobilization - treatment or emplacement of nuclear wastes so as to prevent the release of radioactive isotopes.

impact assessment report - a report submitted by the State of affected Indian tribe; provides a basis for determining the amount of financial assistance that the DOE will provide for mitigating public health and safety, environmental, and socioeconomic impacts related to siting and construction of a geologic repository.

improved-performance plan - a waste management system that includes the MRS facility as an integral part. Most or all spent fuel could be shipped directly from reactor sites to an MRS facility. Spent fuel from reactors located close to a repository, but an appreciable distance from the MRS facility, may be shipped directly to the repository. Solidified high-level waste could be shipped directly to the repository or to the MRS facility.

Indian tribe - any Indian tribe, band nation, or other organized group or community of Indians recognized as eligible for the services provided to Indians by the Secretary of the Interior because of their status as Indians, including any Alaska native village, as defined in Section 3(c) of the Alaska Native Claims Settlement Act (43 U.S.C. 1602(c)).

induration - the hardening of rock material by heat, pressure, or the introduction of some cementing material.

in situ - in the natural or original position. The phrase is used in this document to distinguish in-place experiments, rock properties, and so on from those in the laboratory.

in-situ stress - the magnitude and state of ground stress in a rock mass. The inherent stress in a rock mass at depth.

in-situ tests - tests that are conducted with subject material in its original place (i.e., at the repository site and depth).

integrated waste management system - a waste management system in which all components and elements are optimized to work with the other components and elements. This system is usually meant to include an integral monitored retrievable storage facility.

interested Indian tribes - Indian tribes, who because of their proximity to nuclear waste shipping routes maintain an interest in the waste management program.

interim storage facility - a Federally owned and operated system that would provide storage for no more than 1,900 metric tons of spent nuclear fuel from civilian reactors whose owners cannot reasonably provide adequate storage capacity on site.

Interim Storage Fund - the fund provided for in the Act that ensures that those using the interim storage facilities will pay the full costs.

interstitial - a term referring to the space between particles or grains.

intrinsic properties - strength, permeability, and sorption characteristics of rocks.

irradiation - exposure to radiation (as from a nuclear reactor or particle accelerator).

ions - an atom or group of atoms that is not electrically neutral, but instead carries a positive or a negative electrical charge.

isolation - inhibiting the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.

isotope - one of two or more species of the same chemical elements, i.e., having the same number of protons in the nucleus, but differing from one another by having a different number of neutrons.

lava - molten material (magma) that pours out on the earth's surface from volcanoes or fissures in the earth.

licensing - the process whereby a permit is obtained from the Nuclear Regulatory Commission to build and operate a nuclear facility.

lignad - a group, ion, or molecule coordinated to a central atom in a complex.

lithology - the study of rocks. Also the description of a rock on the basis of such characteristics as structure, color, mineral composition, grain size, and arrangement of its component parts.

lithophysae - hollow, bubblelike structures composed of concentric shells of finely crystalline alkali feldspar, quartz, and other materials.

lithostatic pressure - the confining pressure at depth in the crust of the earth caused by the weight of the overlying rocks.

low-level radioactive waste (LLW) - radioactive material that (A) is high-level radioactive waste, spent nuclear fuel, transuranic waste, or byproduct material as defined in Section 11e(2) of the Atomic Energy Act of 1954 (42 U.S.C.2014(e)(2)); and (B) the Commission, consistent with existing law, classifies as low-level radioactive waste.

magma - molten material that originates from the lower crust and upper mantle from which igneous rocks are thought to have been derived through solidification and related processes.

memorandum of understanding (MOU) with the NRC - the MOU that establishes procedures meeting the requirements of the Act for Nuclear Regulatory Commission review of the test and evaluation facility.

Mercalli scale - a scale for measuring earthquake intensity in terms of the effects perceived by people near the earthquake.

mesostasis - the last-formed interstitial material of an igneous rock.

Mesozoic - an era of geologic time from the end of the Palezoic to the beginning of the Cenozoic.

metal storage cask - a cask constructed primarily of lead and steel or ductile iron with water or other materials providing additional radiation shielding. Cooling is provided by conduction of heat through the metal walls and natural convection to the atmosphere.

metric tons uranium - that measure of weight equivalent to 2,204.6 pounds of uranium and other fissile and fertile material that are loaded into a reactor core as fresh fuel.

mineralogy - the study of minerals, including their formation, occurrence, properties, composition, and classification.

Miocene - an epoch of geologic time within the upper Tertiary Period, after the Oligocene and before the Pliocene.

mitigation - (1) avoiding an impact altogether by not taking a certain action or parts of an action; (2) reducing impacts by limiting the degree or magnitude of the action and its implementation; (3) rectifying the impact by repairing, rehabilitating, or restoring the affected environment; (4) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; or (5) compensating for the impact by replacing or providing substitute resources or environments.

modular storage system - a spent fuel element storage arrangement that offers the economic advantage, to nuclear power plants in need of additional storage, of adding storage in small increments, thereby avoiding large initial capital outlays.

monitored retrievable storage (MRS) - a concept for storing waste or spent fuel for long periods. The waste and spent fuel would be continuously monitored and would be stored in such a way that it could be retrieved, at a later date, and sent to a repository.

natural barrier - the physical, mechanical, chemical, and hydrological characteristics of the geological environment that individually and collectively act to minimize or preclude radionuclide transport.

natural system - the geologic setting that consists of (1) a host rock suitable for repository construction and waste emplacement and (2) the surrounding rock formations. It will include natural barriers that provide containment and isolation by limiting radionuclide transport through the geohydrologic environment to the biosphere, and providing conditions that will minimize the potential for human interference in the future.

nuclear reactor - a device in which a fission chain reaction can be initiated, maintained, and controlled.

Nuclear Waste Fund (NWF) - the fund established by the Nuclear Waste Policy Act to assure that the costs of high-level radioactive waste management and disposal are borne by the owners and generators of the waste.

nuclear waste management - the planning, execution, and surveillance of essential functions related to the control of radioactive and nonradioactive waste, including treatment, solidification, temporary or long-term storage, surveillance, and isolation.

once-through fuel cycle - a fuel cycle that involves no reprocessing of spent fuel; spent fuel is discharged from a reactor, cooled for some period of time in storage, and ultimately disposed of as waste.

open-cycle surface vault - canisters of spent fuel or reprocessed waste stored in large, shielded warehouse-type structures through which cooling air circulates by national convection.

overpack - any receptacle, wrapper, box, or other structure that becomes an integral part of a radioactive waste package and is used to enclose a waste container for purposes of providing additional protection or meeting the requirements of an acceptance or isolation criterion for a specific site.

oxidation - the process of chemically combining with oxygen.

package - pertaining to transportation, the actual package and its radioactive contents as presented for transport.

packaging - pertaining to transportation, the assembly of components necessary to assure compliance with DOT regulations. It may consist of one or more receptacles, absorbent materials, spacing structures, thermal insulation, radiation shielding, and devices for cooling or absorbing mechanical shocks. The vehicle, tie-down system, and auxiliary equipment may sometimes be designated as part of the packaging.

paleoclimate - a climate of the geologic past.

paleohydrology - the study of ancient hydrologic features preserved in rock.

permeability - in hydrology, the capacity of a medium (rock, sediment, or soil) to transmit ground water. Permeability depends on the size and shape of the pores in the medium and how they are interconnected.

petrology - that branch of geology dealing with the origin, occurrence, structure, and history of rocks.

pH value - the negative $\log_{10}$ of the hydrogen-ion activity in a solution; a measure of the acidity or basicity of a solution.

piezometer - an instrument for measuring the change of pressure of a material subjected to hydrostatic pressure.

plutonium - a radioactive element with an atomic number of 94. Its most important isotope is fissionable plutonium-239, produced by neutron irradiation, or uranium-238.

pluvial - pertaining to rain or precipitation. Also said of a climate characterized by relatively high amounts of precipitation.

porosity - the ratio of the total volume of interstices in a rock or soil to its total volume, usually expressed as a percentage.

potentiometric - said of, or relating to the hydrostatic pressure level of ground water.

potentiometric surface - the level to which the water from a given aquifer will rise by hydrostatic pressure. The potentiometric surface is usually represented as a contour map in which each point tells how high the water would rise in a well tapping that aquifer at that point.

pressurized water reactor (PWR) - a reactor system that uses a pressurized-water primary cooling system; steam formed in a secondary cooling system drives turbines to generate electricity.

Price-Anderson Act - the legal act referred to when dealing with liability concerns; provides a comprehensive system of financial protection.

prime farmland - land that has the best combination of physical and chemical characteristics for producing agricultural crops with minimum inputs of fuel, fertilizer, pesticides, and labor and without intolerable soil erosion as determined by the Secretary of Agriculture pursuant to the Farmland Protection Policy Act of 1982 (Public Law 97-98). Prime farmland includes land that possesses the above characteristics and is being used currently to produce livestock and timber, but it excludes land already in, or committed to, urban development or water storage.

"Q" system - the classification system for the rock-mass quality of the Cohassett dense interior and estimate the rock-support requirements; rocks are classified as very poor to fair.

Quality assurance (QA) - all the planned and systematic actions necessary to provide adequate confidence that a structure, system, or component is constructed according to plans and specifications and will perform satisfactorily.

Quaternary Period - the second period of the Cenozoic Era, following the Tertiary, beginning 2 to 3 million years ago and extending to the present; the most recent geologic period, within the past 1.5 million years.

radioactive - unstable in a manner shown by spontaneous nuclear disintegration with accompanying emission of radiation and particles consisting of alpha, beta, and gamma radiation.

radioactive waste - high-level radioactive waste (HLW) and radioactive materials other than HLW that are received for emplacement in a geologic repository. Spent nuclear fuel is included in the term radioactive waste.

radioisotope - a radioactive isotope of an element.

radiolysis - the decomposition (splitting) of a molecule (often the water molecule) due to effects of radiation.

radionuclide - an unstable radioactive isotope that decays toward a stable state at a characteristic rate by the emission of ionizing radiation(s).

receiving and handling (R&H) building - one of the main components of the MRS facility where the materials are prepared and packaged so that they can be safely shipped to the repository or stored and retrieved for future shipment.

repository - any system licensed by the Nuclear Regulatory Commission that is intended to be used for, or may be used for, the permanent deep geologic disposal of high-level radioactive waste and spent nuclear fuel, whether or not such system is designed to permit the recovery, for a limited period during initial operation, of any materials placed in such system. This term includes both surface and subsurface areas at which high-level radioactive waste and spent nuclear fuel handling activities are conducted.

reprocessing - the mechanical and chemical process by which irradiated nuclear fuel is separated into waste material to be disposed of and useful materials, such as thorium, uranium, and plutonium, to be reused as nuclear fuel.

reracking - a rearrangement of the water pool used for storage of spent fuel which results in additional spent-fuel storage capactiy.

restricted area - any area to which access is controlled by the DOE for purposes of protection of individuals from exposure to radiation and radioactive materials, but not including any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

retrieval - the act of intentionally removing radioactive waste from the underground location at which the waste had been previously emplaced for disposal.

rhyolitic - characteristic of a group of extrusive igneous rocks, generally porphyritic and exhibiting flow texture with phenocrysts of quartz and alkali feldspar in a glassy to cryptocrystalline groundmass (rhyolite).

"RMR" system - the system used to classify the rock-mass quality of the Cohassett dense interior and estimate the rock-support elements; rocks are classified as fair to good.

rock salt - the best-known evaporite; forms by the precipitation of sodium chloride from saturated evaporating bodies of water in shallow basins.

rod consolidation - (see consolidation)

rubble zones - rock regions located at the base and top of basalt lava flows and most of the sedimentary interbeds; zones of relatively high permeability that commonly act as aquifers.

salt dome - individual pillars of salt surrounded by sedimentary rock, formed when deeply buried, bedded salt was forced upward by a release of overlying pressure.

saturated zone - the part of the earth's crust beneath the deepest water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

scouring - erosion, especially by moving water.

screening methodology document - the program document that describes how the region-to-area screening will be conducted and reflects the consultation process with the States over its development.

sealed storage cask - a large steel-lined reinforced-concrete cylinder that holds welded stainless-steel canisters of spent fuel and is closed with a thick concrete shield plug and a welded steel lid.

Secretary - the Secretary of the U.S. Department of Energy.

sedimentary rock - rock formed of sediment, especially (1) clastic rocks (e.g., conglomerates, sandstone, and shales) formed of fragments of other rock transported from their sources and deposited in water and (2) rocks formed by precipitation from solution (e.g., rock salt and gypsum) or from the secretions of organisms (e.g., most limestones).

seismic - pertaining to, characteristic of, or produced by earthquakes or earth vibrations.

shaft - an excavation of small cross-sectional area, compared with its depth, made for locating or mining ore or coal; raising water, rock, or coal; hoisting and lowering men and material; or ventilating underground workings. Often specifically applied to approximately vertical shafts as distinguished from an incline or inclined shaft. A shaft in a repository will be large enough to permit access and allow workers to place seals.

shear zone - a tabular zone of rock that has been crushed and brecciated by many parallel fractures caused by shear strain.

site - a potentially acceptable site or a candidate site as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same

site characterization - for a repository, activities, whether in the laboratory or in the field, undertaken to establish the geologic condition and the ranges of the parameters of a candidate site relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository; but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken. With regard to a monitored retrievable storage facility, the activities, whether in the laboratory or in the field, undertaken to establish the geologic conditions and the ranges of the parameters of a site relevant to the location of an MRS facility, including borings, surface excavations, and in situ testing needed to evaluate the suitability of a site.

site characterization plan - the program document that will reflect expected site conditions for each of the three sites recommended for site characterization. This document will provide the basis to identify the quantity and types of tests and analyses to be performed during site characterization; will reflect the integration of the site characterization (exploratory shaft) facilities with the repository in terms of design, construction, and performance so that their impacts with respect to suitability of the site can be assessed.

site-screening process - the search for sites with geologic, hydrologic, and lithologic characteristics suitable for construction of a large underground facility for long-term waste isolation.

siting - the collection of exploration, testing, evaluation, and decisionmaking activities associated with the process of site screening, site nomination, site recommendation, and site approval for characterization or repository development.

social impacts - those impacts that deal primarily with a community's social organization and with perceptions of group and personal well-being.

solidification - the conversion of liquid high-level waste to glass.

sorption - retardation of chemicals in solution by absorption; the term for retention of one substance by another, by close-range chemical or physical forces. Absorption occurs within the pores of a material; adsorption occurs chiefly at the surface of a material.

specific yield - the ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity to the volume of that mass.

spent fuel - (see spent nuclear fuel)

spent-fuel assemblies - the arrangement of fuel rods, support grids, tile plates, and other structural members of the nuclear fuel removed from a reactor after irradiation.

spent fuel rods - the irradiated metal tubes containing the uranium-bearing fuel pellets removed from a reactor. Part of the spent fuel assembly.

spent nuclear fuel - fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing. Spent fuel is thermally hot and highly radioactive.

standard disposal contract - see contract.

storage - retention of high-level radioactive waste, spent nuclear fuel, or transuranic waste with the intent to recover such waste or fuel for subsequent use, processing, or disposal.

storage basin - a water-filled, stainless steel-lined pool for the interim storage of spent fuel.

storage pool - a concrete chamber filled with water to provide shielding for irradiated fuel elements.

storativity - the volume of water released from storage in a vertical column of 1 square foot when the water table or other piezometric surface declines 1 foot. In an undefined aquifer, it is approximately equal to the specific yield.

strata - beds or layers of rock regardless of thickness.

stratigraphy - the branch of geology that deals with the definition and interpretation of the rock strata; the conditions of their formation, character, arrangement, sequence, age, and distribution; and especially their correlation by the use of fossils and other means of identification.

stress - in a solid, the force per unit area acting on any surface within it and variously expressed as pounds or tons per square inch, or dynes, or kilograms per square centimeter; also, by extension, the external pressure which creates the internal force.

subseabed disposal - the concept of emplacing high-level waste in suitable containers in relatively thick beds of sediments located in deep, quiescent, remote, and biologically inactive regions of the oceans where slow sedimentation has taken place over tens of millions of years and where continued sedimentation and stability are expected over millions of years in the future.

subsidence - a local movement downward, as in settling or sinking of an area of the earth's surface, with little or no horizontal motion.

synclines - broad troughs caused by deformation, that separate anticlines; characteristic of basalt flows.

systems - the sites engineered components, and associated processes and events, considered as an integrated entity, that affect expected waste facilities performance.

system requirements and description (SRD) document - the program document that will define the overall requirements of the waste management system and describe the current design of the integrated waste system that meets those requirements.

systems engineering - the engineering activities that provide a disciplined, systematic approach to planning and analysis.

systems engineering management plan - the program document that will identify and document the procedures and responsibilities necessary for the engineering of a major, complex waste management system.

systems integration - a comprehensive attempt to consider all of the elements of any waste management program as part of a single system, optimized as a unit to best meet the program requirements.

tectonics - the branch of geology dealing with the broad architecture of the outer part of the earth; that is, the regional assembling of structural or deformational features, and the study of their mutual relation, their origin, and their historical evolution.

test and evaluation facility - an at-depth, prototypic, underground cavity with subsurface lateral excavations extending from a central shaft that is used for research and development purposes, including the development of data and experience for the safety handling and disposal of solidified high-level radioactive waste, transuranic waste, or spent nuclear fuel.

thermal conductivity - a measure of the ability of a material to conduct heat.

thermal expansion - the increase in linear dimensions that occurs when materials are heated.

thermomechanical - the transformation of heat energy into mechanical work.

topography - the general configuration of a land surface or any part of the Earth's surface, including its relief and the position of its natural and manmade features.

transmutation - conversion of one element or isotope into another by bombarding it with nuclear particles.

transpiration - the process by which water absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface.

transportable metal casks - large metal casks currently being considered by a number of utilities for the dry storage of spent fuel at reactor sites.

transportation business plan - the program document that will provide information on contracting procedures, equipment requirements, funding availability, and other areas of interest to conducting the business of developing the transportation capability.

transportation institutional plan - the program document that will identify those institutions affected by development of a transportation system; provide guidance in establishing an interactive communications network; and suggest plans, including schedules, for the final resolution of transportation-related issues.

transporter cask - a cask to provide shielding for the canister as it is taken from the building loadout area to the underground emplacement hole.

transshipment - shipping spent fuel from one reactor of a utility company to the site of another reactor of the same type owned by the same company for the purpose of storage at the second reactor site.

transuranic (TRU) waste - material produced primarily from the reprocessing of defense spent-reactor fuels, the fabrication of plutonium to produce nuclear weapons, and, if it should occur, plutonium fuel fabrication for use in nuclear power reactors that contains more than a specific concentration of alpha-emitting radionuclides (including urnaium-233 and its daughter products) of long half-life and high specific radiotoxicity.

tuff - a medium-grained rock formed of compacted volcanic ash and dust; it is usually porous, stratified, and soft.

tunnel drywells - mined tunnels into which sealed metal canisters containing spent fuel or high-level waste are placed.

tunnel rack - an underground open-cycle vault. Large, open racks of spent fuel or reprocessed waste canisters are stored in tunnels using remotely controlled emplacement equipment. Cooling is by natural convection, and radiation shielding is provided by the surrounding media.

undue risk - risk that is unnecessary and could be prevented, or risk that is excessive.

universal cask - a cask that could be used for spent-fuel storage and transportation and emplacement in the repository without further repackaging or overpacks.

unsaturated zone - the zone between the land surface and the water table. Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric.

uplift - (1) the process that results in evaluation of a portion of the earth's crust relative to an adjacent portion. (2) a structurally high area in the crust produced by movements that have raised or upthrust the rocks, as in a dome or arch.

uranium - a naturally radioactive element with the atomic number 92 and an atomic weight of approximately 238. The two principal naturally occurring isotopes are the fissionable U-235 (0.7% of natural uranium) and the fertile U-238 (99.3% of natural uranium).

vaults - large structures or caverns where spent-fuel packages are stored.

waste cannister - metallic or nonmetallic container enclosing the waste form.

waste form - the radioactive waste materials and any encapsulating or stabilizing matrix.

waste management system - the collection of facilities, equipment, personnel, and sites to be developed and deployed under the control of the U.S. Department of Energy's Office of Civilian Radioactive Waste Management to accomplish the permanent disposal of spent fuel and high-level radioactive waste.

waste package - the system of engineered components immediately surrounding an individual waste container that may include waste form, stabilizer, cannister, overpack, sleeve, and emplacement hole backfill designed to contain nuclear waste for an extended period of time. It must preserve the ability to retrieve the wastes through the required retrieval periods and must act as a barrier to waste migration and release into the geologic system.

water flux - a stream of flowing water; flood or outflow of water.

water table - the water surface in a body of ground water at which the water pressure is atmospheric.

welded tuff - indurated volcanic ash in which the constituent glassy shards and other fragments have become welded together, apparently while still hot and plastic after deposition.

zeolites - any of the various silicates analogous in composition to the feldspars which occur as secondary minerals on cavities, along fractures, and on joint planes in basaltic lavas. Occur also as authigenic minerals in sedimentary rocks.

LIST OF ACRONYMS AND ABBREVIATIONS

ACD	Advanced conceptual design
ACP	Area-characterization plan
A&E	Architect and engineer
AECL	Atomic Energy of Canada Ltd.
AMFM	Alternative Means of Financing and Managing (radioactive-waste facilities)
ARR	Area-recommendation report
BLM	Bureau of Land Management
BWIP	Basalt Waste Isolation Project
BWR	Boiling-water reactor
CA	Construction authorization
C&C	Consultation and cooperation
CFR	Code of Federal Regulations
CHEMTREC	Chemical Transportation Emergency Center
CHLW	Commercial high-level waste
CP&L	Carolina Power & Light Company
CRP	Crystalline Rock Project
CRWM	Civilian Radioactive Waste Management
CSM	Colorado School of Mines
D&E	Development and evaluation
DEIS	Draft environmental impact statement
DHLW	Defense high-level waste
DOE	Department of Energy
DOE-HQ	Department of Energy Headquarters
DOT	Department of Transportation

DWPF	Defense Waste Processing Facility
EA	Environmental assessment
EDBH	Engineered design borehole
EIA	Energy Information Administration
EIS	Environmental impact statement
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
ES	Exploratory shaft
ESF	Exploratory-shaft facility
FEIS	Final environmental impact statement
FEMA	Federal Emergency Management Agency
FIS	Federal interim storage
FPC	Final procurement and construction
FR	Federal Register
FY	Fiscal year
GETT	Grants equal to taxes
GWe	Gigawatts electrical
HLW	High-level waste
HQ	Headquarters
INEL	Idaho National Engineering Laboratory
IRG	Interagency Review Group
LA	License application
MOU	Memorandum of understanding
MRS	Monitored retrievable storage
MSL	Mean sea level
MTU	Metric tons of uranium
NEA	Nuclear Energy Agency

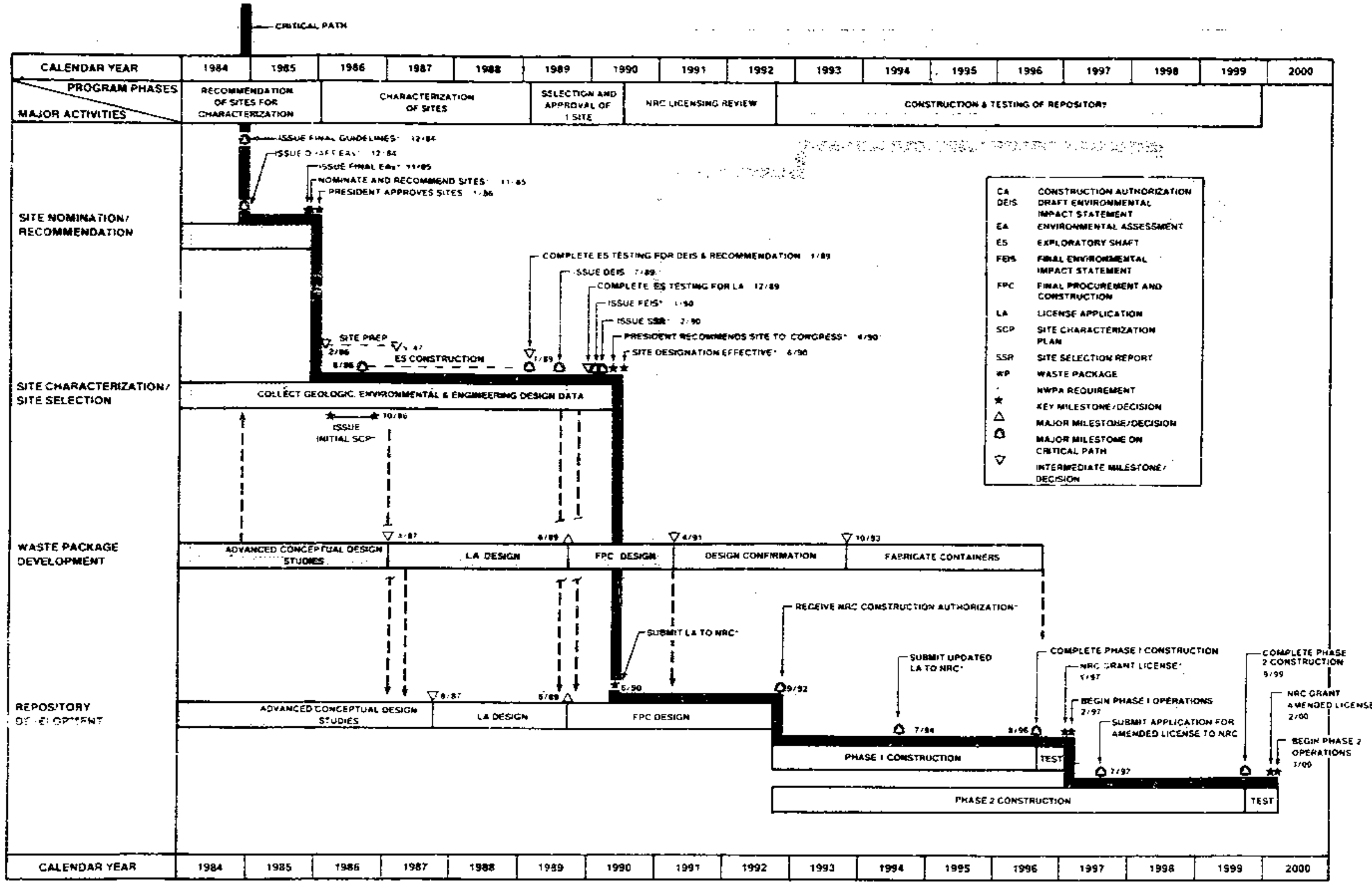
NEPA	National Environmental Policy Act
NFS	Nuclear Fuel Services
NRC	Nuclear Regulatory Commission
NSTF	Near-Surface Test Facility
NTS	Nevada Test Site
NUSCO	Northeast Utilities Service Company
NWPA	Nuclear Waste Policy Act
OCRWM	Office of Civilian Radioactive Waste Management
OGR	Office of Geologic Repositories
OMB	Office of Management and Budget
OPIO	Office of Policy, Integration and Outreach
OSTS	Office of Storage and Transportation Systems
ORM	Office of Resource Management
PA	Performance assessment
PAP	Performance-assessment plan
PCCB	Program Cost and Control Board
PDS	Project Decision Schedule
P.L.	Public Law
PMIS	Program Management Information System
PMS	Program Management System
PRDA	Program Research and Development Announcement
PSAR	Preliminary safety analysis report
PWR	Pressurized-water reactor
QA	Quality assurance
QMPR	Quality Management Policies and Requirements
RCR	Regional characterization report
R&D	Research and development

RFP	Request for proposal
R&H	Receiving and handling
ROD	Record of decision
RW	Radioactive waste
RRL	Reference repository location
SAR	Safety analysis report
SCP	Site-characterization plan
SF	Spent fuel
SNF	Spent nuclear fuel
SRD	System requirements and description
SSR	Site-selection report
TEF	Test and evaluation facility
TDS	Total dissolved solids
TRU	Transuranic
TVA	Tennessee Valley Authority
URL	Underground Research Laboratory
USGS	U.S. Geological Survey
VEPCO	Virginia Electric & Power Company
WBS	Work-breakdown structure
WIPP	Waste Isolation Pilot Plant
WP	Waste package
WPAS	Work Package Authorization System
WVDP	West Valley Demonstration Project

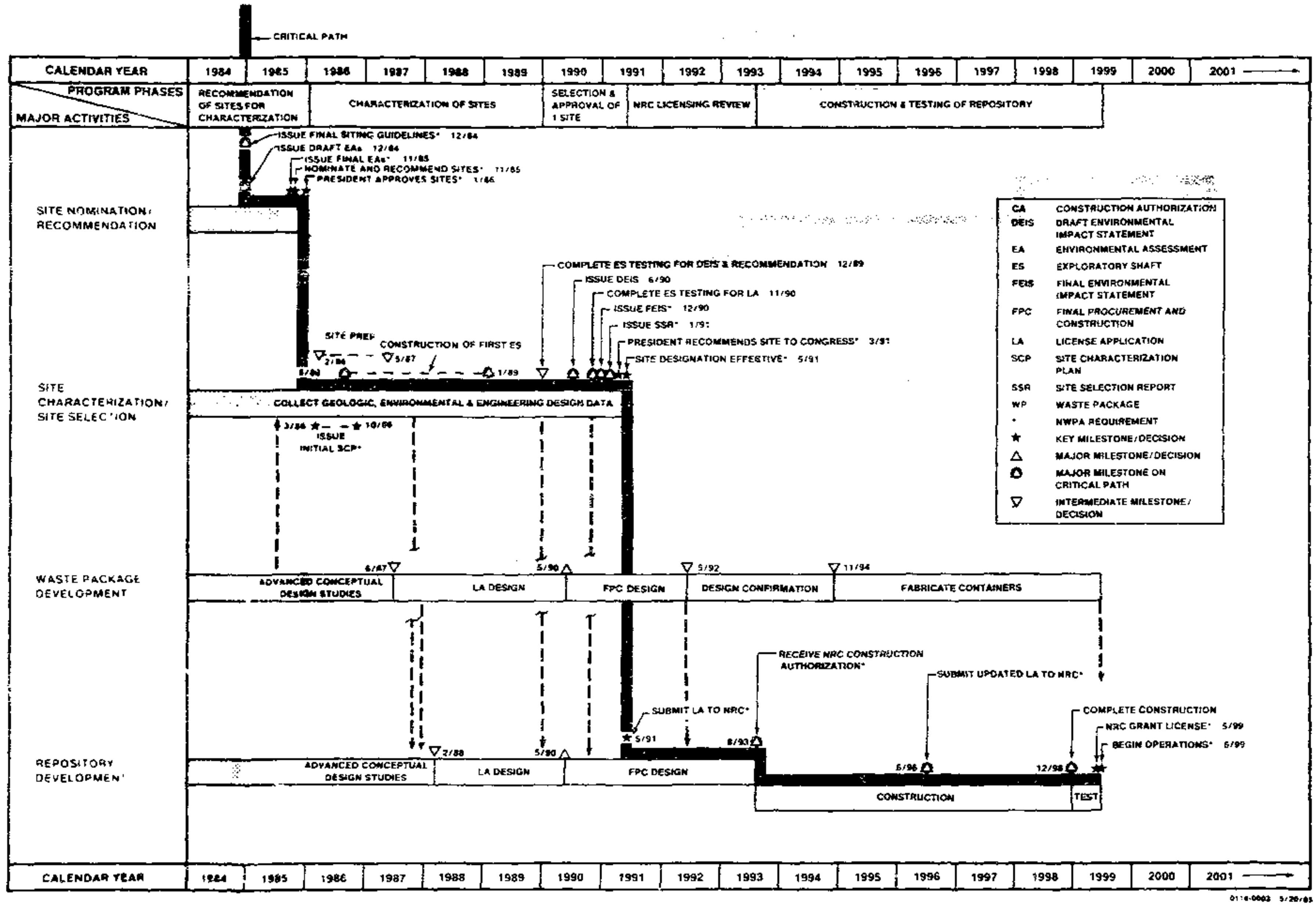
INDEX

Appendix A

ALTERNATIVE SCHEDULES FOR THE FIRST REPOSITORY



Alternative schedule 1—first geologic repository.



Alternative schedule 2—first geologic repository.

Appendix B

GENERAL GUIDELINES FOR THE RECOMMENDATION OF SITES FOR NUCLEAR WASTE REPOSITORIES

federal register

Thursday
December 6, 1984

Part III

Department of Energy

10 CFR Part 960

Nuclear Waste Policy Act of 1982; General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories; Final Siting Guidelines

DEPARTMENT OF ENERGY

10 CFR Part 960

Nuclear Waste Policy Act of 1982; General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories

AGENCY: Department of Energy.

ACTION: Final siting guidelines.

SUMMARY: In accordance with the requirements of the Nuclear Waste Policy Act of 1982 (Pub. L. 97-425) (the Act), the Department of Energy (DOE) is issuing general guidelines for the recommendation of sites for repositories for the disposal of high-level radioactive waste and spent nuclear fuel in geologic formations. These guidelines will be used in the various steps of the site-selection process, as required by the Act. They are compatible with the regulations issued by the Nuclear Regulatory Commission (NRC) in 10 CFR Part 60 and those proposed by the Environmental Protection Agency (EPA) in 40 CFR Part 191. The guidelines establish performance objectives for a geologic repository system, define the basic technical requirements that candidate sites must meet, and specify how the DOE will implement its site-selection process.

These guidelines were developed by the DOE through the consultation process required by the Act (i.e., consultation with affected and interested States, the Council on Environmental Quality, the Administrator of the EPA, and the Director of the U.S. Geological Survey) as well as extensive review and comment by interested members of the public, affected Indian tribes, and interested Federal agencies. They have received the concurrence of the NRC, in accordance with the requirements of the Act. The NRC's concurrence decision was rendered on June 22, 1984, and published on July 10, 1984 (49 FR 28130).

EFFECTIVE DATE: January 7, 1985.

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SUPPLEMENTARY INFORMATION: This supplementary information, also referred to as the "preamble" and the "statement of basis and purpose," explains the DOE siting process, the development of the guidelines, the general issues raised about the guidelines, and the structure of the guidelines. It also presents a detailed analysis of each guideline. A table of contents is listed below.

Contents

I. Background Information

The Department of Energy (DOE), pursuant to the Atomic Energy Act of 1954 as amended, the Energy Reorganization Act of 1974, the Department of Energy Organization Act of 1977, and the Nuclear Waste Policy Act of 1982 (the Act), has the responsibility to provide for the disposal of high-level radioactive waste and spent nuclear fuel.[1] The DOE selected mined geologic repositories as the preferred means for the disposal of commercially generated high-level radioactive waste and spent fuel (46 FR 26677, May 14, 1981) after evaluating various alternative means for the disposal of these materials and issuing an environmental impact statement (1). To carry out this decision, the DOE has been conducting research and development and performing siting studies.

The Act, signed into law on January 7, 1983, establishes a process and schedule for siting two mined geologic repositories.[2] It also, in Section 112(a), requires that the Secretary of Energy "issue general guidelines for the recommendation of sites for repositories." The guidelines issued under this notice are the general guidelines called for in the Act.

A. Requirements Established by the Act

As described below, the Act requires specific steps in the process of selecting repository sites. The implementation of guidelines in terms of those steps is discussed in the next section.

The initial steps required by the Act have been completed: the Secretary of Energy has identified the States with one or more potentially acceptable sites for the first repository and has so notified the Governors and the State legislatures, and the tribal council of any affected Indian tribe of the potentially acceptable sites within these States.

After issuing the siting guidelines, the Secretary is to nominate at least five sites as suitable for site characterization. The nomination of each site is to be accompanied by an environmental assessment that includes an evaluation of the site in terms of the guidelines.

The Act contains requirements for the DOE to continue its consultation and cooperation with the States and to specifically consult with the Governors of the States that contain potentially acceptable sites.

The Act requires the Secretary of Energy to recommend three of the nominated sites to the President for characterization as candidate sites. Site

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[1] For brevity, the terms "radioactive waste" and "waste" are frequently used in this notice and in the siting guidelines to mean "high-level radioactive waste and spent nuclear fuel."

[2] The Act requires the President to evaluate, by January 7, 1985, the use of one or more of these repositories for the disposal of high-level radioactive waste resulting from atomic energy defense activities.

characterization is defined as activities "undertaken to establish the geologic conditions and the ranges of the parameters . . . relevant to the location of a repository, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in-situ testing. . . ."

The President may approve or disapprove the recommendation submitted by the DOE or may permit the characterization to proceed by failing to act within 60 days. He may also delay the decision for 6 months if, in his opinion, insufficient information is available for a decision.

The information to be collected during site characterization will be specified in a site-characterization plan that is to be submitted for review and comment to the Nuclear Regulatory Commission (NRC), the State in which the site is located, and the governing body of any affected Indian tribe. The plan will also be made available for public review and comment.

Before proceeding to sink the exploratory shafts needed for tests and studies at the proposed depth of the repository, the DOE is to hold a public hearing in the vicinity of the site to inform the residents of the site-characterization plan and to receive their comments. When the site characterization itself has been completed, public hearings are to be held in the vicinity of each site being considered for development as a repository to inform the residents of the area that the site is under consideration and to obtain their comments on the possible recommendation of the site.

After completing site characterizations and conducting hearings, the Secretary is to recommend to the President the first site to be developed as a repository. This recommendation is to be accompanied by a final environmental impact statement in accordance with the requirements of the National Environmental Policy Act as modified by Section 114(f) of the Act.

After a site is recommended to Congress for development as a repository, the State in which the site is located or the affected Indian tribe on whose reservation the site is located may submit, within 60 days, a notice of disapproval to Congress. This disapproval prevents the use of the site for a repository unless Congress passes a joint resolution approving the President's recommendation within the next 90 days of continuous session.

If the site designation becomes effective, the DOE is to seek, from the NRC, authorization to construct the repository. The Act requires that the application for this authorization be submitted not later than 90 days after the effective date of the site designation. When a construction authorization has been received from the NRC, the construction of the repository will begin.

The Act requires the promulgation of regulations by two other Federal agencies—the NRC and the Environmental Protection Agency (EPA). The NRC is required to issue technical requirements and criteria to be used in approving or disapproving DOE applications for the construction and operation of repositories; these regulations have been issued as 10 CFR Part 60. The EPA is required to promulgate generally applicable standards for protecting the public from the radioactive material in repositories; these regulations (40 CFR Part 191) have been released in draft form for public comment (47 FR 58196). Both sets of regulations were used in developing the DOE siting guidelines (see also Sections II.A and III.A).

To provide the information base needed for informed decisions in carrying out the repository program, the Act requires the Secretary of Energy to prepare a comprehensive mission plan. The topics covered in the mission plan are to include the information needed for the siting and construction of repositories; the significant results of research and development programs, and their implications for each of the host rocks being considered; the financial, political, legal, or institutional problems that may impede the implementation of the Act; the adverse economic and other impacts that may result from the development of a repository; and the siting guidelines. A draft of the mission plan (2), dated April 1984, was issued for review and comment by the States, affected Indian tribes, the NRC, other Government agencies, and the public. The DOE is now in the process of reviewing the comments that have been received. Once finalized, the mission plan will be submitted to Congress in accordance with the requirements of the Act.

B. The DOE Siting Process

Before the Act was passed, the Federal Government had been carrying out a program for the development of geologic repositories. Directed primarily by the DOE and its predecessor agencies, the program had begun about three decades earlier. The Act established a process for the siting of repositories by integrating the then-existing DOE siting program into its requirements and procedures. To help the reader understand how the guidelines will be used, this section explains an important part of the program—the siting process—as it and the plans for it now stand, after modification by the Act and the consultation process.

In seeking sites for radioactive-waste repositories, the DOE divides the siting process into the following phases: (1) screening, (2) site nomination, (3) site recommendation for characterization, (4) site characterization, and (5) site selection (recommendation for development as a repository).

1. The Screening Phase

During the screening phase, the DOE identifies potential sites for characterization. This phase provides the information needed for judging which of these sites appear to justify the investment in characterizing them.

a. *General description.* The screening phase may consist of up to four stages, each of which narrows to a land unit of smaller size:

(1) A survey of the Nation or geologic provinces, narrowing to regions.

(2) A survey of the regions, narrowing to areas.

(3) A survey of the areas, narrowing to locations.

(4) A survey of the locations, narrowing to sites.

Screening can begin with one or more of the 17 physiographic provinces identified in the contiguous 48 States. The landforms in a province possess similarities resulting from corresponding similarities in the geologic and hydrologic processes and conditions throughout the province. Regions are normally smaller than provinces, but may also extend across several States. The sizes of areas, locations, and sites are not exact. Areas encompass hundreds to thousands of square miles, and locations are typically tens to hundreds of square miles. While a location may be large enough to contain several sites, only one potential site is usually identified in a single location.

During the early screening stages, it may be necessary to divide a particularly large geographic unit and identify an intermediate set of smaller units before proceeding to the next stage. A geographic stage may be deleted if the early survey reveals that smaller land units are obviously suitable for further study. For example, in a search for suitable salt domes, which are discrete geologic formations, the completion of regional surveys led next to the study of specific individual salt domes and their environs, rather than to some undifferentiated general area of hundreds to thousands of square miles.

Within each screening stage, the DOE identifies as many potentially suitable land units as judged to be necessary for an adequate sample to be studied in the next stage. Only the regions, areas, and locations believed most likely to contain suitable sites receive further study; all others are deferred. Although the deferred land units may contain suitable sites, studying every possible candidate would not be practicable. Even though some suitable sites may be dropped, this allows more thorough investigation of the remaining candidates.

Data for comparing regions, areas, and locations become increasingly detailed as progressively smaller land units are considered and as exploration and testing concentrate on them. National, province, and regional surveys are based on information available in the open literature—for example, national maps of faults, earthquake epicenters, land use, recent volcanic activity, and locations of potential host rocks. Areas, locations, and sites require more-thorough investigation, including field exploration, field testing, and increasingly refined laboratory analyses of rock and water characteristics. Finally, after the first three phases (screening, site nomination, and site recommendation for characterization) have been completed, site characterization will be performed to collect the data needed for a rigorous evaluation and comparison of candidate sites.

It is prudent that screening be conducted in a way that will lead to nominations and recommendations of sites in diverse geohydrologic settings and types of rock. Such screening increases the probability that sites suitable for characterization will be available even if studies should reveal a generic deficiency in a type of rock or a geohydrologic setting. The principle of seeking diversity in types of rock is a central theme of the siting provisions in the Act (Sections 112(a) and 113(a)); it has been part of the geologic repository program since its inception.

Before the Act was passed, the site screening conducted by the DOE evaluated and compared progressively smaller land units according to geologic criteria or other factors described in References 3 through 8. This process led to the identification of the potentially acceptable sites considered for the first repository. During the development of the Act, the status of the DOE's siting program, including the screening studies conducted to date, was well documented before Congress. Congress, as evidenced by its structuring of the Act, did not intend the DOE to revisit screening decisions that preceded the Act. Section 116(a) of the act requires that States containing "potentially acceptable sites" be identified within 90 days of the passage of the Act, but allows 180 days for issuing the siting guidelines. Future screening for the second repository will be based on the siting guidelines issued by this notice.

b. *Current status of screening.* At the time the Act was passed, the DOE was studing nine sites for the first repository and had begun regional surveys for the second repository. The nine sites for the first repository are in three different host rocks (basalt, salt, and tuff) and in six States; they are distributed as follows: two sites in the bedded salt of the Palo Duro Basin in Texas; two sites in the bedded salt of the Paradox Basin in Utah; two salt domes in Mississippi and one in Louisiana; a site in basalt in the Pasco Basin in Washington; and a site in tuff in the Southern Great Basin in Nevada. (For the bedded salt in Texas; the DOE identified two potentially acceptable sites of about 190 and 300 square miles each. In March 1984, the DOE issued, for public review and comment, a draft report on a screening study that narrowed the size of the two sites for further consideration to about 9 square miles for each location. The final report, *Identification of Sites Within the Palo Duro Basin,* was issued by the DOE in November 1984.) After the passage of the Act, in accordance with Section 116(a), the DOE, on February 2, 1983, formally identified these nine sites as being potentially acceptable. From these nine sites, in accordance with the Act, the DOE will nominate at least five sites and recommend no fewer than three for characterization.

The bedded-salt sites under consideration in Texas and Utah were found by the general siting process described above, beginning with national surveys and progressively narrowing to locations and sites. The salt domes were selected by a screening that began with more than 200 domes and ended with the three sites under consideration.

The selection of sites in basalt and tuff began on the basis of land use: the DOE began to search for suitable repository sites on some Federal lands where radioactive materials were already present; this approach was recommended by the Comptroller General of the United States (9) and a House resolution (10). Although land use was the beginning basis for this screening of Federal lands, the subsequent progression to smaller land units was based primarily on evaluations of geologic and hydrologic suitability. The studies began at roughly the area stage, and the screening has now progressed to two sites: the site in basalt is on the Hanford Site, and the site in tuff is adjacent to the Nevada Test Site.

The site-screening process for the second repository began with a national survey of crystalline rocks. This survey identified for further study near-surface and exposed crystalline rocks in 17 States divided into three regions: northeastern (Maine, Vermont, New Hampshire, New York, Pennsylvania, Connecticut, Massachusetts, New Jersey, and Rhode Island), north central (Michigan, Minnesota, and Wisconsin), and southeastern (Maryland, Virginia, North Carolina, South Carolina, and Georgia).

The site-screening process for the second repository is now in the regional phase. Being developed in consultation with the 17 States listed above, the screening approach is based on the siting guidelines published in this notice: first the disqualifying conditions in the guidelines are applied to eliminate land units and then the favorable and potentially adverse conditions of the guidelines are applied to identify preferred land units. The objective is to use the existing evidence to evaluate the favorability of each land unit, selecting the most favorable land units for further study.

2. The Site-Nomination Phase

The nomination process begins with the DOE examining the data for each potentially acceptable site to be sure that no site contains an obvious flaw that would disqualify it without further consideration. After this preliminary examination, the DOE begins its more-detailed evaluation by grouping the potentially acceptable sites according to the geohydrologic settings in which they are located. Choices among sites require comparisons that can be made more easily and accurately when the sites are in similar settings than when they are in dissimilar settings: the significance of differences among settings is more difficult to determine than the significance of differences among sites in the same setting. The grouping therefore places the subsequent siting choices on a basis that is technically more defensible.

After a comparative evaluation of all the sites within each setting, the DOE will select a preferred site within each setting. If fewer than five settings are available, the DOE will select additional sites from settings containing more than one site, as needed to obtain the required number of sites for nomination. The sites selected by this process will be the sites considered for nomination; each will be subjected to two separate evaluations. The first evaluation will be based on the siting guidelines that do not require site characterization for their application; it will focus on the suitability of the site for development as a repository, considering activities from the start of site characterization through decommissioning. The second evaluation will be based on the guidelines that do require site characterization for their application; its objective will be to establish that the site is suitable for characterization—that is, suitable for further study.

The Secretary will nominate no fewer than five of these sites. Each site nomination is to be accompanied by an environmental assessment, which must include a number of evaluations and descriptions listed in the Act and differs in procedure, format, and content from an environmental assessment prepared under the National Environmental Policy Act of 1969. For the nine sites identified as potentially acceptable for the first repository, the DOE has held the required public hearings in the vicinity of the sites to inform residents of the proposed nomination and to solicit and receive any recommendations on issues to be addressed in the environmental assessment as well as the site-characterization plan.

The environmental assessments will report the analyses made in the nomination steps described above. They will describe the bases on which the decisions were made, including the results of preliminary performance assessments, with emphasis on the natural barriers, for each site. In addition, each will include a summary of how the potentially acceptable sites were selected. A chapter common to all the assessments will contain a comparative evaluation of the sites considered for nomination.

The environmental assessment for each site being considered for nomination will be made available in draft form for public comment. After the final environmental assessments have been prepared, the Secretary will select at least five sites as suitable for characterization and, before nominating a site, will notify the Governors and the legislators of the States in which the sites are located or the governing body of any affected Indian tribe, as appropriate, of the nominations and the basis for the nomination. The Secretary will publish in the **Federal Register** a notice specifying the sites nominated and announcing the availability of the final environmental assessments for those sites.

3. The Site-Recommendation Phase

The site-recommendation phase will occur subsequent to site nomination, when the Secretary recommends to the President that three of the nominated sites be characterized as candidate sites. The decision to recommend a site will be based on (1) the available geophysical, geologic, geochemical, and hydrologic data (unless the Secretary certifies, pursuant to Section 112(b) (3) of the Act, that such available data will not be adequate to satisfy applicable requirements of the Act in the absence of further preliminary borings or excavations); (2) other information; and (3) the associated evaluations and findings reported in the environmental assessments. The decision will also consider the diversity of geohydrologic settings, the diversity of rock types, and, after the first repository, regionality, as specified by §§ 960.3-1-1, 960.3-1-2, and 960.3-1-3, respectively, of the implementation guidelines (see Section IV.B).

4. The Site-Characterization Phase

Site characterization will occur only at the sites recommended to, and approved by, the President. It will involve studies that are much more detailed than those conducted during the screening phase. As already discussed in Section I.B., the DOE will develop a site-characterization plan for each of the three sites selected for characterization.

During site characterization, the DOE will collect detailed information on the geologic, hydrologic, and other characteristics that determine compliance with the siting guidelines requiring site characterization for their application. Standard geophysical tests and exploratory drilling from the surface will continue throughout site characterization. For subsurface investigations, exploratory shafts will be constructed to the depth at which a repository would be built. Limited subsurface excavations (tunnels and rooms) for testing purposes will be made in the host rock in the immediate vicinity of the shafts. The shafts will be large enough to allow people and test equipment to be transported from the surface to the rooms. The shafts, tunnels, and rooms will allow detailed study of the host rock, including lateral exploratory drilling. A variety of tests will be performed in these underground facilities, including, for example, measurements of in-situ stress and permeability and heat-transfer experiments. Every 6 months, the DOE will report to the NRC and to the affected States and Indian tribes on the nature and the extent of the site-characterization activities and the information obtained from these activities.

In parallel with site characterization, the DOE will collect additional information about other aspects of the site. This activity, informally called site investigation, will be carried out in order to establish compliance with the guidelines that do not require site characterization (e.g., demographic, socioeconomic, and ecological characteristics) and to comply with the National Environmental Policy Act of 1969.

5. The Site-Selection Phase

When site characterization is completed, the site-selection phase will begin. During this phase, the sites that have been characterized will again be evaluated to determine whether they are suitable for the development of a repository. As required by Section 114(a) of the Act, a comparison of these sites will be reported in an environmental impact statement.

An important part of this analysis will be a detailed performance assessment; that is, for each site, the DOE will predict the effects of a repository as an entire system, during the time it is open for the emplacement of waste and after it has been closed. This assessment will evaluate the responses of the repository to the conditions that might affect its performance: natural events and processes, human actions, and the interactions between the waste and the repository. In the entire process of narrowing the number of potentially acceptable sites to one, this phase will be the first time it is possible to conduct such a complete performance assessment. This assessment requires the detailed information that can be obtained only during site characterization.

Before preparing a draft environmental impact statement the DOE will hold a scoping meeting in the vicinity of each site to receive comments on the issues that should be addressed. The draft environmental impact statement will be released for public review and comment. After preparing a final environmental impact statement, the Secretary will recommend that the President approve one of the sites for development as a repository. This environmental impact statement will be submitted to the President and to the public as part of a comprehensive statement of the basis for this recommendation. This statement will also contain specific technical material and comments by outside parties (Federal agencies, States, and affected Indian tribes), as required by the Act.

If the President approves the recommendation, he will recommend the site to Congress, and the DOE will have completed its part of the site-selection phase. The remainder of the process of obtaining final approval of the site and final authority for constructing a repository was described above in Section I.A. The DOE's schedule and cost estimates for the repository program are presented in the draft mission plan (2), which was released for review and comment in April 1984.

II. Development of the Guidelines Through Consulation, Public Comment, and NRC Concurrence

After explaining the original basis for the guidelines, this section discusses the process of consultation and comment as well as NRC concurrence. It also summarizes the major changes that resulted from these processes.

A. Basis for the Proposed Guidelines

After the Act was passed, the DOE assembled a task force of program experts to prepare proposed guidelines.[3] The task force began by considering the criteria used earlier in the National Waste Terminal Storage (NWTS) Program, including its own program objectives, system performance criteria, and site performance criteria (3,4); other sets of criteria defined for geologic repositories by the National Academy of Sciences (5), the International Atomic Energy Agency (6), and earlier programs in the United States (7,8); advance information made available by the NRC (11); and the requirements of the Act.

Requirements for the content of the guidelines are given in Section 112(a) of the Act. The guidelines are to specify "detailed geologic considerations that shall be primary criteria" for site selection; the Act also requires the guidelines to specify "factors that qualify or disqualify any site from development as a repository" and lists the factors to be included.

In developing the proposed guidelines, great care was taken to make them compatible with existing applicable regulations (12,13) and with the regulations that had been recently proposed by the NRC and the EPA concerning the disposal of high-level radioactive waste and spent nuclear fuel in geologic repositories. The NRC had by then nearly completed the pertinent technical criteria (14), and the EPA had issued, for public comment, proposed environmental standards (15). The proposed guidelines referred frequently to these criteria and standards through direct quotations and paraphrasing.

B. Consultation and Public Comment

Section 112(a) of the Act requires that, before issuing siting guidelines, the DOE (1) consult with the Council on Environmental Quality, the Administrator of the Environmental Protection Agency, the Director of the Geological Survey, and interested Governors and (2) obtain the concurrence of the NRC. To comply more effectively with these requirements, the DOE developed the guidelines through a notice-and-comment procedure that enhanced the opportunity for general public participation. On February 7, 1983, the proposed guidelines were published in the **Federal Register** (48 FR 5670) for public review and comment. The notice that accompanied the publication specified a 45-day public-comment period ending on March 24, 1983. The formal comment period was subsequently extended (48 FR 8269) to April 7, 1983, in response to numerous requests for additional time.[4]

In addition to publishing the proposed guidelines in the **Federal Register** of February 7, 1983, the DOE specifically solicited review and comment by mailing copies of the guidelines to the Governors of the 6 States previously identified as having potentially acceptable sites for the first repository (Louisiana, Mississippi, Texas, Utah, Nevada, and Washington) and the 17 States containing crystalline-rock formations being studied for the second repository; to interested Federal agencies; to more than 4000 individuals who had previously commented on, or inquired about, various aspects of the NWTS Program; and to approximately 200 public-interest and consumer groups.

During the public-comment period, the DOE held a series of regional public hearings to receive comments on the guidelines. These hearings were held in Chicago, Illinois, on March 4, 1983; in New Orleans, Louisiana, on March 7; in Washington, D.C., on March 10; in Salt Lake City, Utah, on March 14; and in Seattle, Washington, on March 21. Record transcripts were prepared for all of the hearings, and the panels that had conducted the hearings prepared summary reports for DOE review.

To explain and discuss the guidelines, the DOE staff met individually with officials from the six States with potentially acceptable sites. These consultations included meetings in Louisiana on February 25, 1983, in Mississippi on March 3 and March 25, in Utah on March 3, in Texas on March 18, in Nevada on March 23, and in Washington State on March 25. Also, on February 10, 1983, a group meeting with representatives of interested crystalline-rock states was held in Chicago to discuss the provisions of the Act as well as the proposed guidelines.

During this period of comment and consultation, the DOE received 119 written replies containing about 2000 separate comments; at the 5 public hearings, 57 persons provided oral comments. Among the commenters were private citizens and representatives of Federal, State, and local governments; Native American groups; and organizations that could be classified as special-interest or public-interest groups.

Near the end of the comment period for the proposed guidelines of February 1983, the DOE reconvened the task force that had developed the proposed guidelines. After categorizing and analyzing the comments, the task force drafted a set of alternative guidelines and a comment-response document (16) that summarized the comments, discussed the issues raised in the comments, and showed how the comments had been addressed in the alternative guidelines.

The interested States (i.e., the States containing potentially acceptable sites and the States containing the crystalline-rock formations under consideration for the second repository) had commented that they needed more than the notice-and-comment procedure if the consultation afforded by the Act were to meet their needs. Therefore, on May 11, 1983, the DOE sponsored a plenary consultation meeting with the interested States to set up a framework for continued consultation. At this meeting, held in Dallas, Texas, the States expressed a strong desire for additional opportunities to comment on the guidelines. To accommodate this request, an expanded consultation program was developed; it was structured around consultation meetings with the individual States and a plenary session when the guidelines neared their

[3] As described in Section II.B, several draft versions of the siting guidelines have been released: the proposed guidelines of February 1983 and the alternative guidelines of May 1983, both of which were issued for public review and comment; the revised guidelines of August 1983, which served as a basis for additional consultation with States, Indian tribes, and Federal agencies; and the revised guidelines of November 1983, which were sent to the NRC for concurrence. The final guidelines issued herewith reflect the NRC's final concurrence decision.

[4] The DOE was actually able to consider all late comments, some of which were not received until as late as May 20.

final form. The States requested that sufficient time be allowed for the review and that additional opportunity for public involvement be provided. On May 27, 1983, copies of the draft comment-response document and the alternative guidelines were forwarded to the States and Federal agencies.

The DOE also made these documents available to the public for review and comment. A notice of availability, published in the Federal Register on June 7, 1983 (48 FR 26441), announced a 30-day comment period, the second such period in the development of the guidelines. The notice made it clear that these alternative guidelines were intended not to supersede the proposal of February 7, 1983, but rather to serve as an alternative to the guidelines originally prepared that would be considered in writing the final guidelines. Copies of the alternative guidelines were mailed to the persons and groups who had been on the mailing list for the proposed guidelines, to anyone who had asked to be added to the list, to those who had submitted comments on the proposed guidelines, to participants in the public hearings on the guidelines, and to the participants in hearings held to scope the environmental assessments. Moreover, copies of both the draft comment-response document and the alternative guidelines were placed in 10 DOE reading rooms across the country as well as in 156 libraries in 23 States.

Individual consultation meetings were then scheduled with the six States containing potentially acceptable sites, and both individual and group meetings were scheduled with the States containing crystalline-rock formations. The purpose of these meetings was to discuss the differences between the proposed guidelines and the alternative guidelines and to identify and discuss outstanding issues. The meetings were held on the following dates: Texas on June 27 and 28, 1983, Nevada on June 29, Mississippi on June 29 and 30, Washington on June 30, Louisiana on July 6, and Utah on July 8, Vermont on June 14, Maine on June 15, New York on June 16, Wisconsin on June 20, Michigan on June 21, and Minnesota on June 27. In addition, a group meeting attended by eleven of the crystalline-rock States was held in Columbus, Ohio, on June 29.

The DOE conducted similar consultation meetings with several Federal agencies: the Council on Environmental Quality (June 21), the U.S. Geological Survey (June 24), the NRC (June 26), the Department of the Interior (June 28), and the Department of Transportation and the EPA (June 29).

After these consultation meetings and the end of the second public-comment period on July 7, 1983, the DOE task force reconvened to analyze and consider the additional comments received. Some 75 written responses arrived during the second comment period; they contained about 900 separate comments. Revised guidelines that reflected the comments on both the proposed and the alternative guidelines were then drafted. In addition, the comment-response document which explains the disposition of comments on the proposed guidelines of February 1983, was prepared for publication in final form (16); it had been released in draft form on May 27, 1983.

On August 1, 1983, the revised guidelines were forwarded to the States for their information, and on August 19 a second plenary consultation meeting was held in Dallas, Texas, to receive comments on the remaining issues that were of general concern to the States. Modified as necessary in response to comments from the States, these revised guidelines of August 1983 were later sent to the States for their information and submitted to DOE management for review and approval. The DOE-approved guidelines were thus developed after two formal public-comment periods and two rounds of consultation with the interested States, including both individual and plenary sessions. Numerous changes were made to the guidelines in response to comments from the public, State consultations, and the NRC concurrence interactions, but, with respect to scope and issues, the guidelines being finalized here do not differ substantially from those that were initially proposed.

C. NRC Concurrence

On November 22, 1983, the DOE submitted the guidelines to the NRC for concurrence. At the same time, the DOE mailed copies to States and to more than 1200 persons and organizations on the guidelines mailing list; copies were also placed in DOE reading rooms and State libraries.

The NRC had earlier found (48 FR 39536) that its concurrence proceeding is not a rulemaking and hence did not require notice and opportunity for public comment. Nevertheless, in order to accommodate requests to structure the concurrence process on a notice-and-comment rulemaking and to crystallize the issues, the NRC decided to accept written comments and to conduct a public meeting on the siting guidelines. On December 15, 1983, the NRC described its decision-making process and set forth the procedural format for a public meeting on the siting guidelines (48 FR 55789). In this notice, the NRC scheduled the public meeting for January 11, 1984, and requested that any written comments on the guidelines be submitted to the NRC by January 9, 1984. At the public meeting on January 11, the period for receiving written comments on the guidelines was extended to February 1, 1984.

The NRC applied the following criteria in making its preliminary concurrence decision:

1. The siting guidelines must not be in conflict with 10 CFR Part 60.

2. The siting guidelines must not contain provisions that might lead the DOE to select sites that would not be reasonable alternatives for an environmental impact statement.

3 The siting guidelines should not contain provisions that are in conflict with the Act.

On March 14, 1984, the NRC announced (49 FR 9650) that, on the basis of these criteria, the NRC would concur in the siting guidelines provided that the DOE met the following conditions:

1. Amended the siting guidelines to recognize NRC's jurisdiction for the resolution of differences between the guidelines and 10 CFR Part 60.

2. Committed to obtain the NRC's concurrence on revisions to the siting guidelines that relate to NRC jurisdiction.

3. Revised the siting guidelines as follows:

a. Modified its use of high effective porosity to limit its use to those situations that could be considered as a favorable siting condition.

b. Committed to revise its siting guidelines on the unsaturated zone so that they are consistent with the final NRC amendments on the unsaturated zone.

c. Moved the favorable condition on ground-water with a high total-dissolved-solids concentration from § 960.4–2–1(b) to Section 960.4–2–8–1, where effects on natural resources are considered.

d. Did not frame its guidelines such that a 1000-year ground-water travel time (10 CFR 60.113) would be adjusted, particularly in the early stages of site selection.

e. Deleted the word "permanently" from its definition of "disturbed zone."

f. Clarified the meaning of "short-term" extreme erosion and revised the guidelines as appropriate.

g. Deleted the word "significant" from § 960.4–2–8–1(c)(2)) of the siting guidelines, where reference is made to "evidence of *significant* subsurface mining."

h. Modified the guidelines so that they are consistent with the Commission's definition of "anticipated" and "unanticipated" processes and events.

i. Modified the guidelines so that potentially adverse conditions would be considered if they affect isolation within the controlled area even though the condition may occur outside the controlled area.

4. Modified the siting guidelines to make clear that engineered barriers cannot constitute a compensating measure for deficiencies in the geologic media during site screening.

5. Specified in greater detail how the guidelines will be applied at each siting stage, including site nomination and characterization (for example, specified in the implementation guidelines which guidelines would be applied at each stage of site screening).

6. Supplemented the guidelines to indicate the kinds of information necessary for DOE to make decisions on the nomination of at least five repository sites and subsequently recommending three sites to the President for characterization.

7. Added additional disqualifying conditions to the guidelines with sufficient specificity to ensure that unacceptable sites are eliminated as early as practicable. Disqualifying conditions should be provided for those factors specified in Section 112(a) of the Act, including seismic activity, atomic energy defense activities, proximity to water supplies, the effect upon the rights of users of water, the location of valuable natural resources, hydrology, geophysics, proximity to populations, and proximity to components of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, and National Forest Lands.

In announcing its preliminary concurrence decision, the NRC invited public comment on the preceding conditions. Copies of all comments submitted to the NRC were provided to the DOE and considered in developing this final rule. The NRC also instructed its staff to meet with DOE representatives to discuss the NRC's conditions and the DOE's proposals for their resolution. Six meetings were subsequently held, beginning on March 14, 1984, and ending on May 3, 1984; these meetings were open to the public, which was invited to comment at the end of each meeting. To accommodate those interested in the transactions of these meetings, the DOE made copies of the transcripts or minutes of the meetings available to the public in the DOE public reading rooms.

The preliminary concurrence conditions and ensuing meetings between the NRC and DOE staffs resulted in a number of changes to the guidelines (see Sections III.A and IV.B). The guidelines, reflecting the DOE's response to the NRC's concurrence conditions, were forwarded to the NRC for its final concurrence on May 14, 1984, with copies mailed to the interested States, affected Indian tribes, and appropriate Federal agencies.

On June 11, 1984, the NRC's Executive Director for Operations submitted to the Commissioners a policy paper (SECY-84-233) proposing a final decision (concurrence) on the guidelines of May 1984. The Commission then scheduled a meeting on this subject on June 22, 1984. At this meeting, the Commissioners heard comments on the guidelines by several interested States and Indian tribes as well as a presentation by the DOE. The Commissioners then reviewed and discussed the issues raised about the guideline revisions made in response to the NRC's preliminary concurrence conditions. As a result of these discussions, the NRC and the DOE agreed to make three changes in the guidelines (see Section IV.B for more detailed discussions):

1. Revise § 960.1 of the guidelines to agree to submit to the NRC for its concurrence all future revisions of the guidelines rather than only the "revisions relating to NRC jurisdiction."

2. Delete from § 960.3-2-3, which specifies the procedure to be followed in recommending sites for characterization, the following sentence: "Such recommendation shall include a preliminary determination by the Secretary, referred to in Section 114(f) of the Act, that such sites are suitable for the development of repositories under the guidelines of Subparts C and D."

3. Revise § 960.3-1-5, "Basis for Site Evaluations," to clarify that, in considering engineered barriers for the purpose of obtaining realistic source terms, it is necessary to establish the sensitivity of the natural barriers to the engineered barriers.

The Commissioners then voted unanimously to grant concurrence on the guidelines submitted by the DOE on May 14, 1984, as revised at the June 22 meeting. In the formal statement of their final decision, dated July 3, 1984, and published on July 10 (49 FR 28130), the Commissioners concluded "on the basis of a review of the public comments, that the preliminary decision need not be modified nor is there a need to add new conditions" and that the DOE had "satisfactorily resolved the conditions set forth in the Commission's preliminary decision."

D. Major Changes in Guideline Structure and Format Resulting From the Comment, Consultation, and Concurrence Process

The consultation, comment, and concurrence process produced changes in the format and structure of the guidelines. These changes are discussed below. (See also Section III for responses to general comments on the guidelines.)

The commenters generally supported the structure of the alternative guidelines. After considering the comments received, the DOE task force decided to retain the structure of the alternative guidelines issued on May 27, 1983. The task force had altered the basic structure of the guidelines in response to many comments requesting an explanation of the relative importance of the various guidelines and the order in which they will be used. The revised organization separates the guidelines into two distinct sets governing the postclosure and the preclosure periods. This separation makes clear the differences in the roles played by the individual guidelines that pertain to the siting, construction, operation, closure, and decommissioning of a repository (preclosure guidelines in Subpart D) and by those that pertain to the long time periods after a repository is closed (postclosure guidelines in Subpart C). The reorganization allows the DOE—in evaluating safety, environmental impacts, socioeconomic effects, and costs—to clearly distinguish the unique concerns about a repository from the more common and more familiar concerns about constructing and operating large-scale mining projects and nuclear facilities. The reorganization thus emphasizes the unique mission of a geologic repository. As explained in Section IV.A, it also makes explicit the priorities that the DOE intends to assign to the guideline groupings in making siting decisions.

Another general change was made in response to comments on the alternative guidelines. As discussed in more detail in Section III, this change was a revision in format, particularly the addition of explicit qualifying conditions.

Other changes, made in response to a number of comments and the NRC's preliminary concurrence conditions, were to define more precisely the way in which the guidelines are to be applied. The directions for their application are given in the implementation guidelines (§ 960.3), which have been revised to satisfy the NRC's concerns and amplified with two new appendices. Section IV.B of this notice explains both the implementation process and how the DOE intends to apply the guidelines.

The changes described above revised the format of the guidelines, refined their structure, and clarified how they will be applied. They did not change the content or the meaning of the individual guidelines. Changes in content stemmed from the comments about individual guidelines or the NRC's preliminary concurrence conditions; they are addressed in the comment-response document (16) and in Section IV.B. However, throughout the guideline-development process, the scope of the guidelines and the issues associated with the guidelines remained substantially the same.

III. General Issues Raised in the Consultation, Comment, and Concurrence Process

Many of the comments on both the proposed and the alternative guidelines were highly specific, dealing with particular guidelines; these are discussed in the comment-response document (16) and in Section IV. Other comments were general, covering many or all of the guidelines, or they were directed at the consultation process itself; these comments are discussed below. Many of the comments, however, were concerned with issues that are not related to the guidelines; among them were issues that pertained to the geologic repository program, such as the need for additional research on waste disposal; questions about the properties of a specific rock type; and statements against the use of nuclear power plants. Since these issues lie outside the scope of the guidelines, they are not addressed in this notice.

A. General Comments on the Guidelines

The general comments on the guidelines were divided into five categories: the use of proposed EPA and NRC regulations, the vagueness and lack of specificity in the guidelines, the lack or inadequacy of qualifying and disqualifying conditions, the lack of weighting factors, and the lack of definition of the site-screening process. The sections that follow contain brief summaries of, and responses to, the comments received on both the proposed and the alternative guidelines as well as the NRC's preliminary concurrence conditions.

1. The Use of Proposed EPA and NRC Regulations

Many comments objected to the DOE's basing its guidelines on proposed NRC and EPA regulations. Some comments expressed concern that guidelines based on those regulations might be defective because the regulations had not yet been issued in final form. Others felt that the DOE should not use standards issued by other agencies but should develop the guidelines independently. The EPA and NRC staffs found the use of their proposed regulations in the DOE guidelines appropriate. Some commenters requested that the guidelines be made more explicitly consistent with the proposed EPA standards and with the NRC criteria and that they be modified in the future when the final EPA standards are issued.

Geologic repositories must be constructed, operated, and closed in accordance with the EPA and NRC regulations. The central fixture of both of these regulations is the chosen site; the NRC, through a licensing action that will permit repository construction, will make the ultimate decision on the technical adequacy of the site proposed by the DOE. A site is therefore the objective of the DOE siting program, and the guidelines could not guide the siting process without reference to every particular of that objective. The NRC criteria (10 CFR Part 60) have now been published in final form (17), and their compatibility with the guidelines has been verified by the NRC, which used absence of conflict with 10 CFR Part 60 as one of the criteria for concurrence. In the event of a conflict between the guidelines and either 10 CFR Part 60 or 40 CFR Part 191, these NRC and EPA regulations will supersede the guidelines and constitute the operative requirement in any application of the guidelines.

2. Vagueness and Lack of Specificity in the Guidelines

A large number of commenters felt that the guidelines were too vague to be useful. A nearly equal number requested more-specific wording and additional quantitative values; among them were numerous general suggestions for changes in the guidelines. Several commenters felt that the guidelines did not cover enough topics. Some, however, expressed satisfaction with the level of detail in the guidelines, feeling that site-specific numerical criteria are inappropriate in general guidelines that are to be used in various stages of the site-selection process and applied to the evaluations of different host rocks. A few suggested that rock-specific guidelines should be developed for each rock type under consideration, especially for the early stages of screening.

Several comments indicated that the alternative guidelines represented a significant improvement over the proposed guidelines in terms of specificity.

In developing the guidelines, there were two possible approaches: (1) to develop, for each guideline, numerical limits that must be met for a site to be acceptable or (2) to develop generic qualitative guidelines to be used as a basis for comparing sites.

The first approach would require setting numerical limits on the characteristics of a site—for example, on its geometrical configuration and the geologic, geochemical, and hydrologic characteristics of the host rock. This approach would disqualify sites with characteristics that fail to meet the limits; only sites that met the numerical limits would remain under consideration. Though appearing to sharply discriminate against unacceptable sites, such an approach would ignore the most important aspect of a repository—that is, the ability of its parts to work together.

For example, the time it would take radionuclides to travel from a repository to the accessible environment, once they were released from a waste package, depends on (1) the length of the path traveled; (2) the retardation of radionuclides, which depends, in a complex way, on the physical and chemical properties of the geologic environment; and (3) the velocity of ground-water flow, which in turn depends on the hydraulic conductivity, the hydraulic gradient, and the porosity of the geohydrologic system. In a host rock with a low retardation potential, a long path or a low velocity can provide long travel times and, hence, confidence that a site is safe. In a host rock with a more rapid flow, a long path or a high retardation potential can provide this confidence. No single numerical value for any one of these three features is either necessary or sufficient for safety; to determine whether a respository site is safe, the three features must be considered in combination.

As this simple example illustrates, the geologic, hydrologic, and geochemical conditions of a site will interact in affecting the performance of a repository. An assessment of the performance of a complete repository must take into account these and other conditions. A detailed assessment of this performance will not be possible until after site characterization, because the performance depends on many complex, interdependent conditions, such as the lengths of time the waste canisters can be expected to remain intact, the rates at which the waste might be leached from the waste form, and the rates of radionuclide transport discussed earlier. Independently establishing numerical requirements for parts of the site without recognizing that they are interdependent would severely limit the flexibility of the DOE in designing the most effective waste-isolation system and of the NRC in licensing it.

The DOE, therefore, selected the second approach—developing generic qualitative guidelines as a basis for comparing sites. The DOE believes that generic qualitative guidelines are most appropriate for comparing and evaluating sites that are in different geohydrologic settings and host rocks, especially where the features of each site must work together, as a complete system, to prevent the release of radioactive material. Comparative evaluations must therefore consider the interactive elements in coming to a definitive finding with regard to each feature or each guideline. To make the guidelines useful and directly applicable early in the siting process, the DOE identified conditions that qualify and disqualify sites, as well as conditions that are considered to be favorable and conditions that are considered to be potentially adverse. These four conditions are explained in Section IV.A.

Some commenters appeared not to realize that the general guidelines will be the basis for more quantitative analyses in the later phases of siting. The site-characterization plans to be prepared before sinking exploratory shafts at candidate sites will identify site-specific issues, derived from the guidelines, that affect the suitability of each site for development as a repository. Furthermore, an important basis for the final selection of a site for development will be detailed performance assessments (Section I.B.4), which will be fully quantitative evaluations of the ability of the characterized sites to meet the system guidelines.

3. Lack or Inadequacy of Qualifying and Disqualifying Conditions

Many commenters objected to the lack of explicitly labeled qualifying conditions in the proposed guidelines; many felt that the guidelines should contain more disqualifying conditions and that they should be strengthened. Others suggested that qualifying and disqualifying conditions should be stated in qualitative terms. The comments contained numerous suggestions for rewording these conditions and for adding new statements to them. Some comments indicated that each guideline should contain a specific disqualifying condition, and some suggested that the DOE state the inverse of the qualifying condition as a disqualifying condition. The comments revealed an apparent misunderstanding about the purposes of the qualifying and the disqualifying conditions.

In response to these comments, qualifying conditions were added for all guidelines, additional disqualifying conditions were developed, and the format was revised to indicate explicitly which conditions are required for the qualification of a site and which conditions would be disqualifying. To answer the questions raised in the comments and to help clear up the apparent misunderstanding, a discussion of the structure of the guidelines and the meaning of the conditions is presented in Section IV.A of this notice.

A request for additional disqualifying conditions with sufficient specificity to ensure that unacceptable sites are eliminated as early as practicable was one of the seven NRC preliminary concurrence conditions (see Section II.C). Specifically, the NRC asked that disqualifying conditions be provided for all the factors specified in Section 112(a) of the Act. All of the factors specified in the Act had been accounted for in the qualifying conditions, but, as explained in Section IV.A, these conditions cannot be used early in the siting process.

In developing the guidelines, the philosophy of the DOE had been to develop for system and technical guidelines qualifying conditions stating those conditions that a site must meet in order to be considered adequate in terms of that guideline. Failure to meet the qualifying condition of any guideline would disqualify a site. In addition, the DOE identified explicit disqualifying conditions that were considered to be so adverse as to disqualify a site without further investigation if they were present. The number of these very serious disqualifying conditions was limited. However, in view of the NRC's concurrence condition 7 and the continuing requests by the States and the public to include disqualifying conditions for at least each of the factors specified in the Act, the DOE reevaluated the factors in an attempt to develop additional applicable disqualifying conditions. As a result of this reevaluation and discussions with the NRC staff, the DOE added new disqualifying conditions for two postclosure guidelines (§ 960.4-2-7, Tectonics, and § 960.2-4-8-1, Natural Resources) and four preclosure guidelines (§ 960.5-2-4, Offsite Installations and Operations; § 960.5-2-6, Socioeconomic Impacts; § 960.5-2-10, Hydrology; and § 960.5-2-11, Tectonics). In addition, the DOE revised the disqualifying conditions for two postclosure guidelines (§ 960.4-2-1, Geohydrology, and § 960.4-2-6, Dissolution) and one preclosure guideline (§ 960.5-2-5, Environmental Quality). The specific changes are discussed in the section-by-section analysis of Section IV.B. Furthermore, 10 of the 17 disqualifying conditions included in the final guidelines can be applied at the first stage of the site-selection process; they are identified in *Appendix III to the guidelines.*

4. Lack of Weighting Factors

Among the comments that appeared most frequently were suggestions for a weighting system for using the guidelines. Many commenters felt that a weighting system would make it easier to review and control decisions made in the siting process. Many pointed out that some guidelines will be more important than others in evaluating sites and that to rank them according to priority would make the weighting explicit. Others suggested that the guidelines be grouped qualitatively—for example, into collections of primary and secondary importance. Still others warned against the ranking of general guidelines intended to cover interacting features of complex systems in diverse media.

The DOE agrees that a qualitative grouping may be useful in guiding the application of the guidelines at certain steps in the siting process. The implementation guidelines now specify steps at which particular guidelines are to be grouped according to primary and secondary significance as well as the order of importance to be assigned to the three groups of preclosure guidelines.

5. Lack of Definition of the Siting Process

Many commenters felt that the DOE had not explained its siting process well enough to make the proposed or alternative guidelines understandable. The comments contained a number of questions about the history of the siting process before the Act was passed; they also questioned its relationship to the process outlined in the Act.

Agreeing that further explanation of the siting process would be helpful, the DOE has provided it in two sections of this notice: Section I.B, which explains the process, and Section IV.B, which discusses the application of the guidelines during the siting process.

B. Comments on the Consultation Process

1. Adequacy of the Consultation Process

Many of the comments on the proposal of February 7, 1983, criticized the consultation process for the guidelines. Some said that consultation with the States and Federal agencies had not been adequate and had not begun early enough, and some stated that early consultation would have improved the proposed guidelines. One commenter suggested an additional series of hearings in States with potentially acceptable sites after final guidelines have been prepared. A number of commenters also requested specific details of the process the DOE intends to follow for consultation with the States during the implementation of the guidelines.

Many of the commenters complained that the time allowed for review and comment on the guidelines was too short, that the public had not been adequately notified of public hearings, that the location and the scheduling of the hearings were inconvenient, and that, before publishing final guidelines, the DOE should release for another round of public comment guideline revisions resulting from public comments on the proposed guidelines. Also raised were questions about the process of obtaining NRC concurrence and future revisions of the guidelines as allowed by the Act, especially revisions made to reflect possible changes in the EPA and the NRC regulations (see Section III.A.1).

The Act prescribed a time period within which the DOE was to issue final guidelines and a process for consulting on guideline development. As explained in Section II, the DOE greatly expanded this process to allow wide opportunity for review and comment on the draft guidelines and to provide for continued consultation with States and Indian tribes (see also the comment-response document (16) for more-detailed responses to the comments on consultation). The process to be followed for consultation with the States during the implementation of the final guidelines will be specified in the consultation-and-cooperation agreements that will be negotiated with the affected States and affected Indian tribes in accordance with the provisions of the Act.

The Act allows the guidelines to be revised as necessary. Such revisions will be made through a process of notice and comment in accordance with the Administrative Procedure Act. In response to the NRC's preliminary concurrence condition 2 (Section II.C) and concerns expressed during the NRC's meeting on June 22, 1984, the DOE has made a commitment in § 960.1, "Applicability," to submit all guideline revisions to the NRC for its review and concurrence before issuance.

2. Endorsement of the Alternative Guidelines

Several comments asked why the alternative guidelines of May 27, 1983, were attributed to the DOE-appointed task force and had not been endorsed by the DOE. Many of the comments stated that the alternative guidelines represented a very significant improvement over the proposed guidelines. Some requested that the DOE formally reissue the alternative guidelines as a DOE proposal and allow another full round of public comment. Many parties stated that the DOE's consultation process on the guidelines had greatly improved and expressed the hope that similar consultations would continue through all phases of the DOE's siting investigations for repositories.

The DOE wished to allow the task force the greatest flexibility in developing alternative guidelines that met the requirements of the Act and responded to the comments on the original proposal of February 7, 1983. Moreover, the DOE wished to involve the States and Act-designated Federal agencies in the development of the guidelines at the earliest possible time. Therefore, the alternative guidelines were provided to States and agencies for review and comment and were made available to the public as well. Because of the generally favorable comments from States, Federal agencies, and the public, the DOE used the alternative guidelines as the basis for preparing the guidelines that were submitted to the NRC for concurrence (see Section II for a more detailed discussion).

IV. Overview of the Guidelines

The process of consultation, comment, and NRC concurrence (Section II) led to revisions in the guidelines. This section explains the final guidelines in detail, giving the reasons for the choices that the DOE made in developing their form and content. In addition to the changes described in this section, many editorial changes were made in response to suggestions for making the guidelines clearer and easier to understand.

A. Structure of the Guidelines

The guidelines are presented in three major categories: implementation guidelines, postclosures guidelines, and preclosure guidelines.

The implementation guidelines govern the application of all other guidelines in the evaluation of sites and establish general rules to be followed during site screening, nomination, recommendation for characterization, and recommendation for repository development.

The postclosure guidelines govern the siting considerations that deal with the long-term behavior of a repository—that is, its behavior after waste emplacement and repository closure. These are the considerations most important for ensuring the long-term protection of the health and safety of the public.

The preclosure guidelines govern the siting considerations that deal with the operation of the repository before its is closed, while waste is being received and emplaced. These are the considerations important in protecting the public and the repository workers from exposures to radiation during repository operations. They are also the most important considerations in protecting the quality of the environment and in mitigating socioeconomic impacts, because most of the environmental and the socioeconomic effects of a repository will occur during its construction and operation.

The purpose of separating the preclosure and the postclosure guidelines is to make clear the differences in the roles played by these guidelines. This separation is consistent with the structure of the proposed EPA standards (40 CFR Part 191), which establish different radiological-safety objectives for the preclosure and the postclosure periods, and the NRC criteria (10 CFR Part 60), which are similarly separated.

Both the postclosure and the preclosure guidelines are divided into system and technical guidelines. The postclosure system guideline states broad requirements that are based generally on the objective of protecting public health and safety and the environment and are based specifically on applicable regulatory standards. The postclosure system guideline states such requirements for the repository system, and each of the corresponding postclosure technical guidelines specifies requirements for one or more elements of the repository system—the physical properties and physical phenomena at the site. The three preclosure system guidelines state broad requirements for three different systems. These systems include, in addition to some characteristics of the site and more engineered components, the people and the environment near the site. Each of the corresponding preclosure technical guidelines specifies requirements on one or more elements of those systems; these elements are defined in Section III.B.4. Both the postclosure and the preclosure technical guidelines specify conditions that would qualify or disqualify sites, and they specify conditions that would be considered favorable to potentially adverse.

Each technical guideline contains a *qualifying* condition. Taken together, these qualifying conditions are the minimum conditions for site qualification. A site will be qualified only if it meets all of the qualification conditions; no single qualification condition is sufficient to qualify a site. A site will be disqualified if site characterization shows that it fails to meet any one of the qualifying conditions. Failure to meet a qualifying condition can usually be determined only after site characterization and the concurrent investigations of environmental and socioeconomic conditions; qualifying conditions must generally be stated in terms of specifications that require analyses of the repository system, and data for such analyses will be available only after site characterization and investigation. Before site characterization, however, evaluations that compare sites will be able to reveal the relative potential of those sites to meet the qualifying conditions of the technical guidelines. The findings that can be made during various stages of the site-selection process are defined and listed in Appendix III to the guidelines.

Twelve technical guidelines also contain *disqualifying* conditions. Each describes a condition that is considered so adverse as to constitute sufficient evidence to conclude, without further consideration, that a site is disqualified. Almost all of the 17 disqualifying conditions pertain to conditions whose presence or absence may be verifiable at a site without extensive data gathering or complex analysis; ten of them can be applied in the first phase of the site-selection process (see Appendix III to the guidelines). Application of the disqualifying condition on ground-water travel time (§ 960.4-2-1) may, however, require data collected during site characterization. It is because of the intent that the qualifying conditions should be useful early in the siting process that the converse of each qualifying condition was not listed as a disqualifying condition.

The inclusion of the favorable and potentially adverse conditions is based on the NRC's 10 CFR Part 60. These conditions can be used to predict the suitability of a site before detailed studies of the site have been performed. They provide preliminary indications of system performance.

Although favorable conditions need not exist at a given site for that site to meet the qualifying condition, the existence of such conditions leads to an expectation that subsequent evaluations will yield enhanced confidence in a site's suitability. Similarly, the purpose of determining whether any potentially adverse conditions exist at a site is to provide an early indication of conditions that must be examined carefully before judging the acceptability of that site. Such examinations must evaluate the effects of other, possibly compensatory, conditions present at a site. Thus, a site that has most of the favorable conditions may be presumed likely to meet the system guidelines, while a site with many potential adverse conditions may not meet them.

By providing preliminary indications of system performance, favorable and potentially adverse conditions are intended to be used primarily in the screening phase of site selection, during the search for potentially acceptable sites. They will also help determine the most effective use of available resources for site investigation when those resources are limited. Some level of system evaluation may later be required to determine whether a potentially adverse condition so identified is actually adverse and, if so, to what extent it affects site suitability.

At some point, available evidence may be sufficient to conclude that a potentially adverse condition is, in fact, so seriously adverse as to support a conclusion that the related qualifying condition is not, and will not, be satisfied. In such a case, the site will be disqualified. For example, potentially adverse conditions related to the possibility of requirements for engineering measures beyond reasonably available technology may, upon sufficient study, be found to impose with certainty such extraordinary engineering measures and as a result cause disqualification.

In the guidelines of November 1983, the technical guidelines in both the postclosure and the preclosure sections were subdivided into smaller groups. The postclosure guidelines were organized into two groups: (1) guidelines for the conditions and processes that would be expected to affect the performance of a repository and (2) guidelines for potentially disruptive processes and events that, though not expected, might disrupt the repository. The first group was to be assigned greater importance in site evaluations.

This grouping and the hierarchy of importance were objectionable to the NRC because the grouping was not strictly consistent with the NRC's categories of "anticipated" and "unanticipated" processes and events. Furthermore the NRC was concerned that not all of the guidelines assigned to the second group (potentially disruptive processes and events) could be considered to be of secondary importance, and thus in the site-selection process the DOE may overlook "some site characteristics that are important to repository performance." In its preliminary concurrence condition 3(h), the NRC asked the DOE to make the postclosure guidelines consistent with the NRC's categories of "anticipated" and "unanticipated" processes and events. In response, the DOE, after evaluating the hierarchy of the postclosure guidelines, decided to delete the subcategories.

As a consequence, the postclosure guidelines are no longer ranked, but they continue to retain precedence over the preclosure guidelines. The elimination of ranking for the postclosure guidelines was acceptable to the NRC, which had stated in its preliminary concurrence decision that it "sees no explicit requirement for this or any other ranking" in the Act and that "the issue of ranking or ordering the guidelines will not materially affect NRC in carrying out its statutory responsibilities" (49 FR 9659). Furthermore, the NRC considers (49 FR 28135) that arguments for guideline ranking are motivated by the need for some assurance that the DOE's site-selection process will proceed in a "logical and verifiable fashion." The DOE's response to preliminary concurrence condition 5 provides such assurance, by specifying during which phase of the siting process specific guidelines are to be applied and the findings to be made in these applications. (See Section IV.B for a more detailed discussion.)

The preclosure guidelines are grouped into three categories, which separately address concerns about radiological safety; environmental impacts, socioeconomics, and transportation; and the ease and cost of repository siting construction, operation, and closure. These categories of guidelines are evaluated by different techniques, and the separation is intended to facilitate their application.

The organization of the guidelines, therefore, is intended to make clear how they can be used during the siting process. Early in the process, when data are few, the disqualifying conditions are to be applied to eliminate unsuitable land units, and then the favorable and potentially adverse conditions must be applied to the remaining land units to provide the best approximations of suitability. As more data become available, the qualifying conditions of the technical guidelines can be used as standards for approximating suitability. The process will culminate after site characterization and investigation, when enough data are available to reliably establish whether the system guidelines are met.

B. Section-by-Section Analysis

As explained in Section II, the DOE submitted the guidelines to two rounds of public review and comment. The first followed the publication of the proposed guidelines on February 7, 1983; the second followed the publication of the alternative guidelines on May 27, 1983. The comments received on the proposed guidelines were considered in developing the alternative guidelines; the disposition of these comments is discussed in detail in the comment-response document (16). Comments on the alternative guidelines were considered in developing the final guidelines, whose structure and format were adopted from the alternative guidelines. The resolution of these comments is discussed in the sections that follow, which also present the purpose and intent of each final guideline and describe the changes that resulted from the NRC concurrence process. Comments on the proposed guidelines of February 1983 are discussed here only when necessary to elucidate the development of the final guidelines.

1. General Provisions (Subpart A)

This section of the guidelines consists of the statement of applicability of the guidelines and the definitions.

Section 960.1 Applicability. As specified in Section 112(a) of the Act, the Secretary of Energy shall use these guidelines in evaluating the suitability of sites for development as repositories. The guidelines will be used for all suitability determinations made pursuant to Section 112(b) and preliminary suitability determinations required by Section 114(f).

In the November 1983 guidelines, this section stated that, in applying the guidelines, the DOE will resolve any inconsistencies with the Act, 10 CFR Part 60 and 40 CFR Part 191 "in a manner determined by the DOE to most closely agree with the intent of the Act." In its preliminary decision, the NRC pointed out that its interpretation of 10 CFR Part 60 is binding on the DOE and requested, in preliminary concurrence condition 1, the DOE to recognize the NRC's jurisdiction over the resolution of differences between the guidelines and 10 CFR Part 60. The DOE responded by revising Section 960.1 to acknowledge the jurisdiction of the NRC in this matter. Further, because of the necessity for any site selected by the DOE to ultimately comply with 10 CFR Part 60 and 40 CFR Part 191, in the event of a conflict between the guidelines and either 10 CFR Part 60 or 40 CFR Part 191, these NRC and EPA regulations will supersede the guidelines and constitute the operative requirement in any application of the guidelines.

In the guidelines of May 1984, the DOE also made the commitment, in response to the NRC's preliminary concurrence condition 2, to obtain the NRC's concurrence on revisions to the siting guidelines that relate to NRC jurisdiction. The DOE had always intended to submit guideline revisions to the NRC for concurrence but had not explicity stated this intention, assuming that, since it was required by the Act, submittal of revisions for NRC concurrence was understood.

The NRC had explained (49 FR 9650) that it would have jurisdiction to review the guidelines insofar as they might bear on the exercise of NRC responsibility under the Atomic Energy Act, the Energy Reorganization Act, the National Environmental Policy Act, and the Nuclear Waste Policy Act. In view of the broadness of this jurisdiction and comments made by the States at the June 22, 1983, NRC meeting, the Commission requested, and the DOE agreed, that all revisions of the guidelines would be submitted for NRC concurrence.

Section 960.2 Definitions. To clarify the intent of the guidelines, the DOE has included an extensive list of definitions. The sources of the definitions are the Nuclear Waste Policy Act of 1982; the NRC's 10 CFR Part 60 (17), the EPA's proposed 40 CFR Part 191 (15), Water-Supply Paper 1988 of the U.S. Geological Survey (18), and the *Glossary of Geology* of the American Geological Institute (19). Some of the definitions obtained from these sources were slightly modified to enhance clarity or ease of application. Where the NRC and the Act provided differing definitions, an attempt was made to incorporate the intent of both definitions. If a given term was defined differently by the NRC and a source other than the Act, the NRC definition was used for consistency and to facilitate future NRC reviews of siting and licensing documents. For terms that had not been previously defined, new definitions appropriate to the guidelines were formulated.

Many commenters complained that the terms "reasonable expectation" and "beyond the state of the art" were difficult to understand or to demonstrate. "Reasonable expectation" has been eliminated because the DOE has changed the approach to reaching a decision on suitability; instead of demonstrating reasonable expectation, the DOE will make a comprehensive evaluation of the compliance of the site with all guidelines.

"Beyond the state of the art" has been replaced with "reasonably available technology," which is defined to mean "technology which exists and has been demonstrated" or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time periods.

The term "disturbed zone" elicited a large number of comments, most of which questioned how this three-dimensional "zone" could be considered a part of a two-dimensional "area." Reference to the definition of a "controlled area," which specifically includes the underlying subsurface, should help clarify the issue. "Disturbed zone" had been defined to mean that portion of the controlled area whose physical or chemical properties are projected to change permanently as a result of the construction of the underground facility and the emplacement of heat-producing waste such that the resultant change of properties could have a significant effect on the performance of the repository. Thus the definition includes both mechanical disturbances, which will occur during construction and operation, and heat-induced disturbances, which will occur after closure. The definition of this term is important because the boundary of the disturbed zone (i.e., the boundary between the altered and the unaltered host rock) is the starting point in calculating the time of ground-water and radionuclide travel to the accessible environment. Excluded from the disturbed zone as defined in the guidelines are the shafts from the surface to the underground facility. Although they will be considered as potential flow paths for radionuclide travel, they are explicitly excluded from the definition of "disturbed zone" because they are not realistically the starting point for radionuclide travel. (The shafts will be sealed after closure, and the seals will be part of the engineered-barrier system.)

In its preliminary concurrence condition 9(e), the NRC requested that the word "permanently" be deleted from the definition of "disturbed zone' because the "disturbed zone," as defined in 10 CFR Part 60, is not limited to areas that have changed "permanently." The NRC was therefore concerned that the DOE might neglect transient changes that could have a significant effect on repository performance or that the DOE might make siting decisions on the basis of a disturbed zone that is different from that specified in 10 CFR Part 60. Since the purpose of the DOE's definition is accomplished by the NRC's definition in 10 CFR Part 60 and by the phrase "such that the resultant change of properties could have a significant effect on the performance of the geologic repository," the DOE agreed to delete the word "permanently."

The definitions of "accessible environment" and "controlled area" elicited approximately 20 comments. Because of the relationship between these two terms, they are discussed here in terms of concerns about the controlled area. The comments indicated considerable misunderstanding of the concepts and expressed concern about (1) the releases of radionuclides in the controlled area, both underground and on the surface; (2) the level or levels of control over access and future use; and (3) the extent of the controlled area (i.e., the distance from the underground facility to the accessible environment).

The concept of a controlled area was developed by the NRC in 10 CFR Part 60 to exclude incompatible activities before and after permanent closure: the outer boundary of the controlled area is the accessible environment. Radionuclide releases underground in the controlled area will be controlled by the waste package during its effective lifetime; after the package containment is lost, they are to be limited to the allowable rate of release from the engineered system (1 part in 100,000 per year). Containment by the waste package is required to be essentially complete during the first several hundred years, when most of the radiation and heat in the engineered-barrier system comes from the radioactive decay of fission products. The containment period and the low release rate after containment, combined with the retardation of radionuclide migration through the host rock and the surrounding geologic formations, will drastically limit the concentration of radionuclides that can reach ground-water and thus be transported to the accessible environment.

During operation, surface releases within restricted areas of the controlled area will be governed by 10 CFR Part 20, the NRC's standards for protection against radiation. Surface releases outside the restricted areas will be governed by 10 CFR Part 60, the NRC's criteria for geologic repositories, and 40 CFR Part 191, Subpart A, the EPA's environmental standards for waste management and storage.

Access to the surface facilities will be restricted (the "restricted area"). The controlled area will be subject to lesser controls. Outside the restricted area, activities that could affect the performance of the repository, such as deep drilling, will be prohibited, but surface activities could be permitted by the DOE. Additional information on site ownership and control is found in §§ 960.4-2-8-2 and 960.5-2-2. The size of the controlled area, at a given site, will depend mainly on the rate of radionuclide movement through ground-water and will be established on a site-by-site basis to ensure that releases to the accessible environment will not exceed those permitted by 40 CFR Part 191. It can extend to as much as 10 kilometers in any direction from the underground facility, but it need not be this large if the EPA standards can be met in a shorter distance.

Nearly 20 commenters requested particular definitions of "high-level waste." The definition of "high-level waste" was taken from the Act and is slightly different from the definition used by the NRC in 10 CFR Part 60 in that high-level radioactive waste is not considered to include spent nuclear fuel. The Act always refers to high-level radioactive waste and spent nuclear fuel separately. However, since the spent fuel transferred to the DOE for disposal will have been declared to be waste by its owners, such spent fuel is included in the broader category of "radioactive waste" that will be disposed of at the repository. For brevity, therefore, the terms "radioactive waste" and "waste" are frequently used in the guidelines to denote "high-level radioactive waste and spent nuclear fuel."

More than 20 new terms were defined to clarify the intent of the guidelines; many of these definitions were requested by commenters. Among them are geologic terms (e.g., "active fault" and "lithosphere"); geohydrologic terms (e.g., "confining unit," "ground-water flux," "ground-water travel time," "hydraulic gradient," and "hydraulic conductivity"); terms related to the performance of the repository (e.g., "cumulative releases of radionuclides," "expected repository performance," "geohydrologic system"); and terms related to the development and operation of a repository (e.g., "restricted area," "site characterization," "surface facilities," and "closure").

For consistency with revisions in the postclosure guidelines (Subpart C), the terms "characteristics and processes affecting expected repository performance" and "potentially disruptive process and events" were deleted. To clarify revisions of the implementation guidelines (Subpart B) made in response to the NRC's concurrence conditions 4 and 5, four terms were added: "application," "evaluation," "finding," and "source term." Also deleted from the definitions was the term "capillary fringe" because it is not used in the NRC's proposed modification to 10 CFR Part 60 for disposal in the unsaturated zone; the definition of "unsaturated zone" was modified accordingly.

2. Implementation Guidelines (Subpart B, Section 960.3)

Although the proposed guidelines discussed in general terms their application during siting, many commenters requested a more detailed description of the procedures to be used and a fuller discussion of a number of issues. Because of the numerous requests for a clearer, more specific discussion, the task force developed, for the alternative proposal of May 27, 1983, implementation guidelines that specified the procedures for applying the rest of the guidelines.

The comments on the implementation guidelines in the alternative proposal of May 27, 1983, included several that disagreed with particular provisions, but again many commenters requested additional clarification. The DOE therefore revised the implementation guidelines and prepared a description of the process by which they will be applied. That description is presented in this section, after a discussion of the NRC's preliminary concurrence conditions for the implementation guidelines.

Two of the comments on the implementation guidelines did not address any particular provision. One of these was concerned with the favorable and potentially adverse conditions: one commenter interpreted the implementation guidelines to require that the favorable and potentially adverse conditions be simply counted up to determine site suitability. This is not at all the intent. The mere presence of a potentially adverse condition requires an evaluation of its influence on ability to comply with the qualifying conditions of the pertinent system guideline and a determination that it is mitigated by related favorable conditions or some other site-specific factors. Such evaluations are not restricted to the form of simple counting since the significance of each of these conditions may be amplified or diminished by other site-specific conditions.

The second general comment was a request, from many States, that the guidelines (or later amendments) include a numerical (or equivalent) method for "computing" compliance with the guidelines and for the resulting site-recommendation decisions, thereby ensuring that future findings and decisions are "objective." The DOE has not found support in the technical community, in particular in consultation with the U.S. Geological Survey, for such a method nor has the DOE been able to determine the framework for a predetermined method that would be sufficiently complete to eliminate the exercise of judgment on the part of the Federal officials who will make these decisions after consultation with the States. The DOE does not believe that the performance of a system as complex as a repository site, taking the natural structures and systems alone, can be represented by arithmetic formulas without seriously distorting critical synergies among the component elements. The DOE has, in the guidelines, made an effort to provide guidance by prescribing the relative importance of subsets of the guidelines, with the postclosure guidelines being assigned primary importance.

In its meeting on June 22, 1984, the NRC requested the DOE to delete from § 960.3–2–3, "Recommendation of Sites for Characterization," the statement that the basis for the recommendation decision will include "a preliminary determination, referred to in Section 114(f) of the Act, that such sites are suitable for development of repositories." This statement had been added to the May 1984 guidelines in an effort to clarify the siting process, but several States objected that the provision could not be implemented before site characterization. The DOE agreed that the discussion of the preliminary determination was outside the scope of the guidelines and accordingly revised § 960.3–2–3 by deleting the above-mentioned statement.

Three of the NRC's preliminary concurrence conditions were related to the implementation guidelines: condition 4, which asked the DOE to clarify the role of engineered barriers in site evaluations; condition 5, which asked the DOE to specify in greater detail how the guidelines will be applied; and condition 6, which asked the DOE to indicate the kinds of information needed for decisions about site nomination and recommendation for site characterization. In response to these conditions, the DOE revised and expanded the implementation guidelines. The principal changes are discussed below. This discussion is followed by a detailed explanation of the revised implementation guidelines.

Summary of Revisions Made in Response to the NRC's Concurrence Conditions

Engineered barriers. In its preliminary concurrence condition 4, the NRC asked the DOE to modify the siting guidelines to make clear that "engineered barriers cannot constitute a compensating measure for deficiencies in the geologic media during site screening." Furthermore, during the public meeting held by the NRC on January 11, 1984, the EPA testified that, in making comparative performance assessments for potential sites, the DOE should assume that the performance of engineered barriers (i.e., waste packages and waste forms) is at least 10 times less effective than that required by 10 CFR Part 60 in order to compare the isolation capabilities of the sites.

The DOE had never intended that engineered barriers be used to compensate for site deficiencies. These barriers were mentioned in the guidelines because the EPA's proposed standards in 40 CFR Part 191 specify requirements for the total repository system, which includes engineered barriers. Furthermore, the role of engineered barriers as part of the total system is recognized by the NRC, which has established specific performance requirements for the waste package in 10 CFR 60.113. In response to comments on the alternative guidelines of May 1983 and to comments received during subsequent meetings with the States (see Section II), the DOE had revised § 960.3 in the November 1983 guidelines to clarify the role assigned to engineered barriers. However, the revision was apparently not explicit enough to satisfy the concerns of those who objected to the use of engineered barriers as compensating measures.

Therefore, to satisfy the NRC's condition 4, the DOE revised implementation guideline § 960.3–1–5 (formerly § 960.3–1–4) to state that in comparative site evaluations engineered barriers "shall be considered only to the extent necessary to obtain realistic source terms for site evaluations" and "shall not be used to (1) compensate for an inadequate site; (2) mask the innate deficiencies of a site; (3) disguise the strength and weaknesses of a site and the overall system; and (4) mask differences between sites when they are compared." Furthermore, to accommodate the EPA's proposal, the DOE added to this implementation guideline requirements about the assumptions to be used about engineered barriers in comparative evaluations, specifying that "a range of levels in the performance of engineered barriers" is to be used (the performance varying by at least a factor of 10 above and below the requirements of 10 CFR 60.113).

At the June 22, 1984, meeting of the NRC, the DOE agreed to further clarify the role assigned to engineered barriers in site evaluations (see Section II.C).

Application of guidelines at each siting stage. In its preliminary concurrence condition 5, the NRC asked the DOE "to specify in greater detail how the guidelines will be applied at each siting stage, including site nomination and characterization." The creation of a standard for determining the DOE's level of confidence in data supporting site nomination had also been raised by several commenters. Throughout the guideline-development process, the DOE had intended that each site would be evaluated against all guidelines in the siting stages applicable to the first or the second repository—that is, to apply all guidelines throughout the siting process. However, during the concurrence meetings, the NRC staff suggested that the term "apply" be used to mean "evaluate and make a finding against." After considering this suggestion, the DOE agreed that this definition would be helpful in clarifying the guideline-application process. This suggestion was implemented by preparing a new appendix (Appendix III) for the siting guidelines and revising the implementation guidelines, especially § 960.3–1–5, "Basis for Site Evaluations."

Appendix III specifies how the guidelines are to be applied at the principal decision points of the siting process: site identification as potentially acceptable, nomination as suitable for characterization or recommendation for characterization, and recommendation for development as a repository. In particular, this appendix specifies the types of findings that are to result from the applications of the disqualifying conditions and the qualifying conditions. Two levels of finding, one showing an increased level of confidence over the other, are specified for both the disqualifying and the qualifying conditions. For the disqualifying conditions, a level 1 finding (i.e., the evidence does *not* (or conversely, does) support a finding that the site is disqualified) must be made at the nomination stage, while a level 2 finding (i.e., the evidence supports a finding that the site is *not* disqualified and is *not* likely to be disqualified, or that the site is disqualified or is likely to be disqualified) must be made and supported at the time of recommendation for repository development (site selection). For the qualifying conditions, a level 3 finding (i.e., the evidence does *not* (or, conversely, does) support a finding that the site is *not* likely to meet the qualifying condition) must be made at the nomination stage, while a level 4 finding (i.e., the site meets the qualifying condition and is likely to continue to meet it or that the site cannot meet the qualifying condition or is unlikely to be able to meet it) must be made and supported at the recommendation for repository development.

Section 960.3-1-5 was revised (1) to delete the grouping of the postclosure guidelines into two categories (see Section III); (2) to clarify the role of engineered barriers in site evaluation, as already explained above; and (3) to make various editorial changes for greater clarity of meaning and intent. In its final concurrence decision, the NRC agreed that the DOE's additions and modifications satisfy the requirements of condition 5 and the revised guidelines describe an implementation process that "provides confidence that alternative sites will be selected in a manner that meets the requirements of the National Environmental Policy Act."

Kinds of information. The NRC's preliminary concurrence condition 6 states that the "DOE should supplement the guidelines to indicate the kinds of information necessary for DOE to make decisions on the nomination of at least five repository sites and subsequently recommending these sites to the President for characterization. . . ." Similar questions on the data to support nomination had been presented to the DOE by several commenters. The DOE agreed that such information would be helpful and in response added a new appendix (Appendix IV) and a new section (§ 960.3-1-4) to the implementation guidelines. The new section, "Evidence for Siting Decisions," is discussed in the subsequent explanation of the implementation guidelines.

Appendix IV specifies the types of information the DOE expects to be included in the evidence used for the guideline applications set forth in Appendix III at the time of site nominations as suitable for characterization. The appendix presents these information elements for each technical guideline; the types of information listed are considered to be the most significant for the evaluation of a site against that particular guideline. For example, for guideline § 960.4-2-5, Erosion, Appendix IV requires "a description of the structure, stratigraphy, and geomorphology of the site, in context with the geologic setting" and states that the types of information that would support this description would include "the depth, thickness, and lateral extent of the host rock and the overlying rock mass; the lithology of the stratigraphic units above the host rock; and nature and rates of geomorphic processes during the Quaternary Period."

Where necessary, Appendix IV allows the use of technically conservative assumptions or extrapolations of regional data to supplement the information collected for the site, since this stage of the site-selection process precedes site characterization. Furthermore, it is recognized that the specific information for the guideline applications set forth in Appendix III is expected to differ from site to site, both with regard to favorable and potentially adverse conditions and with regard to the sources and the reliability of the information.

Explanation of the Implementation Guidelines

The paragraphs that follow discuss the final implementation guidelines, which incorporate the DOE's responses to the NRC's concurrence conditions.

Siting provisions (§ 960.3-1). The implementation guidelines begin with five provisions for the siting process. The first three of these provisions (§§ 960.3-1-1 through 960.3-1-3) govern the efforts to find sites with a diversity of geohydrologic settings, a diversity of types of host rock, and, when siting the second repository, a regional distribution. These provisions are derived from the Act, which specifies that the guidelines are to require the Secretary to consider regionality and various geologic media.

The fourth siting provision (§ 960.3-1-4) resulted from the DOE's efforts to comply with the NRC's preliminary concurrence condition 6 and was developed after discussions with the NRC staff. It discusses the evidence (i.e., information, evaluation, assumptions, etc.) that is to be used to support the decisions that must be made in four of the five phases of the siting process—site identification as potentially acceptable, site nomination for characterization, site recommendation for characterization, and site recommendation for repository development. It is supported by a new appendix (Appendix IV), which, as explained above, gives examples of the types of information that will be used in the nomination phase.

Included in the provision for evidence is a discussion about the use of assumptions. Before site characterization is completed, preliminary assessments of the potential of a site to meet the qualifying conditions must necessarily employ judicious assumptions where definitive data are missing. Many commenters were concerned that consistent optimism in such assumptions would create benefits out of deficiencies in the scope of field testing and research undertaken by the DOE. Accordingly, § 960.3-1-4 only allows the use of assumptions that would tend to underestimate the ability of a site to meet the qualifying conditions. Such assumptions are commonly termed "conservative" because they are chosen in order to minimize the possibility that later findings will prove the assumptions to be wrong. This is a commonly used approach in engineering and in scientific predictions. Where some data exist, a statistical range of uncertainty may constrain the latitude of such assumptions. Even where no direct date exist, it is often possible to establish a sufficiently conservative range of values by examining comparable situations in nature or by inference from related phenomena. Thus, there are techniques for establishing realistically conservative assumptions that allow reasonable decisions to be made in the face of uncertainties. It should be emphasized, however, that one of the primary focuses of this guideline is to ensure, to the extent practicable, that analyses performed in the absence of complete data (as will necessarily often be the case) do not produce erroneous projections about the suitability of a site.

At several steps in the siting process the guidelines will be used in assessing individual sites and in comparing sites with one another. The fifth provision, § 960.3-1-5, describes the basis on which these evaluations will be made. This criterion begins by assigning primary significance to the postclosure guidelines and secondary significance to the preclosure guidelines; this assignment is to be used in all the evaluations except those made during the screening phase of the siting process. This assignment of significance received general approval, but some commenters argued that equal significance should be assigned to postclosure and preclosure guidelines. The fundamental purpose of a geologic repository is to provide long-term isolation for radioactive waste in a manner that protects the health and safety of the public. That fundamental purpose will be achieved primarily by the site features related to the postclosure guidelines. The postclosure guidelines are accordingly given primary significance. The DOE recognizes that the preclosure guidelines govern highly important aspects of a repository, but during the siting process the postclosure guidelines are collectively to be given primary significance over the preclosure guidelines, taken together, because the long-term concerns about public health and safety must take precedence over concerns about preclosure effects, which will be temporary. Nonetheless, in order to qualify for repository development, a site must meet the qualifying conditions of all the guidelines.

The evaluation-basis provision of § 960.3-1-5 next establishes an order of importance for the technical guidelines in the preclosure categories. Unless it can be demonstrated to the satisfaction of the NRC that the repository will be safe during its preclosure phase, the repository cannot be built. For the preclosure period, the evaluation-basis provision therefore assigns highest importance to radiological safety. A secondary importance is assigned to the guidelines governing environmental quality, socioeconomic impacts, and transportation. The lowest order of importance is assigned to the guidelines governing ease and cost of siting, construction, operation, and closure.

Section 960.3-1-5 next specifies rules for evaluating individual sites. It requires that the evaluation of technical and system guidelines not be entirely separate. Because the repository must work as a system, an evaluation of the features governed by a technical guideline must retain some consideration of the contributions that those features make to the performance of the entire system. Similarly, an evaluation against a system guideline must include consideration of the technical guidelines accompanying the system guideline, and the evidence related to the system guideline. In recommending sites for the development of repositories, this evidence is to include analysis of expected repository performance and the likelihood of compliance with 40 CFR Part 191 and 10 CFR Part 60, in accordance with the postclosure system guideline.

The provision next gives rules for making comparisons among sites. These comparisons are to be based on evaluations against system guidelines to the extent allowed by the data; they are intended to allow comparative evaluations of sites in terms of the capabilities of the natural barriers for waste isolation. When adequate data are not available for an evaluation of the system guideline, the comparison is to use the technical guidelines, assigning primary significance to the postclosure guidelines and following the orders of importance listed above for the preclosure guidelines.

Section 960.3-1-5 specifies that comparative site evaluations are to place primary importance on the natural barriers of the site. This specification responds to many comments that unrestrained assumptions about engineered barriers could make all sites appear adequate and mask inherent differences between the sites. Therefore, in evaluations against the postclosure guidelines, engineered barriers are to be considered only to the extent necessary to obtain realistic estimates of the amounts and kinds of radionuclides that would constitute a release of radioactivity (i.e., the source term). Included in the provision are specifications for the treatment of engineered-barrier performance in comparative evaluations.

The evaluation-basis provision ends with rules for site comparisons performed to support the last phase of the siting process—the recommendation of sites for the development of repositories. It specifies that these comparisons will consist of two evaluations that predict radionuclide releases for 100,000 years after repository closure and explains how they are to be conducted.

Siting process (§ 960.3-2). The guidelines will be used to evaluate sites at several points in the siting process, which is explained in detail in Section I.B. This part of the guidelines prescribes the procedures to be followed at each step and is summarized below.

Screening for potentially acceptable sites (§ 960.3-2-1). The implementation guideline governing this step places requirements on the screening to be conducted during the selection of a site for the second repository; the guideline states that this section is not applicable to the first respository site, for the reasons explained in Section I.B.1.

Nomination of sites as suitable for characterization (§ 960.3-2-2). The guidelines will next be applied in several steps during the nomination of sites as suitable for site characterization; the nomination process itself is explained in Section I.B.2.

In the first of these steps, the DOE will examine each of the potentially acceptable sites to determine whether any should be disqualified without further consideration. The guideline governing this step (§ 960.3-2-2-1) requires that the DOE evaluate each potentially acceptable site against each disqualifying condition in the technical postclosure and preclosure guidelines. Sites at which any disqualifying condition is present will be eliminated from further consideration. This requirement is provided so that the potentially acceptable sites for the first repository, which predate the guidelines, will be given a "fatal flaw" test before further effort is expended in evaluating them.

The next application during the nomination phase will occur after the DOE has grouped (Section I.B.2) the potentially acceptable sites according to their geohydrologic settings. The guideline covering this step (§ 960.3-2-2-2) requires that the DOE select a preferred site in each setting that contains more than one site; the DOE is to use the evaluation-basis provision (§ 960.3-1-5) in making the selections.

To accomplish this selection, the sites within a single setting will be compared with one another by using the postclosure and the preclosure technical guidelines. Because the sites in a single setting will necessarily have many similar features, not all those guidelines will discriminate among the sites. For example, sites in a single setting will probably satisfy equally well the favorable condition calling for hydrologic features that can be modeled. In selecting a preferred site, the DOE, in accordance with this governing guideline, will primarily evaluate the conditions specified in the guidelines that will discriminate among the sites. The discriminating guidelines in one setting will usually be different from the discriminating guidelines in another setting; a necessary part of the selection process will be the identification of discriminating guidelines in each setting where a selection will be made.

The group of preferred sites, along with the sites that are the only sites in their settings, will be the sites considered for nomination. The guideline requires that at least five sites be proposed; if fewer than five geohydrologic settings are available, the

DOE will select additional sites from settings that contain more than one site, as required to obtain the minimum of five sites.

The next two application steps in the nomination process require that the guidelines be separated into two groups: those that, in the language of the Act, "require site characterization as a prerequisite" for their application and those that do not require site characterization for that purpose.

After selecting the sites being considered for nomination, the DOE will evaluate the suitability of each of them for development as a repository. This evaluation will, as required by the Act, use the guidelines that do not require site characterization as a prerequisite for their application.

In the next step in the nomination process, the DOE will evaluate the suitability for characterization of each site being considered for nomination. This evaluation will use the technical and system guidelines identified as requiring characterization and will consider the favorable and potentially adverse conditions (Section IV.A) at each site. The evaluation will examine whether, on balance, the presence of such conditions affects significantly the ability of a site to meet the qualifying conditions and to avoid disqualification.

At this point in the nomination process the DOE will have identified a set of five or more sites for nomination; it will have evaluated the suitability of each of these sites for development as a repository and for characterization. The DOE will bring all of these results together in a summary comparative evaluation of the sites. The guideline governing this collection of results (§ 960.3–2–2–3) requires the DOE to summarize the information supporting the determinations made up to this point in the nomination process.

The actual nomination of a site as suitable for characterization must be accompanied by an environmental assessment (EA). The DOE will prepare an EA to accompany the nomination of each of the five or more sites; implementation guideline § 960.3–2–2–4 requires that this EA describe the decision process that led to the nomination of that site. The EA must also include other evaluations and discussions described in the Act and in the guidelines. The guideline also specifies that the draft EAs will be made available for public comment and that the governments of States and affected Indian tribes will be notified of such availability.

Implementation guideline § 960.3–2–2–5 prescribes procedures for the formal nomination of sites as suitable for characterization. This guideline calls for a determination of suitability for characterization. This determination is to be based on the information and analyses in the environmental assessments.

Recommendation of sites for characterization (§ 960.3–2–3). The next application of the guidelines will occur during the process of recommending sites for characterization. Under the Act, the Secretary of Energy will recommend no fewer than three sites for characterization for the first and the second repository. The recommendation decision is to be based on the available geophysical, geologic, geochemical, and hydrologic data (unless the Secretary certifies, pursuant to Section 112(b)(3) of the Act, that such available data will not be adequate to satisfy applicable requirements of the Act in the absence of further preliminary borings or excavations); (2) other information; and (3) he associated evaluations and findings reported in the environmental assessments. The guideline governing this step specifies a procedure for making the selection. It requires that the sites nominated for characterization first be considered in order of preference for characterization. The guideline requires next an application of the provisions for diversity of geohydrologic settings and rock types, and, for siting the second repository, the provision for regional distribution, as specified by §§ 960.3–1–1, 960.3–1–2, and 960.3–1–3, respectively, of the implementation guidelines. This application will determine a final order of preference for characterization.

Some States felt that the guidelines should not be used beyond the recommendation of sites for characterization of that, after site characterization, the licensing criteria should take effect. The DOE believes that this is not the intent of the Act and would create an illogical discontinuity in the siting process. As discussed earlier, under the "Use of Proposed EPA and NRC Standards," the standards of site suitability to be used by the licensing authority (NRC) are to be reflected in the guidelines so that siting and other program decisions will be consistent with these requirements. Section 114 of the Act provides that the "Secretary shall submit to the President a recommendation that the President approve such site for the development of a repository," where the site referred to is one of at least three candidate sites for which site characterization has been completed under Section 113(b) of the Act. Section 113(b) requires the site-characterization plan for each candidate site to include "criteria to be used to determine the suitability of such site for the location of a repository, developed pursuant to Section 112(a)." Section 112(a) is the section that requires the DOE to develop siting guidelines, and therefore the guidelines are intended to be used in deciding which among the characterized sites is to be recommended to the President, the Congress, and finally to the NRC for appropriate approvals.

Recommendation of sites for the development of repositories (§ 960.3–2–4). The final application of the guidelines to decisions made during the siting process will occur during the site-selection phase. Site characterization will then have been completed, and the DOE will select one site for development as a repository. The implementation guideline governing this selection requires that the DOE compare the characterized sites on the basis of the postclosure and the preclosure guidelines. It also requires the DOE to submit to the President and make available to the public a comprehensive statement of the basis for the selection, including an environmental impact statement.

Consultation (§ 960.3–3). Throughout the siting process the DOE will consult with designated officials of affected States and governing bodies of affected Indian tribes, as defined by the Act. This guideline prescribes that this consultation be carried out, defines procedures for responding to requests for information, and specifies that the DOE enter into binding written agreements in accordance with the Act.

The Department of the Interior commented on the prudence of consulting with Federal land managers as soon as the siting process considers lands in their jurisdiction. This comment was taken to have a wider validity and led to the inclusion of consultation with Federal agencies in the guideline on consultation.

Environmental impacts (§ 960.3–4). This guideline requires the DOE to consider environmental impacts throughout the site-characterization, site-selection, and respository-development process and to mitigate them to the extent practicable.

3. Postclosure Guidelines (Subpart C, Section 960.4)

The postclosure guidelines are designed to establish the performance objectives (system guideline) and technical conditions important to meeting those objectives (technical guidelines) for the repository system over the long term after permanent closure. The length of this postclosure time period has not been rigorously

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defined, although the proposed EPA standard (40 CFR Part 191) suggests that the major emphasis for ensuring waste isolation should be placed on the first 10,000 years after closure. The postclosure guidelines are structured to accommodate any time period ultimately adopted by the EPA and the NRC. Naturally, confidence in such predictions will diminish as predictions reach further into the future; however, the radiological toxicity of the wastes to be isolated also diminishes with time.

Section 960.4-1 Postclosure System Guideline. The postclosure system guideline requires compliance with those EPA and NRC regulations that are intended to ensure that the health and safety of the public and the quality of the environment will be protected until the radioactivity in the waste has diminished to safe levels.

Several comments on the alternative guidelines objected to the inclusion of engineered barriers in determining compliance with the system guideline, the objections being based on the concerns that engineered barriers would be used to compensate for inadequacies in natural systems and that the term "state of art" implies untested technology. The intent of including engineered barriers was not to compensate for an inadequate site. Rather, engineered barriers are intended to enhance the natural system's containment and isolation capacities to the extent that is practicable. This approach is consistent with the "multiple-barrier" approach endorsed by both the EPA and the NRC as a method of compensating for uncertainties in performance predictions. The multiple barriers consist of both natural-system components (e.g., the host rock, hydrologic conditions, and geochemical conditions) and engineered components (e.g., long-lived waste packages, relatively insoluble waste forms, repository seals and backfill materials that resist water movement). The inclusion of engineered barriers in system assessments is stipulated in both 10 CFR Part 60 and 40 CFR Part 191. The DOE agrees, however, that engineered barriers are secondary to the natural system with respect to long-term isolation. Consequently, the postclosure guidelines are premised explicitly on a recognition of the primacy of natural barriers and, as discussed above in regard to the implementation guidelines, site evaluations will consider engineered-barrier systems only to the extent necessary to obtain realistic source terms. The term "state of the art" is replaced by "reasonably available technololgy" (see discussion in Section IV.B.1).

Some commenters asserted that the guidelines should specify the manner in which performance assessments, probability estimates, uncertainty analyses, and risk assessments would be performed in complying with the guidelines. The DOE maintains that the development, validation, and implementation of those assessment techniques are outside the scope of these guidelines, whose purpose is to guide and direct the DOE's siting process rather than to prescribe analytical methods and procedures.

Several commenters expressed concern that repository-system failures could damage major ecosystems like the Great Lakes. Since the repository will have to comply with the release limits specified in the NRC criteria and the EPA standards, and the site will have to meet the siting guideline on environmental quality, such consequences cannot be reasonably postulated.

A corollary concern is that, since the proposed EPA limits apply at the accessible environment, significant contamination of subsurface rocks and ground water could occur within the controlled area. Some comments urged the inclusion of all ground water as part of the accessible environment, both inside and outside the controlled area, and suggested that a "zero release" standard be applied. In regard to the first concern, the NRC criterion (10 CFR 60.113) for releases from the underground facility will afford significant protection to subsurface areas outside the underground facility but inside the controlled area. In regard to the second concern, a ground-water system may provide very long times for transport to the accessible environment, and such a system is an important component of a multiple-barrier system. The importance of that barrier system and its components is recognized by both the NRC and the proposed EPA regulations, and hence the concept of the controlled area and the accessible environment was adopted by the NRC and proposed by the EPA. The "zero release" concept is an ideal objective that cannot be adopted as a standard because of the uncertainties in the predictions of postclosure performance and the long time periods that are of concern.

Several comments suggested that the guidelines actually state the requirements of the NRC and EPA regulations instead of merely referencing them. The final guidelines include two appendices (Appendix I and Appendix II) that summarize the central elements of those regulations that bear most directly on the system guidelines.

Some commenters cautioned the DOE on the need for consistency between the guidelines, the proposed EPA standard, and 10 CFR Part 60. Several of the commenters noted that the proposed guidelines did not appear to be consistent with the proposed EPA assurance requirements. Other commenters requested clarification regarding the respective roles of the DOE, the NRC, and the EPA. The DOE intends to ensure consistency between the guidelines and the NRC and EPA regulations for the disposal of high-level radioactive waste and spent fuel (see also Section III.A.1 and the discussion of "Applicability" in Section IV.B.1). Furthermore, should the final EPA standards include assurance requirements that appear to be inconsistent with the guidelines, the DOE will reevaluate the guidelines.

In regard to the roles of the three agencies, the EPA is charged with establishing general environmental standards for the protection of public safety and the environment outside the facility or site boundaries. The NRC is charged with establishing and implementing requirements for licensing the repository, which includes enforcing any applicable standards, including the EPA regulations, and with discharging the NRC's responsibilities under the National Environmental Policy Act of 1969. The DOE is charged with identifying, characterizing, and demonstrating the suitability of sites and developing and operating a repository consistent with these guidelines, the EPA standards, and NRC licensing requirements.

Several commenters requested the adoption of the ALARA (as low as reasonably achievable) concept in the system guidelines. They seem to have been looking for assurance that (1) the waste isolation provided by the geologic setting at the site will be weighted heavily in comparing alternative sites during the selection process and (2) the DOE will take reasonable measures to ensure that radiation exposures will be as low as is reasonably achievable. Both of these concerns will indeed be accommodated through the guideline-implementation process, in which public health and safety will be the primary consideration. However, for postclosure releases, the ALARA concept as such cannot be implemented, because the potentially affected populations are not known; the releases may not occur for tens of thousands of years. Estimates of the integrated population doses that would be required to implement the ALARA criterion and applying an appropriate cost-benefit (e.g., dollars per man-rem) factor for releases predicted far into the future would be highly speculative. Therefore, the ALARA concept, per se, will not be rigorously applied for the postclosure phase.

A number of comments stressed the importance of using system-analysis techniques in assessing compliance with the guidelines rather than treating each parameter (e.g., geohydrology) independently. Conversely, several commenters believed that too much importance was placed on the system guideline—that each technical factor should be considered separately. The final implementation guidelines specify that comparisons of sites are to be based on the system guidelines. Thus, both the sufficiency of individual technical factors and the system-analysis concept are taken into account.

Some commenters suggested that the system guidelines should require postclosure monitoring. The issue of postclosure monitoring will be addressed by the DOE and the NRC at several points from the time of repository licensing through the time of permanent closure. If the state of technology at those future times is such that useful information could be gained, monitoring may be included for confirmatory or research purposes. However, postclosure monitoring is not considered to be a key factor in site selection.

Finally, in response to the NRC's preliminary concurrence condition 4 regarding the role of engineered barriers (see Section II.C and the discussion of implementation guidelines in Section IV.B.2), the postclosure system guideline was revised to clearly separate the roles assigned to the geologic setting at the site and to the engineered barriers.

Section 960.4-2 Postclosure Technicial Guidelines. The postclosure technical guidelines specify qualifying, favorable, potentially adverse, and, in five guidelines, disqualifying conditions on the characteristics, processes, and events that may affect the performance of a repository after closure. Those characteristics, processes, and events have been identified through numerous evaluations by technical experts from several countries and adopted in various forms by agencies and institutions charged with waste-isolation responsibilities, including the Nuclear Regulatory Commission, the National Academy of Sciences, and the International Atomic Energy Agency.

In response to the NRC's condition 3(i), the introductory paragraph for the postclosure technical guidelines was revised by adding the statement that potentially adverse conditions that affect waste isolation within the controlled area will be considered even if they occur outside the controlled area.

Section 960.4-2-1 Geohydrology. The geohydrologic technical guideline is focused on the present and expected characteristics of the geohydrologic setting of a site, which must be compatible with waste containment and isolation. The most likely mechanism for the release of radionuclides from a repository to the accessible environment is transport by ground water. For this reason the geohydrologic conditions at a site must be adequately understood; furthermore, future conditions must be reliably predicted and upon evaluation must be shown to be compatible with waste isolation.

It is obvious from the numerous and thoughtful comments on the geohydrology guidelines that most reviewers believe geohydrology is a critical factor in the siting process. Most of the comments addressed the disqualifying condition and the potentially adverse conditions.

Twenty-four commenters were critical of the disqualifying condition pertaining to the 1000-year travel time from the disturbed zone to the accessible environment. This proposed condition stated that a site would be disqualified if the "expected pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment is less than 1000 years, unless the characteristics and conditions of the geologic setting, such as the capacity for radionuclide retardation and the ground-water flux, would limit potential radionuclide releases to the accessible environment to the extent that the requirements specified in § 960.4-1 could be met." The criticisms of this disqualifying condition can be grouped into four groups: (a) the "fastest" travel time should be specified instead of the "average" travel time, (b) the statement needs an explanation of how travel time will be calculated, (c) the 1000-year period should be increased to 10,000 years, and (d) the "unless" clause providing for the consideration of radionuclide retardation and ground-water flux should be deleted and renders the statement of the disqualifying condition ambiguous.

The question of "fastest" vs. "average" travel time is a complex issue that involves not only travel time but also the amount of water that moves to the accessible environment. Conceivably there could be situations where very minute amounts of water would travel at the fastest rate, whereas the real concern is the travel time of large amounts of water. The DOE has chosen to clarify this question by using the nonspecific words "travel time" in the disqualifying condition and by explaining how travel time will be calculated in the definition of ground-water travel time (§ 960.2). The definition provides for the consideration of the rate at which most of the water moves.

The 1000-year travel time in the disqualifying statement is consistent with the NRC criterion on travel time to the accessible environment. In addition, 1000 years is a sufficient period for most of the fission products to decay to generally innocuous levels of radiotoxicity.

The "unless" clause pertaining to retardation and ground-water flux in the disqualifying statement on travel time to the accessible environment attracted comments arguing that the clause made the rest of the statement ambiguous and violated the intent of having the 1000-year travel time as an absolute condition. It should be noted that the NRC criteria provide an opportunity for exceptions to the 1000-year travel time. The DOE believed it is appropriate to provide for exceptions, particularly in cases where the ground-water flux is small or where processes promoting radionuclide retardation are important in providing for excellent isolation capabilities. However, the NRC, in its preliminary concurrence condition 3(d), stated that the "DOE should not frame its guidelines such that a 1000-year ground-water travel time (10 CFR 60.113) would be adjusted, particularly in the early stages of site selection." The NRC agreed that 10 CFR 60.113 allows adjustments to a 1000-year ground-water travel time, but these adjustments must be approved or specified by the NRC. Condition 3(b) thus stemmed from the NRC's concern that the DOE might assume an adjustment that the NRC would not approve.

In response to the NRC's concerns, the DOE has deleted from the disqualifying condition for geohydrology (§ 960.4-2-1(d)) the provision that would allow the selection of sites with a ground-water travel time of less than 1000 years. Moreover, disqualifying condition § 960.4-2-1(d) was revised to read as follows: "A site shall be disqualified if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1000 years along any pathway of likely and significant radionuclide travel." This statement differs from the performance objective of 10 CFR 60.113 by the words "and significant." The DOE maintains that these words must be included because the DOE will not know, until after site characterization, the pathways, rates, and amounts of ground-water travel in sufficient detail to know precisely whether the site complies with the 1000-year travel time. Thus, the words "and significant" were added to avoid disqualifying an adequate site when early predictions (before site characterization and before the extent of the disturbed zone and the boundaries of the accessible environment are accurately known) indicated that small amounts of water incapable of carrying significant amounts of radionuclides might reach the accessible environment in less than 1000 years. In its final decision, the NRC stated that, "in the absence of a substantive concern," the NRC would not object to the difference in phrasing between the DOE's guideline and its counterpart in 10 CFR Part 60. The NRC reiterated the statement made in its preliminary concurrence decision that the guidelines need not be identical with 10 CFR Part 60 because they serve different purposes and concluded that the DOE's final revision is not in conflict with 10 CFR Part 60.

Twenty comments recommended that some or all of the potentially adverse conditions be upgraded to disqualifying conditions. The two potentially adverse conditions receiving by far the most endorsements for upgrading were the one pertaining to the presence of ground water along the travel path to the accessible environment and the one concerning the difficulty of modeling the geohydrologic system.

The rationale given for changing to a disqualifying condition the presence of ground water along the flow path to the accessible environment is that the presence of ground water increases the probability that radionuclides will reach the accessible environment. The DOE agrees with this rationale, but it does not agree that the increased probability in all cases is sufficient to warrant disqualification. Similarly, the potentially adverse condition pertaining to the difficulty of modeling was not changed to a disqualifying condition, because complexity by itself does not necessarily reduce the isolation capabilities of the geohydrologic system of a site. In fact, in some cases complexity may enhance these isolation capabilities. The DOE also reevaluated the other potentially adverse conditions in the geohydrology guideline, but does not believe it is appropriate to change any of these to disqualifying conditions.

Five comments remarked on the favorable condition concerning high effective porosity. Two suggested "low effective porosity" is more favorable than "high effective porosity," one suggested "low hydraulic flux" was a preferred phrase, another asked for an explanation of why a high effective porosity is a favorable condition and another suggested that most rocks with high effective porosity also have high hydraulic conductivity, and vice versa, and so the favorable condition has no basis in reality. Effective porosity is one of three parameters that directly affect ground-water velocity, the others being hydraulic conductivity and hydraulic gradient. The velocity of the ground water is expressed mathematically as the product of the hydraulic conductivity and the hydraulic gradient divided by the effective porosity. If the product remains constant, as porosity increases, the flow velocity will decrease, with an attendant increase in radionuclide travel time. Therefore, a high effective porosity along such flow paths would be a favorable condition and was retained in the guidelines of November 18, 1983, which were sent to the NRC for concurrence. In addition, a high effective porosity provides an increased surface area for radionuclide retardation. In the guidelines, hydraulic conductivity and hydraulic gradient are addressed separately in the favorable conditions.

However, the favorable condition on high effective porosity was revised in the final guidelines to accommodate the NRC's preliminary concurrence condition 3(a), which asked the DOE "to modify its use of high effective porosity to limit its use to those situations that could be considered as a favorable siting condition." The NRC pointed out that, before a high effective porosity could be considered favorable, the product of the hydraulic gradient and conductivity must remain constant. In some instances, this product is not constant because porosity and hydraulic conductivity can be positively correlated, which would be an adverse, rather than favorable, condition. The DOE agrees with the NRC's position and has therefore revised the statement of this favorable condition to reflect the inverse relationship between porosity and conductivity; it says that the DOE will consider a high effective porosity together with a low hydraulic conductivity. Furthermore, the statement was moved from the favorable conditions applicable to both the saturated and the unsaturated zones to the favorable conditions postulated for the saturated zone because it is more pertinent to the saturated zone.

In response to the NRC's preliminary concurrence condition 3(b), the DOE made a commitment to revise its guidelines, if necessary, to ensure consistency with the final NRC amendments to 10 CFR Part 60 for the unsaturated zone.

Moreover, in response to condition 3(b), favorable condition § 960.4–2–1(b)([illegible]), which dealt with the presence of ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel, was moved to § 960.4–2–0–1; this section is more appropriate because it is concerned with effects on natural resources. Regarding the geohydrology guideline, the NRC had indicated concerns that the presence of ground water with a high concentration of total dissolved solids might be a potentially adverse geohydrologic condition, rather than a favorable one, because it could complicate the design of the waste canister and perhaps hamper the DOE's efforts to satisfy the containment and release-rate requirements of 10 CFR Part 60. However, the NRC agreed that the presence of such ground water is a favorable condition in the consideration of natural resources because such ground water is unlikely to be desirable as a natural resource whose recovery could lead to human intrusion into the repository.

Five commenters remarked on the fact that the guideline on geohydrology does not address the interval in the ground-water travel time to the accessible environment between 1000 and 10,000 years and suggested that the interval between 1000 and 10,000 years should be explicitly stated as a potentially adverse condition (1000 years is a disqualifying condition and 10,000 years is a favorable condition). The fact that a condition is identified as favorable does not imply that the absence of such a condition is adverse. In this instance, a ground-water travel time of more than 10,000 years adds to confidence in the isolation capabilities of a site, but travel time is not unacceptable until it falls below 1000 years, which is the stated disqualifier. Therefore the interval between 1000 and 10,000 years can be regarded as a "neutral" zone, and the DOE did not provide a potentially adverse condition to address the condition of a ground-water travel time of less than 10,000 years and more than 1000 years.

Four commenters recommended that the presence of an aquifer above or within the host rock should be a disqualifying condition. The presence of sources of ground water, suitable for irrigation or human consumption without treatment, along flow paths to the accessible environment is recognized as a potentially adverse condition. Aquifers near or above a repository will be thoroughly evaluated during site characterization to ensure that radionuclides will not reach the accessible environment in amounts exceeding permissible limits, but the presence of aquifers does not mean that permissible limits will be exceeded.

One commenter argued that the 10,000-year travel time as a favorable condition is too long, as is the 100,000-year time specified in the favorable condition pertaining to hydrologic processes affecting waste isolation. These times may indeed be more conservative than necessary, but the DOE believes that acceptable sites can be identified with the specified conditions, and the DOE prefers to be overly conservative provided acceptable sites are not eliminated in so doing.

Section 960.4-2-2 Geochemistry. The objective of the geochemistry technical guideline is to ensure that present and expected geochemical characteristics of a site are compatible with waste containment and isolation. The guideline therefore addresses two aspects of the geochemical environment: the conditions that affect the release of radionuclides from the engineered-barrier system and the conditions that affect the release of radionuclides into the accessible environment (e.g., the conditions related to radionuclide precipitation or sorption and the formation of complexes or physical states that increase the mobility of radionuclides).

Three commenters recommended that the DOE change to disqualifying conditions some or all of the three potentially adverse conditions: ground-water conditions that could adversely affect the engineered-barrier system, geochemical processes or conditions that could adversely affect repository performance, and ground-water conditions that are oxidizing. However, containment and isolation capabilities depend on the total geologic, geohydrologic, and geochemical environment of a site rather than on any single geochemical condition. The DOE believes that none of the potentially adverse conditions is of such importance to long-term performance that its presence would warrant the disqualification of a site. The DOE has therefore not upgraded to disqualifying any of the potentially adverse conditions in the geochemistry guideline.

One commenter recommended that the DOE upgrade to a qualifying condition the favorable condition pertaining to geochemical conditions that promote radionuclide retardation. The effect of this recommendation would be to eliminate all sites not having geochemical isolation capabilities. The DOE does not accept this recommendation because to do so might eliminate some acceptable sites that would quite adequately meet the requirements of the postclosure system guideline by having very long ground-water travel times or other conditions contributing to the isolation of radionuclides.

Four commenters recommended that the converse of the qualifying condition should be explicitly stated as a disqualifying condition. The guidelines provide that, in order to be acceptable, a site must meet all qualifying conditions. Thus, if a site fails to meet any one qualifying condition after site characterization is completed, it is eliminated from further consideration. As explained in Section IV.A, the DOE chose not to explicitly restate the converses of the qualifying conditions as disqualifying conditions.

Three commenters supported that the qualifying condition pertaining to permissible radionuclide releases to ground water and the accessible environment be reworded to require that no radionuclides be released to ground water. Such a "zero-release" requirement would be more restrictive than the EPA proposed regulation and NRC regulations and would not constitute a realistic objective, as discussed under the "Postclosure System Guideline." Therefore the DOE did not accept the recommendation.

Section 960.4-2-3 Rock Characteristics. Postclosure rock characteristics are important to the long-term isolation capability of the host rock. The mining operations during repository construction and the heat generated by the emplaced wastes must not cause fractures or the thermal alteration of minerals that would significantly diminish the ability of the site to contain the waste. If extensive changes in the host rock occur, new pathways for radionuclide migration from the repository could result, and the isolation capabilities of the rock could be impaired.

The objective of the postclosure guideline on rock characteristics is therefore to ensure that the present and expected characteristics of the host rock and surrounding units can accommodate the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, the host rock, ground water, and the engineered-barrier system.

A number of commenters objected to the use of the term "engineering measures beyond the state of the art" in the first potentially adverse condition given for the rock-characteristics guideline. They were concerned that the DOE intended to employ "unproved" engineering techniques to compensate for adverse rock conditions. There was also concern that the DOE intended to rely on technological breakthroughs, which cannot be presumed to occur. To clarify the DOE position, the potentially adverse condition in the final guideline now reads "engineering measures beyond reasonably available technology." The DOE's position is that a potentially adverse condition would exist if the rock conditions encountered at a site could require more than available engineering measures. If there is a definitive finding that rock conditions would require engineering measures beyond reasonably available technology in order for the repository to fulfill its function, then the site would not satisfy the qualifying condition until and unless suitable technology is developed. The DOE, therefore, retained this potentially adverse condition in the guideline.

Six commenters suggested specific additions to the postclosure guideline on rock characteristics. They questioned whether the Ogallala aquifer overlying salt beds in Texas could cause dissolution, whether the drill-and-blast mining techniques could jeopardize a granite site, whether salt domes should be considered as a unit with possible anomalous zones or shear zones, whether large-diameter shafts in salt can be constructed, whether homogeneity in crystalline rock is required, and whether a salt dome is distinct from the geohydrologic setting. Some of these concerns are also related to the preclosure phase, but all of these site- or media-specific concerns are addressed in the qualifying condition for the postclosure rock-characteristics guideline in the following statement: "Present and expected characteristics of host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure. . . ." The DOE has consistently stated that these are general guidelines and site-specific considerations are not appropriate at this time. The DOE has therefore decided not to incorporate these site- and rock-specific comments into the general guidelines.

Three commenters requested that the DOE quantify the term "thick enough and laterally extensive enough" as used in the favorable condition for the draft alternative guideline (§ 960.4-2-3(b)(1)). Comments seeking specificity or quantification for the guidelines are addressed in Section III.A.2 of this notice.

Two comments recommended adding a disqualifying condition to the postclosure rock-characteristics guideline. One suggested that the converse of favorable condition § 960.4-2-3(b)(1) of the alternative guideline be used as a disqualifying condition, and the other requested that the DOE reconsider whether a disqualifying condition is needed. The converse of the favorable condition is not a disqualifying condition because significant flexibility is merely reduced, not eliminated, by restrictions on thickness or lateral extent unless the thickness and lateral extent are so severely reduced as to preclude meeting the qualifying condition, which in itself would result in disqualification. Reduced flexibility could possibly constrain the design of the repository but would not disqualify the site. The DOE concludes that a disqualifying condition is not necessary for the final postclosure rock-characteristics guideline.

One commenter requested that porous shear zones be added as a potentially adverse condition, and the DOE agrees that this concern is valid. The primary adverse effect of a porous shear zone would be its potential to act as a conduit for the influx of water during the preclosure construction and operation phase. Hence, the DOE added the presence of shear zones to potentially adverse condition § 960.5-2-9(c)(5) for the final guideline on preclosure rock characteristics.

Three comments dealt individually with thermal effects on in-situ stress, the effects of mining on post emplacement performance, and the concept of a buffer zone around the host rock. The DOE agrees that thermal effects on in-situ stress are important in repository operation and therefore should be considered in the site-selection process. Although several parts of the alternative guideline touch on this issue, the DOE felt that the addition of a potentially adverse condition dealing specifically with the various effects of heat would be beneficial. Therefore, potentially adverse condition § 960.4-2-3(c)(3) of the final guideline was added to address conditions under which the heat generated by the waste could significantly decrease the isolation provided by the host rock. The concern dealing with mining effects on postclosure performance is pivotal in the concept of geologic disposal. To highlight this concern, the qualifying condition for the guideline on rock characteristics was modified by adding the following sentence: "The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology." The suggestion that a buffer zone around the host rock could add an extra margin of safety was addressed by expanding the qualifying condition for this guideline to read "present and expected characteristics of the host rock and *surrounding units*. . . ."

Section 960.4-2-4 Climatic Changes. Climatic changes could, over time, alter the geohydrologic system at a site. The guideline for postclosure climatic changes focuses on changes that may favorably or unfavorably affect the ability of a repository to isolate waste after closure.

Four comments stated that favorable condition § 960.4-2-4(b)(2), which specifies climatic conditions that have had little effect on hydrologic systems throughout the Quaternary Period, would eliminate the northern United States from consideration, since multiple glaciations have occurred there in the past 100,000 years. In an extension of this thought, one commenter recommended that any areas previously glaciated should be disqualified.

The DOE believes that the relatively stable hydrologic conditions resulting from a constant climate are important to the prediction of repository performance. It is likely that future glaciations will affect local water systems, but the predominant effect will be on surface-water bodies: lakes and streams will increase in number, volume, and flow rate. To determine whether glaciation would prevent a site from meeting the favorable condition the effect on ground-water systems must be predicted case by case. For example, if the host rock is impermeable and insoluble, it is unlikely that water will gain access to the repository; a host rock overlain by a substantial thickness of porous media can also be examined because it can be adequately modeled to allow prediction of changes in hydrologic behavior and demonstrate the site suitability. Moreover, not meeting the favorable condition would not disqualify any site; the existence of any one favorable condition is not necessary to qualify a site. Each site must be evaluated in the context of its overall characteristics because it is very possible that the existence of a number of other favorable conditions may contribute to a waste-isolation capability that is quite acceptable even if the hydraulic system changes. Past and predicted future climatic changes and their effects must be thoroughly evaluated at all sites being considered. However, the DOE does not agree that the condition of previous glaciation should be disqualifying because it might eliminate sites with superior isolation capabilities.

Several comments suggested that the DOE should specify a 100,000-year period for the favorable conditions and a 10,000-year period for both of the potentially adverse conditions for climatic changes. The DOE agrees that it is appropriate to specify periods of concern for these conditions. The period during which the adverse conditions would be of concern is the 10,000-year period specified by the EPA in proposed 40 CFR Part 191, which specifies limits for releases during such a period; the DOE feels that this time period is appropriate. To reflect a very conservative approach to specifying favorable conditions, the time over which the favorable conditions should be expected to exist was increased tenfold over the EPA time period, to 100,000 years for a surface-water system. Similarly, the DOE will consider changes in hydrologic systems induced by climatic changes throughout the Quaternary Period.

A commenter suggested changing the favorable condition related to climatic behavior in the Quaternary Period, to reflect the expectation of future effects rather than reliance on historical behavior. Another commenter stated that it may be impossible to predict climatic, and related hydrologic, systems on the basis of Quaternary Period records and that the relationship between future climate and hydrologic changes will be complex. The DOE agrees that predicting such future events is difficult; however, the DOE believes that the most appropriate insight into the range of future possibilities can be gained by a review of climatic cycles over the Quaternary Period. Furthermore, it is logical to expect that a relatively constant climate will have little impact on the present hydrologic conditions at the site. This approach minimizes the likelihood that complex changes in hydrologic systems will occur. Accordingly, the DOE has retained the potentially favorable condition of a geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period. The DOE incorporated several changes in wording suggested by commenters to improve ease in reading this guideline.

In developing the final guideline on climatic changes, the DOE consolidated several smaller considerations of climatic changes that had appeared in various sections of the proposed guidelines.

Section 960.4-2-5 Erosion. The objective of the technical guideline on erosion is to ensure that erosional processes will not degrade the waste-isolation capabilities of a site. In evaluating the potential effects of erosion on waste isolation, the depth of the host rock is most important. The site should allow the underground facility to be placed at a depth sufficient to ensure that the repository will not be uncovered or otherwise adversely affected. The disqualifying condition in the guideline on erosion states that the minimum depth is 200 meters; a depth of at least 300 meters is a favorable condition.

Fifteen commenters pointed out the typographical omission of the word "not" in favorable condition § 960.4.2.5(b)(3) concerning exhumation during the first one million years. This omission caused the statement to mean the opposite of what was intended. The omission has now been corrected.

Four commenters suggested or implied that the minimum acceptable depth for a repository should be more than 200 meters and suggested acceptable depths ranging from 300 to 600 meters, or as deep as possible. One commenter stated the minimum acceptable depth could well be much less than 200 meters. The minimum acceptable depth for a repository should be based on credible erosion rates. For example, erosion at an extremely high rate of 1 millimeter per year, which is five or more times greater than the rate at which the Colorado River cut the Grand Canyon, would require 200,000 years to erode to a depth of 200 meters. For sites with more normal erosion rates, a depth of 200 meters is sufficient to isolate wastes for millions of years. The DOE has therefore retained 200 meters as the minimum depth in the disqualifying condition for erosion.

Four commenters recommended increasing the 10,000-year time period pertaining to the probability of radionuclide release in one of the favorable conditions and pertaining to the adverse effects of erosion in one of the potentially adverse conditions. However, the guidelines is consistent with the proposed EPA criteria on permissible limits for the release of radionuclides to the accessible environment, which are specified for a 10,000-year period. The favorable condition is stated in terms of a probability (1 chance in 10,000) that the DOE believes conservatively appropriate for a 10,000-year period.

Two commenters on the favorable conditions suggested or implied that the depth (300 meters or more) specified there is too shallow and suggested depths as great as 600 meters or as deep as possible. One commenter, however, stated that the 300-meter depth limit should be decreased. The favorable depth of 300 meters or more is based on a similar NRC criterion in 10 CFR Part 60. As mentioned in the preceding paragraph, a burial depth of 200 meters or more is considered to be adequate for even the most extreme erosion rates. Under those conditions where more normal erosion rates are expected to prevail, a minimum depth of at least 300 meters is considered to be more than adequate. Therefore, the DOE retained the 300-meter depth as a favorable condition.

Four commenters suggested that the two potentially adverse conditions should be upgraded to disqualifying conditions. These potentially adverse condition pertain to erosion rates during the Quaternary Period and predicted adverse effects in the future. The intent of the two potentially adverse conditions is to require that erosion during the Quaternary Period be documented and studied to determine whether extreme erosion has occurred and to require the predictions be made of erosion rates and processes occurring in the next 10,000 years to evaluate whether they could adversely affect the isolation capabilities of a site. Obviously, past and predicted future erosion rates and their effects must be thoroughly evaluated. However, the two conditions in question may or may not result in a conclusion that a site is compromised; only a thorough evaluation of the consequences of the conditions and the lack of offsetting mitigating conditions can determine whether a site is disqualified. Therefore, the DOE has kept the two conditions as potentially adverse.

In the final guidelines, the first potentially adverse condition (§ 960.4-2-5(c)(3)) has been revised by deleting the word "sustained." This revision was made in response to the NRC's preliminary concurrence condition 3(c), which asked the DOE "to clarify the meaning of 'short-term' extreme erosion and revise the guidelines as appropriate." The term "short-term extreme erosion" had been used by the DOE in a support document to explain why the guidelines used the term "sustained" extreme erosion. The DOE reasoned that short-term erosion would not affect waste isolation, and the term "sustained" would indicate the type of erosion that could be potentially adverse. However, when the NRC questioned the duration of "short term' and explained its concern about catastrophic erosion episodes that might affect the repository, the DOE deleted the word "sustained" from § 960.4-2-5(c)(1).

Section 960.4-2-6 Dissolution. The objective of the technical guideline on dissolution is to ensure that dissolution processes will not adversely affect the waste-isolation capabilities of the site. The principal concern is that the dissolution of the host rock might create new pathways for radionuclide migration to the surrounding geohydrologic system. The sites with salt as the host rock are the most vulnerable to dissolution, and the effects of salt dissolution on waste isolation will be an important consideration in evaluating a site in salt.

Two comments on the disqualifying condition suggested that the 10,000-year minimum length of time for dissolution to connect the underground facility to the geohydrologic system is too short, especially considering the long-lived radionuclides present in the waste. The identification of the first 10,000-year period in the life of a repository as the period of concern is based on the 10,000-year period the EPA used in proposed 10 CFR Part 191, Subpart B. Therefore, the DOE has retained the 10,000-year limit in the disqualifying condition.

Three commenters suggested rewording the disqualifying condition to make it absolute in the sense that any interconnection of the underground facility to the geohydrologic system would disqualify a site regardless of whether or not radionuclides reach the accessible environment in amounts that exceed permissible limits. A site is not necessarily unsafe simply because a connection between a repository and the geohydrologic system may be established in the future. The important possibility to evaluate is whether 161h a connection can introduce radionuclides into the accessible environmental in amounts that exceed permissible limits; this possibility can be evaluated in a performance assessment. Therefore, in the November 1983 guidelines, the DOE did not modify the disqualifying condition, which read as follows: "The site shall be *disqualified* if, during the first 10,000 years after closure, active dissolution fronts will cause a hydraulic interconnection of the underground facility to the geohydrologic system of the site such that the requirements specified in § 960.4-1 cannot be met." This condition was, however, revised in the final guidelines to delete its connection to the postclosure system guideline (i.e., by deleting the phrase "such that the requirements specified in § 960.4-1 cannot be met").

One commenter recommended upgrading to a disqualifying condition the potentially adverse condition pertaining to the presence at a site of dissolution features, such as breccia pipes and dissolution cavities. Dissolution features are of concern, but of themselves are not necessarily sufficient for disqualification. For example, if past dissolution has ceased, it could conceivably be shown that the dissolution will not resume or that, if it does, it will not adversely affect the isolation capabilities of the site. Therefore, the DOE retained the statement pertaining to the presence of dissolution features as a potentially adverse condition.

In the final guidelines, the above-mentioned potentially adverse condition was revised in response to the NRC's preliminary concurrence condition 3(i), which asked the DOE to modify its guidelines so that potentially adverse conditions (e.g., dissolution) would be considered if they affected isolation within the controlled area even though the condition may occur outside the controlled area. The Commission had objected that § 960.4-2-6(c) was not consistent with 10 CFR 60.122(1)(10) because the former referred to "significant dissolution within the site," whereas 10 CFR 60.122(c)(10) would consider dissolution without reference to its significance or location. In reviewing this NRC concurrence condition, the DOE agreed with the NRC's concerns about consistency and therefore deleted the word "significant," replaced the word "site" with "geologic setting," and revised the phrase "a hydraulic interconnection between the host rock and an immediately surrounding geohydrologic unit could occur" to read "a hydraulic interconnection leading to a loss of waste isolation could occur."

One commenter suggested that caprock be added to the examples of dissolution features that are potentially adverse. Caprock is formed as a result of dissolution and indeed is a dissolution feature. However, to list all possible dissolution features in the potentially adverse condition would produce a long and cumbersome statement. The few examples given are not intended to constitute an exhaustive list. The DOE did not change the potentially adverse condition in question.

Section 960.4-2-7 Tectonics. Meeting the requirements of the postclosure guideline on tectonics will ensure that tectonic processes do not adversely affect the waste-isolation capabilities of the site. Tectonic processes and events during the postclosure period could adversely affect waste containment and isolation by creating new ground-water pathways to the accessible environment. While it is difficult to predict geologic processes, this guideline requires that the tectonic history of a site be carefully examined and the results of this examination be used to predict the likelihood of potentially disruptive tectonic processes or events. Igneous activity, uplift, subsidence, folding, and faulting are all important tectonic processes and are included in this guideline.

Twenty-eight comments recommended adding disqualifying conditions. Some of the commenters suggested a disqualifying condition that is the opposite of the qualifying condition. This approach adds nothing to the guideline since all repository sites must meet all the qualifying conditions (see Section IV.A for a more detailed discussion of this generic concern). Other commenters suggested that the potentially adverse conditions be converted to disqualifying conditions. The DOE believes that this conversion would be inappropriately restrictive and could rule out sites that are potentially adequate for waste isolation. None of the six potentially adverse conditions would necessarily compromise waste isolation. If any of them exist at a site, further investigations to increase the understanding of the condition are appropriate, but not site disqualification. However, in response to the NRC's preliminary concurrence condition 7, disqualifying condition § 960.4-2-7(d) was added to the final guidelines because the DOE agreed that a site should be disqualified if the nature and rates of ground motion are expected to be such that a loss of waste isolation is likely.

Two reviewers raised particular concerns that man-induced seismicity should be addressed in the tectonics guideline. One went on to state that the potential impact of a seismic event is the same regardless of the cause of the event. The DOE agrees, but believes that the combination of the current guidelines on human interference (§ 960.4-2-8) and tectonics (§ 960.4-2-7) adequately addresses the concern. The qualifying condition of the human-interference guideline states that the DOE will evaluate human activities that could alter or cause tectonic processes.

Section 960.4-2-8 Human Interference. The technical guidelines on human interference focus on (1) reducing the incentive for postclosure human interference by avoiding sites containing natural resources that would invite potentially disruptive human activities and (2) obtaining land ownership, in accordance with 10 CFR 60.121, in order to establish appropriate passive controls and thus decrease the likelihood of incompatible human activities. Separate technical guidelines are provided for each of these two objectives.

A number of commenters misinterpreted the purpose of the human-interference guidelines, which is to decrease the likelihood of postclosure human activities that would be detrimental to waste containment or isolation. Some thought the guidelines should specify the passive physical controls to be used, while some thought they should address preclosure security.

The general nature of the passive controls (permanent markers and records) is specified in 10 CFR Part 60. The specifications for such controls will be established through the licensing process to provide the maximum confidence in their adequacy.

The adequacy of preclosure security measures will also be addressed in licensing. Preclosure security is routinely addressed for DOE facilities as well as for industrial facilities and does not appear to pose any difficulties for repositories. Siting decisions have little bearing on preclosure security, which is therefore not an appropriate topic for the guidelines.

One set of comments indicated that too much reliance was placed on passive controls like markers and monuments; that commenter believed active (institutional) controls should also be included to prevent postclosure interference. As pointed out by the EPA in the preamble to proposed 40 CFR Part 191, the usefulness of institutional controls for more than a few hundred years is speculative because of the uncertainties about human behavior and institutional stability in the distant future. Moreover, the usefulness of active controls does not appear to be site dependent. The DOE, therefore, has not included specific provisions for active postclosure institutional controls in the final rule. Such provisions will, however, be evaluated during the licensing process.

The overall human-interference qualifying condition, in alternative guideline § 960.4-2-8, was changed to refer to activities "at or near the site" in order to ensure consideration of indirect as well as direct interference activities. Also, that condition now states that the DOE will show that future human activities will not be likely to affect waste containment and isolation; the proposed guideline required only the "site to be located to reduce the likelihood" of "unacceptable impacts," a more subjective requirement than set forth in the final rule. The final guidelines also have been strengthened to explicitly require the DOE to consider the estimated effectiveness of the passive controls in the human-interference evaluations.

Section 960.4-2-8-1 Natural Resources. The purpose of developing guidelines on natural resources was to reduce or remove the incentives for economically motivated postclosure human-interference activities that could adversely affect the isolation capabilities of a site. A number of comments on both the proposed and the alternative guidelines misinterpreted this purpose as being to protect natural resources from repository-related activities. Although the protection of natural resources is of high concern to the DOE, that issue is addressed through the preclosure guidelines on environmental quality and on socioeconomic impacts. The human-interference guidelines for natural resources address the corollary concern—that the present or projected value of the natural resources not invite unacceptable postclosure intrusion.

Many comments suggested that the potentially adverse conditions in the natural resources guideline be redesignated as disqualifying conditions, several citing the EPA assurance requirements in proposed 40 CFR 191.14 or quoting the Act to substantiate their contentions. The DOE has requested that the EPA eliminate or modify the proposed assurance requirements for several reasons. The reason of importance to this guideline is the need to evaluate the significance of past, present, or potential human activities on a site-specific basis to determine whether such activities could adversely affect a repository rather than to assume adverse effects a priori, as the proposed EPA standard does. Although the EPA approach is conservative, its unqualified application could eliminate otherwise qualified sites for reasons that could be insignificant under site-specific conditions. In response to comments on the alternative guidelines, the DOE added a disqualifying condition (§ 960.4-2-8-1(d)). That condition would eliminate sites where exploration, mining, or extraction activities have created significant pathways between the underground facility and the accessible environment.

In the final guidelines the potentially adverse conditions for natural resources remain potentially adverse rather than disqualifying. This designation allows the DOE to determine, from site-specific evaluations whether the potential for resource-related interference activities is so great that the elimination of a site would be prudent. The key considerations in such evaluations are (1) whether interference is likely and (2) if so, whether these potential interference activities could lead to releases of radionuclides exceeding the standards in 40 CFR Part 191.

Several comments recommended specific wording changes in the natural-resources guidelines to add specificity or to highlight items of particular concern to the commenter. The DOE has considered those comments and has made editorial changes that clarify the DOE's intent, give appropriate examples, or otherwise promote understanding of the guidelines.

A number of changes were made in the factors to be considered in the qualifying condition for example, "reasonable projections of value, scarcity, and technology." In response to several comments, ground water suitable for human consumption or crop irrigation is explicitly included as a resource in the final guidelines.

A number of changes directed at reducing ambiguity were made in the favorable and potentially adverse conditions; the most significant was the elimination of a proposed favorable condition that dealt with the value of resources at a site relative to the average for the geologic setting. That proposed favorable condition was the direct converse of a proposed potentially adverse condition, and its elimination makes the concept set forth consistent with 10 CFR Part 60. A new favorable condition has been added; it requires consideration of the resources on the basis of their present or projected absolute value; the potentially adverse condition concerned with relative value (i.e., in relation to other areas in the same geologic setting) was retained. The new favorable condition responds to criticisms by several commenters regarding the shortcomings of comparisons solely within the same geologic setting or region.

Several comments focused on items of specific concern to a particular State or group but not necessarily of generic importance; an example is the suggestion that a salt dome should be considered unattractive for siting because the dome itself is a resource. The DOE addressed those concerns, where appropriate, through a more generic wording rather than focusing on a specific condition of limited geographical applicability. Considering the previous example of a salt dome, the guidelines include several potentially adverse conditions that would require close evaluation for any dome. For instance, 960.4-2-8-1(c)(1)(ii) considers the presence of minerals to be a potentially adverse condition when they are in configurations such as a dome (i.e., more concentrated than the regional average for similar land areas). Other potentially adverse conditions generically address resources associated with certain dome configurations and previous mining or drilling.

Some comments addressed potential human activities that could change ground-water flow or seismic conditions, such as starting or ceasing fluid-injection or petroleum-withdrawal activities. In response to these concerns, the DOE has modified the potentially adverse conditions dealing with significant subsurface mining or resource extraction (§ 960.4-2-8-1(c)(2)), drilling within the site for purposes other than site characterization (§ 960.4-2-8-1(c)(3)), and the potential for foreseeable human activities, (e.g., ground-water withdrawal, extensive irrigation, subsurface injection of fluids), that could change portions of the ground-water flow system (§ 960.4-2-8-1(c)(5)). Moreover, the final postclosure guideline on tectonics include a potentially adverse condition that incorporates the potential for tectonic deformations to affect the ground-water flow system. That potential would include tectonic deformation induced by starting or ceasing the human activities mentioned previously and is believed to be significant in the evaluations of sites.

The final guideline contains a second disqualifying condition (§ 960.4-2-8-1(d)(2)), which was added in response to the NRC's request, in its preliminary concurrence condition 7, to provide a disqualifying condition that corresponds to the "location of valuable natural resources" in the Act. Guideline § 960.4-2-8-1 already specified that a site will be disqualified if previous exploration, mining, or extraction activities have created significant pathways between the underground facility and the environment. Further consideration of the human-interference issue during the

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concurrence discussions with the NRC staff led the DOE to develop a disqualifying condition directed at current or future activities outside the controlled area should inadvertently could lead to a loss of waste isolation. As indicated by the word "inadvertently," the activities in question are considered to be unintentional intrusions; they are postulated to occur outside the controlled area because the "controls" to be exercised in the controlled area should preclude intrusion within the area.

Two other changes were made to guideline § 960.4–2–8–1 in response to the NRC's concurrence conditions 3(g) and 3(c). The first change is the deletion of the word "significant" from the phrase "significant subsurface mining or extraction for resources" in the second potentially adverse condition because the DOE agreed with the NRC that all evidence of subsurface mining should be considered adverse until the evidence has been thoroughly evaluated. The other is the addition of the second favorable condition (presence of ground water with 10,000 parts per million or more of total dissolved solids), which was originally in § 960.4–2–1. The NRC gave the DOE two options for resolving condition 3(c): transfer the provision to § 960.4–2–8–1, where effects on natural resources are considered, or delete the provision altogether. The deletion option reflected the NRC's concern that ground water containing a high concentration of dissolved solids might adversely affect the performance of the engineered-barrier system, complicate the design of the waste canister, and possibly hamper the DOE's efforts to satisfy the containment and release-rate requirements of 10 CFR Part 60; such a condition should therefore not be considered a favorable condition for geohydrology. The DOE chose the first option because it clarified the intent to avoid sites with sources of ground water that can be used for domestic or agricultural purposes.

Several comments insisted that the existence of potable ground water at a site should be disqualifying. The DOE does not agree that the presence of potable ground water is a reasonable basis for a disqualifying condition that would be generally applicable to all sites. However, to ensure the protection of ground water, several modifications were made to the guidelines. In addition, a potentially adverse condition was added to recognize the fact that the presence of ground water could create the possibility for drilling activities to recover this water. The NRC and EPA regulations should also ensure that any risk to potable ground-water sources is very low.

Section 960.4–2–8–2 Site Ownership and Control. The NRC requires the DOE to obtain ownership and surface and subsurface rights to land and minerals within the controlled area of the repository (10 CFR 60.121). Such rights are required largely to help ensure continued functioning of the repository far into the future without adverse human interference. This NRC requirement is the basis for the guideline on site ownership and control.

Several comments questioned the adequacy of the protection afforded by the type of control specified by this guideline. While there can be no guarantees that interference will never occur, the DOE believes that the risk from such activities can be decreased to acceptably low levels through the following measures, taken together: (1) The avoidance in site selection of natural resources that could invite deleterious interference activities, (2) ownership of land and mineral rights, (3) long-term markers and widely dispersed records, and (4) natural and engineered systems chosen to make interference activities more difficult or to mitigate their effects. This belief is also expressed by the NRC in the preamble to 10 CFR Part 60.

Another group of comments contended that ownership priorities should be set forth in the final guidelines. A large number of comments on the proposed rule questioned the preferred status given to land already owned by the DOE and suggested that more attention should be given to potential ownership conflicts with other Federal or State lands used or withdrawn for incompatible purposes and the special problems involved in siting on Indian tribal lands. The proposed potentially adverse condition was revised to be more specific about the conditions that should be adverse. An example of such a potentially adverse condition, as indicated by one comment, would be siting on tribal land, not subject to Federal condemnation procedures, if a voluntary purchase-sell agreement could not be negotiated. The single favorable condition now cites ownership and control by the DOE whereas the proposed guidelines considered ownership and control by other Federal agencies to be favorable as well.

Some comments questioned why both postclosure and preclosure guidelines on site ownership and control were included in the alternative guidelines. Land ownership and control are important to safety in both postclosure and the preclosure phases. The final rule continues to state the land ownership and control guidelines for both phases. It should be noted that, though the statements of the guidelines are similar, the necessary land areas and controls in the postclosure and the preclosure phases may differ slightly. The land-use requirements for both the postclosure and the preclosure phases will need to be integrated in establishing the actual site boundaries.

4. Preclosure Guidelines (Subpart D, Section 960.5)

The preclosure guidelines address (1) preclosure radiological safety; (2) the environmental, socioeconomic, and transportation-related impacts associated with repository development and operation; and (3) the ease and cost of repository siting, construction, operation, and closure. The preclosure guidelines provide system and technical guidelines for each of those three categories. The separation of the guidelines into those three categories allows the DOE to be more definitive in establishing the relative significance of categories of guidelines in accordance with § 960.3–1–5.

Section 960.5–1 Preclosure System Guidelines. The purpose of the preclosure system guidelines is to establish the overall objectives to be met by a repository during the preclosure phase (i.e., siting, construction, and operation through closure). The proposed and alternative guidelines both included one preclosure system guideline that was primarily focused on radiological safety. The final guidelines include three preclosure system guidelines, one each of the major categories indicated above, in order to achieve a parallel relationship between the preclosure system guidelines and the technical guidelines throughout the rule. That parallel relationship should be of value in comparing sites.

For preclosure radiological safety (§ 960.5–1(a)(1)), the pertinent system elements are (1) the site characteristics that affect radionuclide transport through the surroundings; (2) the engineered components whose function is to control releases of radioactive materials; and (3) the people who, because of their location and distribution in unrestricted areas, may be affected by radionuclide releases. This guideline is assigned the greatest importance among the preclosure system guidelines because it is directed at protecting both the public and the workers of the repository from radiological exposures.

Ranked next in importance is the preclosure system guideline on the environment, socioeconomics, and transportation (§ 960.5-1(e)(2)). In the final guidelines, the statement of this guideline was editorially revised for simplicity and clarity. The pertinent system elements will in general consist of (1) the people who may be affected, including their lifestyles, sources of income, social and aesthetic values, and community services; (2) the air, land, water, plants, animals, and cultural resources in the areas potentially affected by such activities; (3) the transportation infrastructure; and (4) the potential mitigating measures that can be used to achieve compliance with this guideline.

The third preclosure system guideline is ease and cost of siting, construction, operation, and closure. It is ranked lowest because it does not relate directly to the health, safety, and welfare of the public or the quality of the environment. Here the pertinent elements are (1) the site characteristics that affect siting, construction, operation, and closure; (2) the engineering, materials, and services necessary to conduct these activities; (3) written agreements between the DOE and affected States and affected Indian tribes and the Federal regulations that establish the requirements for these activities; and (4) the repository personnel at the site during siting, construction, operation, or closure.

Some commenters believed that too much reliance was placed on engineered systems to meet the regulations for radiological safety. Unlike the postclosure phase, which relies heavily on natural systems for containment and isolation, the preclosure phase relies on engineered systems, equipment, and controls, examples being high-integrity engineered structures, water- and air-treatment systems, and monitors that can activate automatic control systems. The use of systems, equipment, and controls similar to (in some cases identical with) those that would be employed for repository operations is well established in industrial practice. Therefore the DOE disagrees with the above comment—the issue raised is not analogous to the postclosure issue on engineered barriers.

One commenter objected to the use of the terms "preserve" and "to the extent practicable" in the second preclosure system guideline (environment, socioeconomics, and transportation), preferring to substitute "minimize impacts to" for the former and to delete the latter. As previously stated, this system guideline has now been editorially simplified and clarified, and these terms are no longer used. The DOE disagreed with the second comment, because practicability must govern the application of this guideline. The minimization of impacts is a desirable objective, but in making repository siting decisions it must be balanced against other objectives.

One commenter suggested that the DOE add to the system guidelines a statement to the effect that the DOE will comply with the intent of State environmental laws and regulations. Although the DOE will comply with the requirements of all applicable environmental laws and regulations, it is not necessary or appropriate to include a guideline to this effect.

A commenter asked that the DOE return to the language used in the original preamble regarding the DOE's commitment to environmental protection. The DOE's commitment to environmental protection is clearly expressed in the guidelines, which are based on the premise that the key objectives in site selection are the protection of the health and safety of the public and the quality of the environment. These guidelines encompass all factors potentially important to waste containment and isolation (e.g., geohydrology, geochemistry, tectonics, human intrusion) as well as the factors that determine the environmental and socioeconomic acceptability of a site. In addition, as discussed under the implementation guidelines in Section IV.B.2, a separate implementation guideline for the consideration of environmental impacts (960.3-4) has been developed.

One commenter suggested the inclusion of the ALARA standard in the preclosure system guidelines. The ALARA standard (i.e., reducing releases to "as low as reasonably achievable" levels) is a part of the reference regulations (i.e., proposed 40 CFR Part 191, Subpart A) for the first preclosure system guideline and is therefore incorporated by reference into the DOE's preclosure guidelines.

One commenter asked whether all of the regulations cited in the first preclosure system guideline would need to be met and, conversely, whether the inability to comply with any single regulation but not all of the regulations would lead to disqualification. The answer to both questions is affirmative.

One commenter requested that a criterion of "zero release" to ground water be established for the preclosure phase. Although this is similar to the "zero release" comment for the postclosure phase, the issues are different. Ground water is not a part of the preclosure multiple-barrier system. Furthermore, the comment is primarily directed at shallow potable-water aquifers as opposed to the deeper aquifers of concern during the postclosure phase, which have less potential as potable-water sources. As already discussed, the NRC regulations governing preclosure operations embrace the ALARA standard (i.e., releases must be as low as is reasonably achievable). For preclosure operations, the application of that standard is expected to lead to no planned discharges of liquid radioactive wastes from the repository. In any case, such discharges would not be made to ground water. Beyond that, the system will be designed to prevent, to the extent practicable, contaminated liquid releases during postulated abnormal conditions. Given the relatively small volume of potentially contaminated liquids in preclosure operations, achieving essentially zero levels of liquid releases is a reasonable objective. Therefore, although not specifically incorporated into the guidelines (because the zero-release criterion is not a factor in siting), the desired assurance that no contaminated liquids will be released to aquifers is consistent with the DOE's objectives for preclosure safety.

One commenter requested that accident release limits for preclosure operations be promulgated by the NRC. This matter has been brought to the attention of the NRC. Such limits, if promulgated by the NRC, will be adopted by the DOE.

One commenter noted that the system guidelines were more sparsely worded than the technical guidelines, implying that the lack of detail appeared inconsistent with the high importance attributed to the system guidelines. The reason for the apparent lesser detail in the system guidelines is that they, incorporate, by reference, detailed regulations promulgated by other agencies. These regulations are not repeated verbatim in order to readily incorporate (also by reference) any changes that may occur with time.

Deleted from the final preclosure system guidelines were the explanatory statements about pertinent system elements because these statements were considered to be more appropriate in this section-by-section analysis.

In summary, the final guidelines include three preclosure system guidelines, whereas the proposed rule had one preclosure system guideline, specifically addressed to radiological safety. The system guideline for preclosure radiological safety was modified to include 10 CFR Part 60 in accordance with the NRC comments on the proposed rule. Also, the term "state of the art" was replaced by "reasonably available technology" because several commenters felt that the former term would allow the use of untested technology.

Section 960.5-2 Preclosure Technical Guidelines. Like the preclosure system guidelines, the preclosure technical guidelines are divided into three categories. The first category, preclosure radiological safety, contains guidelines on population density and distribution, site ownership and control, meteorology, and offsite installations and operations. The second category covers the environment, socioeconomics, and transportation. The third category, which pertains to the ease and cost of siting, construction, operation, and closure, contains guidelines on surface characteristics, rock characteristics, hydrology, and tectonics.

Preclosure Radiological Safety

Section 960.5-2-1 Population Density and Distribution. The objective of the guidelines on population density and distribution is to ensure the selection of a repository site that will minimize risk to the public and permit compliance with the EPA and NRC regulations. The proposed EPA standard (40 CFR Part 191) limits exposures to members of the public; it also requires that these exposures be further reduced below the limits to the extent reasonably achievable. The proposed EPA standard limits the radiation dose that any individual outside the boundary of the restricted area would receive to a maximum yearly dose of 25 millirem to the whole body, 75 millirem to the thyroid, or 25 millirem to any other organ. (Doses from natural background radiation vary between 70 and 200 millirem per year at different locations in the United States.) The results of studies performed to date indicate that the doses that would result from repository releases are very much lower than the EPA maximum permissible doses.

The final guideline on population density and distribution includes a qualifying condition, two favorable conditions, two potentially adverse conditions, and three disqualifying conditions. The two parts of the qualifying condition stipulate that (1) the expected dose to individuals in any highly populated area will not be likely to exceed a small fraction of the EPA limits, by reference to system guideline § 960.5-1(1), and (2) the expected dose received by any individual in the unrestricted area will not be likely to exceed the EPA limits. Any site must meet this two-part test in order to qualify.

The two favorable conditions will require the DOE to analyze the degree to which a site is remote from highly populated areas and to seek sites with low population densities. The first potentially adverse condition will require examination and analysis of the population density within projected site boundaries. The population to be analyzed will include the people residing there, those who are there on a seasonal or transient basis, and those who may be there only during the daytime. The daytime population consists of persons whose work brings them together into dense concentrations and of visitors to popular recreational areas. The second potentially adverse condition will require the analysis of the proximity of the site to highly populated areas or to areas containing 1000 or more persons in a 1-mile-square area.

The three disqualifying conditions specify that the site shall be disqualified if any of the following conditions exist:

1. The surface facility would be located in a highly populated area (coincidence); or
2. The surface facility would be located adjacent to a 1 mile by 1 mile area having a population of not less than 1000 individuals (adjacency); or
3. The DOE could not develop an emergency preparedness program that meets the requirements of DOE Order 5500.3 and related guides or 10 CFR Part 60, Subpart I, "Emergency Planning Criteria."

The DOE arrived at these disqualifying conditions by an iterative process that began in the proposed rule of February 7, 1983, with disqualifiers that were based on both radiation doses and on the adjacency and coincidence of the surface facility with a highly populated area. Comments requesting that the DOE be more specific led to the alternative guideline of May 27, 1983. This version specified that a site will be disqualifed if a surface facility would be adjacent to (abutting) an area 1 mile by 1 mile having a population of not fewer than 1000 individuals or would be located in a highly populated area. Objections to the use of the word "abutting" to define "adjacent surface facilities" led to attempts, discussed with the States, to restructure the disqualifier with both necessary and sufficient conditions. That is, if a surface facility met either of two necessary conditions (adjacency or coincidence), a site would be disqualified if the restricted area of a repository were (1) in a highly populated area or (2) abutting a 1-mile-square area with 1000 or more individuals. A number of States disliked this structure, saying that it was both awkward and perhaps gave an appearance of evading Congressional intent, even though it followed closely the language of Section 112(a) of the Act.

Clearly, no one would suggest that repository facilities should be located in a highly populated area; the DOE has, therefore, concluded that both the coincidence and adjacency conditions of Section 112(a) of the Act should be sufficient to disqualify sites. The purpose of both conditions, and the entire guideline, is the protection of people from harmful exposure to radiation due to releases from repository surface facilities. The dispersal of any airborne releases would depend on local weather conditions, which may vary greatly from site to site. Furthermore, the magnitude of releases is controllable in large degree by engineering measures in common use at radiological facilities. It follows that the DOE must make a site-specific evaluation of adjacency to populations concentrations in order to decide whether a site meets this guideline. This evaluation will determine the distance at which the outer boundary of the restricted area should be set, measured from potential release points, so as to ensure that populations beyond that fenced boundary will not experience radiation doses in excess of the limits set by the NRC and the EPA regulations discussed above.

A commenter stated that 1000 persons per square mile represents a high population density and that the population-density guideline should be more restrictive. The DOE agrees that a low population density in the vicinity of a site is a favorable condition; however, in accordance with the requirements of the Act, the disqualifying condition should be and is stated in terms of high population density.

Eight commenters expressed concern over radiation exposure and dosage, and how these are to be addressed in the guidelines. Six of them called attention to the potentially adverse condition in the alternative guideline § 960.5-2-1(b)), stating that any site where regulatory limits would be exceeded should be disqualified. In response to these concerns, the DOE added a qualifying condition that limits the allowable doses in both highly populated areas and in unrestricted areas, generally. Other commenters were concerned with the

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presence of transient or residential populations. Accordingly, the DOE added potentially adverse condition § 960.5–2–1(c)(1).

One concern expressed by three commenters was that, in performing dose calculations, the DOE should consider future as well as present populations. The DOE agrees and will make population projections through the period of decommissioning for each potential site during site characterization. Because long-range demographic forecasts are inherently speculative, the DOE believes that projections beyond the period of decommissioning would not serve a useful purpose.

One commenter expressed the view that individual, as well as population, dose should be measured, and two reviewers said that dose calculations should include doses from other sources. In calculating dosage, the DOE will follow the procedures outlined in the EPA's final standards (40 CFR Part 191). These calculations estimate individual exposures from other sources as well as from repository operations. The qualifying condition is stated in terms of both individual and population doses.

One commenter expressed the view that increments of distance should be established in the guideline to account for risks associated with increased surface activities and gave an example of converging transportation routes. In order to protect the public, the DOE will identify a restricted area that encloses all repository surface facilities, except the immediately connecting road or rail spurs. The safety of transportation activities is treated in the analysis of the transportation guideline.

Two reviewers commented that the real extent or distance describing the "remoteness" of a site from highly populated areas should be defined. Remoteness varies with land use, terrain, distance, relative accessibility to the public, and the configuration of the potential controlled area. These conditions will be evaluated to determine the degree to which a site may be considered remote from highly populated areas; therefore, the DOE does not believe that it is appropriate to specify a definition for remoteness in the general siting guidelines.

One commenter suggested that "highly populated area" should be left undefined in the guidelines. The DOE thinks that such a definition is necessary, however, in order to identify and avoid highly populated areas early in the site-screening process and to be able to rely upon the potential utility of sites in which much effort will have been expended, should they prove qualified in all other respects. Other commenters felt that a more restrictive definition is necessary. Hence, "highly populated area" is defined in the final guidelines as any incorporated or census-designated place, excluding counties, of 2500 or more persons as long as the population density of the place would equal or exceed the mean population density of the United States (about 64 persons per square mile). This is a more restrictive definition than the one used in the alternative guideline, which stipulated that highly populated areas would include urbanized places within metropolitan statistical areas (MSAs) as defined by the Bureau of the Census. In practice, that criterion would exclude only the most highly populated parts of any given MSA. The new definition does not refer to MSA and is therefore more restrictive. The threshold of 2500 persons was selected for two reasons. First, the Bureau of the Census defines places with 2500 or more inhabitants as urban. Second, the Bureau develops maps to delineate such places, and population-density data are tabulated for these places. The criterion of the mean U.S. population density used in the definition of "highly populated area" will permit the DOE to consider potential sites within extremely large but sparsely settled incorporated communities.

Another commenter felt surface or climatic conditions that might increase the occupational exposure of repository workers to radiation should be considered potentially adverse. The DOE agrees that the exposure of workers at a repository must be limited and will meet the safety requirements for occupational exposure in 10 CFR Part 20. Because any repository will be designed to protect workers from variable climatic conditions, the DOE feels that any site-to-site variations projected in occupational doses would be so small as to make this factor inconsequential in siting.

Another commenter wondered why the DOE would be concerned with population density but not with agricultural productivity in the area of a site and suggested that certain agricultural areas be eliminated from further consideration. In siting any repository, the DOE will comply with the Farmland Protection Policy Act of 1981 (Pub. L. 97–98) and the Department of Agriculture's final rule to implement that Act (49 FR 27716; to be codified as 7 CFR Part 658).

One commenter said that the DOE should ensure that the populations adjacent to a potentially acceptable site will be protected from the effects of a repository at least as well as parks are protected in the environmental quality guideline. The DOE developed the qualifying, disqualifying, favorable, and potentially adverse conditions in both guidelines so that both parks and populations would be protected in a manner commensurate with the type of risk. Industrial facilities are generally precluded from parks, but many industries are commonly located within urban areas. When the industrial operations involve known hazards, then they are usually sited at some distance from the general public, the distance being determined by the degree of hazard. With the park, it is the environment that is at risk; with the population, it is the potential risk to the health and safety of the residents of an area that must be considered. The disqualifiers therefore are based on radiation hazards for the population and either irreconcilable land-use conflicts or unacceptable environmental impacts for the environment.

Section 960.5–2–2 Site Ownership and Control. Although the preclosure and the postclosure guidelines on site ownership and control are stated in similar terms (see § 960.4–2–8–2), they are related to different system guidelines (i.e., the preclosure and the postclosure system guidelines). Moreover, as stated in the preamble for § 960.4–2–8–2, the geographical extent of the land and the controls required also differ for the preclosure and the postclosure periods. However, the comments on these guidelines addressed common issues, which are discussed in § 960.4–2–8–2 of the preamble and are not repeated here.

Section 960.5–2–3 Meteorology. The principal objective of the preclosure guideline on meteorology is to ensure that the weather conditions at the site are favorable for the atmospheric dispersion of any radioactive emissions and to ensure compliance with the system guideline for preclosure radiological safety. Also of concern is the potential for extreme-weather phenomena that could affect the operation and safety of the repository.

A recurrent theme in the comments was the statement that any expected routine radioactive emissions from a repository should disqualify the site because these emissions would pose potential health hazards to local populations and repository workers. Two commenters requested that this disqualification be extended to include emissions to agricultural lands. On the other hand, two commenters pointed out that routine emissions are of significance only if the limits of 40 CFR Parts 190 and 191 are approached for the

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general population or the limits of 10 CFR Part 20 for the work force.

A site should not be disqualified simply because routine emissions of radioactive material are projected for repository operations. The repository operations will be such that these emissions will be very low, well within the limits prescribed by applicable regulations and standards. Moreover the DOE does not intend to rely solely on natural meteorological conditions to protect the public from preclosure emissions; it intends to rely on the engineered design of the repository. The safety of this design will be demonstrated in the license application to the NRC. However, to protect the public from the releases that might occur under unlikely accident conditions or during normal operations, the first potentially adverse condition in the guideline covers site-specific meteorological conditions pertinent to the atmospheric transport of radionuclides (i.e., the prevalence of meteorological conditions under which the emissions would be likely to be transported toward localities with higher population densities than the average for the region). To clarify the concern for protecting the population, the meteorology guideline has been reworded.

Some commenters asked the DOE to clarify what it meant by "high potential for extreme-weather phenomena," and several suggested that severe winter storms be included in this category. In evaluating sites, the potential for, and the severity of, extreme-weather phenomena will be estimated on the basis of historical meteorological records. The second potentially adverse condition, which pertains to extreme-weather phenomena, was rewritten to reflect the historical basis for the evaluation; in addition, it was expanded to include severe and frequent winter storms.

Section 960.5–2–4 Offsite Installations and Operations. The preclosure technical guideline on offsite installations and operations (formerly offsite facilities) has two objectives: (1) to ensure that the impacts of any nearby industrial, transportation, and military installations and operations, including atomic-energy defense activities, on repository siting, construction, operation, closure, and decommissioning are adequately considered and (2) to ensure that any radionuclide emissions from such installations, when combined with preclosure emissions from the repository, would not lead to total radiological exposures in any unrestricted area greater than those allowed by the requirements specified in the pertinent system guideline.

Nine comments were directed specifically toward the proximity of a repository to other nuclear facilities with radioactive effluents at or near the limits specified in 40 CFR Parts 190 and 191; all recommended that such a condition be considered disqualifying, rather than potentially adverse. The comments generally appear to be based on the requirements of 40 CFR 191.03(a) that, for any facilities covered by 40 CFR Parts 190 and 191, the combined annual dose equivalent delivered to any member of the public shall not exceed the limits specified by these standards. The guideline recognizes that the presence nearby of industrial, transportation, and military installations and operations, including atomic-energy defense activities, could be detrimental and requires that the combined releases from these sources and the repository meet the requirements specified in Section 960.5–1(1) for unrestricted areas. The pertinent potentially adverse condition recognizes the presence of nuclear installations and operations with actual or projected releases near the maximum value permissible under 40 CFR Parts 190 and 191. Because such releases might be accommodated by engineering measures, the potentially adverse condition was not changed to a disqualifying one in the guidelines of November 1983.

Added to the final guideline for offsite installations and operations was a disqualifying condition related to atomic energy defense activities that are expected to conflict irreconcilably with repository siting, construction, operation, closure, and decommissioning. This addition was made in response to the NRC's preliminary concurrence condition 7, which asked the DOE to develop new disqualifying conditions that (1) would correspond to the factors cited in Section 112(a) of the Act and (2) could be applied early in the siting process. The DOE had concluded that a specific reference to atomic-energy defense activities in the qualifying condition was sufficient to satisfy the requirements of Section 112(a), but, after further consideration, decided that an explicit disqualifying condition could be developed to accommodate the NRC.

Three comments requested that the other potentially adverse condition, which is related to the presence of nearby potentially hazardous installations or operations, be changed to a disqualifying condition. There were also two suggestions that the word "unacceptable" in § 960.5–2–4(b)(1) of the alternative guidelines be changed to "adversely" in order to broaden the consideration.

As mentioned above, the identification of a potentially adverse condition requires a detailed evaluation of the condition. The results of such an evaluation must indicate that the potential for radionuclide releases does not exceed the limits specified in § 960.5–1(1). The DOE therefore does not accept the suggestion to change the potentially adverse conditions to disqualifying conditions; however, the word "unacceptable" was changed to "adversely."

Several comments pointed out inconsistencies in terms, recommending that a more-inclusive term be substituted for "offsite facilities" to express the broader concerns of the public. The question as to why offsite facilities are not of concern for the postclosure period was also raised. The DOE agrees that the use of terms was inconsistent. Accordingly, the term "installations and operations" is used consistently throughout the final guideline. Offsite facilities are not a postclosure issue, because no emissions will be released from the repository after closure. In addition, the words "siting" and "decommissioning" were added to the qualifying condition of the final guideline to make it more encompassing.

Environment, Socioeconomics, and Transportation

Section 960.5–2–5 Environmental Quality. The objective of the environmental quality guidelines is twofold: (1) to ensure that environmental impacts will be considered throughout all stages of the program and that impacts can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors, and (2) to ensure that the requirements of system guideline § 960.5–1(a)(2) are met.

Comments on the proposed environmental protection guideline were concentrated in two major areas: proximity of a potential respository site to a protected natural area, such as a park, and mitigation of environmental impacts associated with repository development. To accommodate these concerns, a number of changes were made to clarify the disqualifying conditions and to supplement the potentially adverse conditions in these areas. In addition, minor changes were made for clarification in the favorable conditions and the qualifying conditions.

These changes are discussed individually below.

In the guideline of November 1983, the qualifying condition was expanded by adding "closure and decommissioning" to repository activities requiring environmental protection. The qualifying condition was revised to state specifically that the quality of the environment "in the affected area," as well as the actual repository site, will be protected. The definition of "affected area" was modified to reflect this usage.

In the November 1983 guidelines, the qualifying condition included the statement "and projected significant adverse environmental impacts in the affected area can be mitigated to the extent practicable." The final version says "and projected environmental impacts in the affected area can be mitigated to an acceptable degree." The term "significant adverse" is thought to be redundant in this context, and the phrase "to an acceptable degree" is thought to promise greater protection than "to the extent practicable." The word "programmatic" was added to the list of considerations to be weighed in determining what is meant by "to an acceptable degree," correcting an inadvertent omission in a previous draft. Additionally, the qualifying condition was changed to delete the phrase "the health and welfare of the public" to avoid redundancy with the system guideline (§ 960.5-1(2)). (This change was also made in the first disqualifying condition, as discussed below.) The adverb "adequately" was added to the phrase "environment in the affected area * * * will be *adequately* protected" to clarify the degree to which the DOE will afford protection to the environment and to be consistent with the language of the Act (Section 111(b)) regarding the necessary level of environmental protection.

Several commenters suggested that selection of a repository site and support systems should ensure that potental environmental impacts are minimized to the greatest extent possible. Similiar comments urged the DOE to apply the ALARA (as low as reasonably achievable) principle to both engineered measures and siting decisions. The DOE will evaluate alternative mesures to minimize or avoid significant environmental impacts and will adopt reasonable mitigating measures. What is reasonable in a given situation is influenced by a number of factors, including cost, technology, and other environmental and socioeconomic impacts. The DOE's perspective on what is reasonably achievable in mitigating environmental impacts is explained in the final rule by listing the factors that will be considered in making judgments of this nature. The DOE maintains, however, that one cannot apply the ALARA principle to the site-screening process when limited information is available to make an informed judgment as to what constitutes ALARA.

In response to a comment, the first favorable condition was modified to reflect timely compliance with environmental requirements applicable to the site "and the activities proposed to take place thereon." Also, since environmental impacts will occur in the future and regulatory requirements generally apply in the future, the favorable condition now reflects a "projected ability" to meet such requirements.

The final guideline includes a change in the second favorable condition. The DOE defined "reasonable mitigating measures" by adding the phrase "taking into account programmatic, technical, social, economic, and environmental factors."

In response to comments, the proposed environmental guideline was expanded to include six potentially adverse conditions, and in the final rule certain modifications have been made in response to further comments. In the first potentially adverse condition, the term "major" was added in the phrase "projected major conflict with applicable Federal, State, or local environmental requirements." This change was made to clarify the nature of a conflict that would trigger a potentially adverse condition. It is believed that a minor conflict is more likely to be resolved. One commenter asked whether a State or local government could impose environmental restrictions sufficient to prevent a site from being chosen in the jurisdiction, as they believe the first potentially adverse condition suggests. The DOE will consider all applicable environmental laws in the site-screening process.

Another commenter suggested that the term "probable" be deleted from the first potentially adverse condition. The term "projected" has been substituted.

In the second potentially adverse condition, the term "minimized" was changed to "mitigated," in response to a comment. This change is appropriate since the term "mitigate"is used throughout this guideline. Two commenters suggested that the term "significant" be deleted from the second potentially adverse condition. The DOE disagrees. Not all adverse environmental impacts are automatically serious enough to be included in this category.

A number of commenters suggested that the third potentially adverse condition, regarding protected natural areas, should be a disqualifying condition. Others pointed out that a repository would not necessarily conflict with the designated use of the resources cited in the Act (i.e., components of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, and National Forest Land). The DOE's position is that the above-mentioned resources should be given special consideration in repository-siting decisions, and all of them are listed in the third potentially adverse condition.

Several commenters on the third potentially adverse condition suggested that both direct and indirect adverse environmental impacts need to be considered. The DOE agrees. Others suggested that the severity of the impact determines whether a potentially adverse condition exists. To accommodate both concerns, the DOE deleted "direct" to indicate that both direct and indirect environmental impacts would be considered and inserted "significant" to clarify that "significant adverse environmental impacts" on the designated natural resources would trigger the potentially adverse condition.

One commenter requested that the third and fourth potentially adverse conditions be combined. The DOE disagrees. The language as written best distinguishes the treatment of different lands controlled by different government entities. Because the resources in the fourth condition vary from State to State, the specific resources cannot be listed all inclusively. Furthermore, since many different kinds of resources could be at issue, a two-part test is appropriate.

In response to numerous comments, particularly from interested States, the DOE added three potentially adverse conditions to ensure special consideration of a "significant State or regionally protected resource area, such as a State park, wildlife area, or a historical area;" "a significant Native American resource, such as a major Indian religious site;" and "critical habitats for threatened or endangered species." In response to a comment, the DOE added "other sites of unique cultural interests" to the list of resources warranting special consideration.

One commenter suggested adding a potentially adverse condition that would cover the management and disposal of mine spoils. The DOE disagrees. Such potential adverse environmental impacts as may arise from the management and disposal of mine spoils are covered by the second potentially adverse condition. Another commenter asked that the DOE "recognize local or regional engineered water supply systems as a potentially adverse or a disqualifying condition." The DOE disagrees since impacts on such systems are covered by other potentially adverse and disqualifying conditions, such as potentially adverse condition 2 and disqualifying condition 1. One commenter said that the term "potentially adverse condition" is vague. The term has been defined in the glossary (§ 960.2 of the guidelines).

The greatest number of comments on the environmental guideline, both in the proposed guidelines and in the alternative guidelines, pertained to two disqualifying conditions. Both of these disqualifying conditions were retained in the rule of November 1983, but were modified in response to comments, and, in response to comments, a third was added.

In its November 1983 version, the phrase "cannot be mitigated" was modified by the phrase "by reasonable measures, taking into account technical, social, and economic, and environmental factors." In addition, the term "unsatisfactory" was changed to "unacceptable." "Unsatisfactory" was originally chosen to be consistent with the descriptions of the environmental referral process in Part 1504 of the Council on Environmental Quality regulations implementing the National Environmental Policy Act of 1969. However, this change was made to more clearly reflect the fact that a judgment on the acceptability of environmental impacts is involved here. Upon further consideration, this wording was modified in the final guidelines as discussed below.

The first disqualifying condition is now amended in the final guidelines to include "siting" in the list of activities that the condition covers. This stage was inadvertently omitted from an earlier draft.

The phrase "would result in an unacceptable adverse impact on the health and welfare of the public or the quality of the environment, if such impact cannot be mitigated by reasonable measures" has been replaced by "the quality of the environment in the affected area could not be adequately protected or projected environmental impacts in the affected area could not be mitigated to an acceptable degree." This change was made to delete a redundancy in considering the health and welfare of the public, which is covered by the system guideline (§ 960.5-1(a)(2)), and to clarify the need for protecting the environment both now and in the future. Furthermore, the word "programmatic" was added to the list of factors to be weighed in determining the acceptability of the results of impact mitigation.

A commenter asked whether mitigation in this and other places includes compensation. It does, as indicated in the definition of the term in § 960.2 of the guidelines.

Numerous comments were received on the second disqualifying condition, which referred to the coincidence of the restricted area or repository support facilities with the resources named; some expressed concern that it was too narrow, others suggested that it was appropriate. Several commenters argued that proximity to a protected area should be a disqualifying condition, while others suggested that the word "proximity" should be eliminated from the rule to minimize the opportunity for subjectivity in decision making. Some commenters objected to the two-part test in the disqualifying condition, arguing that location of a repository within the boundaries of a protected area is evidence of an irreconcilable conflict.

In this regard, the proposed guidelines did not automatically disqualify a site located within a protected area, because the DOE contends that it could be possible, in certain situations, to locate a repository within a protected area in such a way that it would not adversely affect the dedicated purpose of the area. However, in response to the concerns expressed, the alternative guideline was made more specific with respect to the potential conflict between a proposed repository site and a significant national protected resource. The gideline of November 1983 was made even more specific in that it enumerated the resources to be protected. The second disqualifying condition was expanded into two conditions, as follows:

(2) Any part of the restricted area or repository support facilities would be located within the boundaries of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the National Wild and Scenic Rivers System.

(3) The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated use of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the National Wild and Scenic Rivers System, or any comparably significant State protected resource that was dedicated to resource preservation at the time of the enactment of the Act.

The protected areas listed in these two disqualifying conditions did not include National Forests. Because the charters of National Forest Lands call for multiple uses, including mining, the DOE's position was that the appropriateness of including a repository among these multiple uses would have to be evaluated case by case.

The term "disturbed zone" was changed to "restricted area," which can be more reasonably applied to the required assessment (i.e., the disturbed zone is a projected fringe area far below ground that is related to postclosure, not preclosure, requirements). The phrase "any part of" was added to the second disqualifying condition to alleviate concerns that the entire restricted area or repository support facilities would have to lie within the protected area to trigger the disqualifying condition. Another commenter suggested replacing the word "would" with the word "could" in the second disqualifying condition. The DOE disagrees. The elimination of a site on the basis of what amounts to speculation at the screening stage may unnecessarily eliminate a good site.

Although several commenters suggested alternative phrases, the phrase "would conflict irreconcilably with the previously designated use" was used in the new disqualifying condition, though modified (see below) because the DOE maintains that a conflict can be adequately determined to be "irreconcilable."

The third disqualifying condition addresses State concerns about significant State protected resources. The intent is to afford both national and comparably significant State protected resources the same kind of protection.

The third disqualifying condition was further revised during the NRC concurrence process by the addition of two terms. The first, "resource preservation," is the "previously designated use" which the DOE considers the appropriate baseline condition against which to measure "irreconcilable conflicts." Second, in its concurrence condition 7, the NRC requested the addition of National Forest Lands to the list of resources covered by this disqualifier. After considering this request, the DOE agreed that the irreconcilable conflict with a previously designated resource-preservation use of a National Forest should disqualify a site. The disqualifying condition now reads as follows:'

(1) The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated resource-preservation use of a component of the National Park System, the National Wildlife refuge System, the National Wilderness Preservation System, The National Wild and Scenic Rivers System, or National Forest Lands, or any comparably significant State protected resource that was dedicated to resource preservation at the time of the enactment of the Act.

Several commenters raised various miscellaneous points and concerns. One commenter was concerned that the displacement of homes and families is considered to be a favorable condition and that priority is given to wildlife over people. The DOE disagrees that the guidelines either express or imply either situation. The DOE states, in several places in the guidelines, that the first priority of the site-selection process is the health and safety of the public.

Another commenter said that the environmental quality guideline does not ensure the suitability of the geologic conditions of the site. It is implicit in this guideline that, in order to protect the environment, the geologic conditions must be suitable. Moreover, such suitability is ensured by the postclosure system and technical guidelines.

Finally, several commenters suggested that the DOE include the environmental quality guideline in the postclosure guidelines. The DOE disagrees. The object of the environmental quality guideline, as stated at the beginning of this section of the preamble, is to protect the quality of the environment throughout all stages of geologic repository siting. Postclosure protection will be provided by the system guidelines, which mandate compliance with 10 CFR Part 60 and 40 CFR Part 191.

Section 960.5-2-6 Socioeconomic Impacts. The objective of the technical guideline on socioeconomic impacts is to ensure that any significant adverse socioeconomic impacts of repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation and the requirements of system guideline § 960.5-1(a)(2) can be met.

The DOE is committed to a program of socioeconomic-impact measurement and mitigation. Mitigation, as defined by the Council on Environmental Quality, includes actions that will avoid, minimize, reduce, or compensate for adverse impacts (40 CFR 1508.20).

The potential social and economic impacts of geologic repositories were of concern to a number of commenters. The principal issues were (1) the socioeconomic impacts associated with the labor-force requirements of the repository, (2) adverse effects on primary sectors of local economies (e.g. tourism), (3) adverse effects on water supplies, and (4) the psychological effects of perceived risk.

Some commenters were concerned that the labor-force requirements of a repository would impose undue hardship on the private and public service capabilities of affected localities. The viewpoints expressed were often conflicting; for example, some suggested that socioeconomic impacts could be mitigated through stringent siting requirements, such as requiring that two-thirds of the labor force live within a reasonable commuting distance of the repository, but others felt that the lack of an available labor force should be a favorable condition; one comment said that the potential for increased employment should not be considered a favorable condition. One commenter stated that disruption to primary sectors of the economy of the affected area should be a disqualifying condition. Another felt that irreversible changes in a chosen way of life should be a potentially adverse condition and deplored the possible loss of agricultural land.

The DOE feels it would be inappropriate to specify quantitative labor-force requirements because there are so many variable factors that cannot be controlled. It would be possible, for example, to construct housing at the site for transient labor if sufficient labor were not available within a reasonable commuting distance from the site. The creation of new jobs for locally available labor would be received favorably in most areas; however, an influx of new workers could have significant adverse socioeconomic impacts. For these reasons, the potentially adverse and favorable conditions concerning the supply of labor were retained. In areas where new jobs might not be welcomed, the DOE will work with the State, affected Indian tribes, and the public to identify suitable means of mitigating unwanted impacts and preserving and enhancing the quality of life. Since adverse socioeconomic impacts on affected local economies can generally be mitigated, the DOE does not believe that such impacts are disqualifying. Where agriculture is a primary sector of the affected economy, the loss of agricultural land would be a potentially adverse condition.

A commenter stated that a major disruption of the local economy is almost certain and observed that the guidelines on population density and distribution (§ 960.5-2-1) and socioeconomic impacts (§ 960.5-2-6) are somewhat contradictory. Another asked that socioeconomic and environmental impacts along waste-transportation routes be addressed, and a third suggested that postclosure impacts be included in the socioeconomic guideline.

The DOE agrees that some disruption will be experienced by the local economy, just as it is as in most large-scale industrial developments. However, because most socioeconomic impacts can be anticipated and mitigated, major disruptions can be avoided in most cases. When guidelines §§ 960.5-2-1 and 960.5-2-6 (population density and socioeconomics) are taken together, areas of low population density within a commuting distance of significant labor pools could gain favor in site comparisons if the technical qualifications are equal. Socioeconomic and environmental impacts along local transportation routes will be addressed in the siting process. Postclosure impacts, however difficult to assess, will be the subject of impact-mitigation discussions and agreements between affected States, affected Indian tribes, and the DOE.

Other comments said that (1) the guidelines should emphasize net gains in the overall economy and in employment, (2) the term "affected area" should be changed to "affected region," and (3) the cost of the repository should be taken into account as a socioeconomic impact.

The DOE agrees that net gains in employment and in the local economy should be considered a favorable condition and has revised the guideline accordingly. With respect to the use of "affected area" versus "affected region," repository development may produce socioeconomic impacts in an area of several counties, but it will probably have minimal effect on the economy of an entire region of the country. The costs of the repository need not be treated as a socioeconomic impact because they will be borne by the owners of the radioactive waste. Furthermore, cost ranks below public health and safety, the quality of the environment, and socioeconomic conditions.

Also mentioned were possible adverse impacts on agriculture, tourism, and recreation, but another commenter pointed out that the services and facilities developed for repository workers and their families could enhance the ability of an area to accommodate tourists and seasonal populations.

The DOE is aware of the concern about adverse effects on agriculture, tourism, and recreation. One potentially adverse condition in the socioeconomics guideline is the potential for major disruptions of primary sectors of the economy of the affected area. The DOE will work with States, affected Indian tribes, and localities to anticipate and mitigate such effects if they arise.

Commenters on the alternative guidelines were also concerned about the potentially adverse condition regarding the acquisition of water rights and the effects thereof. One maintained that a model of water usage should be developed. Two commenters asked that disqualifying conditions be specified for water supplies. One commenter requested that the DOE add water use to acquisition of water rights as a potentially adverse condition. Several commenters asked for a guideline that would protect producing aquifers.

The DOE will evaluate water usage during the engineering design of a repository in a specific rock type. With respect to the requests for disqualifying conditions for water supplies, the qualifying condition for the socioeconomic guideline indicates that a potential site is not qualified unless adverse impacts on water supplies can be mitigated or compensated. This guideline reflects the DOE's position that, if adverse impacts on water supplies can be mitigated, then it is not appropriate to disqualify a site because of potential adverse impacts on water supplies. The issue is the ability to mitigate or compensate for adverse impacts, not the potential for their occurrence. The DOE expects that, where water is scarce, there will be controls on its use. Where water usage is controlled by administrative means other than water rights per se, the DOE will consider the acquisition of water through such other administrative controls to be equivalent to the acquisition of water rights. Producing aquifers are protected through the system guideline on environmental quality and the technical guideline on socioeconomics.

One commenter was concerned that the perceived risk of a repository might induce anxiety and stress, causing some people to leave the area, and complained that the issue was not addressed in the guidelines.

The DOE recognizes that the risk of new technologies involving hazardous materials may be perceived to be greater by the general public than it is by technical experts. However, past experience with other new technologies suggests that the anxieties of the public may be alleviated as the technology is seen to be effective and its benefits become more apparent. The overriding emphasis of the guidelines on public health and safety, as well as the DOE's commitment to open communication and public involvement throughout the siting process, is intended to help alleviate public concerns about the risks of a repository. Perceived risk, however, is not an appropriate topic for general repository-siting guidelines; it is a subjective condition that cannot be fairly compared among sites.

The DOE recognizes that the possible impacts of rapid, large-scale growth in sparsely populated rural areas are legitimate concerns in siting a major facility. Therefore, the socioeconomics guideline has been revised to more clearly indicate that the existing socioeconomic base (population, labor force, infrastructure, services, etc.) will be explicitly considered in site selection. The final guideline on socioeconomics includes a qualifying condition, a set of four favorable conditions, and a set of four potentially adverse conditions. Because of the complexity of socioeconomic interactions, the possibility of mitigation, and the extensive analysis and planning required by the Act, the DOE took the position in the guidelines of November 1983 that socioeconomic impacts do not represent an absolute disqualifying condition.

The qualifying condition in the final guideline will ensure that any significant adverse social or economic impacts will be addressed; it will also ensure that the system guideline, whose objective is to protect the socioeconomic well-being of the population, will be met. The qualifying condition also specifies the range of socioeconomic considerations that will be addressed in the analysis.

The four favorable conditions in the final guideline are (1) the ability of an affected area to absorb project-related population changes; (2) the availability of an adequate labor force; (3) projected net increases in employment and in public and private revenues; and (4) the lack of significant disruption to primary sectors of the economy of the affected area.

The four potentially adverse conditions are (1) potential for significant impacts on community services, housing, and public revenues; (2) the lack of an adequate labor force; (3) water-right acquisition that would have potential adverse impacts on the development of the affected area; and (4) potential for major disruption to primary sectors of the economy of the affected area. Since these potentially adverse conditions could be mitigated in many cases, they would not disqualify a site.

In response to the NRC's preliminary concurrence condition 7, which requested additional disqualifying conditions that are directed at the specific factors listed in Section 112(a) of the Act, disqualifying condition § 960.5–2–6(d) was added to the guideline on socioeconomic impacts. This disqualifying condition is concerned with potential effects on the rights of users of water and proximity to water supplies. It was not included in the November 1983 guidelines because these factors were implicitly or explicitly included in the system guideline on environmental quality and the qualifying condition for socioeconomic impacts ("competition for resources such as land, water, and construction materials"). However, to accommodate the NRC's request, the DOE developed an explicit disqualifier. Although this disqualifying condition could have been included in guideline § 960.4–2–8–1, Natural Resources, it was included here because the DOE believes that the most serious effects of a significant degradation of major water sources would be socioeconomic. In editing the final guidelines, the explanatory paragraph that followed the statement of the qualifying condition was deleted because the parameters to be considered are now listed in Appendix IV.

Section 960.5–2–7 Transportation. The objective of the transportation guideline is to ensure that proper consideration is given to the transportation of waste to a repository site, as it could affect the health and safety of the public, the environment, and the cost of waste disposal. The guideline requires the evaluation of a site's proximity to adequate highways and railroads, the characteristics of access routes from existing highways and railroads to the site, the costs and other impacts of designing and constructing the access routes, and the impacts of transporting waste over the access routes. The guideline indirectly requires the consideration of proximity to the sources of waste because one of the favorable conditions is stated in terms of a comparison of costs and risks among sites.

In the proposed guidelines of February 1983, transportation was treated as a subset of population density and distribution. Many comments on the proposed guidelines emphasized the importance of transportation and the need for a separate, more comprehensive guideline. Some comments raised generic issues and problems that cannot be solved by the siting of a repository; such issues are not appropriate for guidelines that govern siting. Apparently, the purpose of including transportation in the siting guidelines was not clearly understood.

In response to the many requests, the DOE prepared a separate, more comprehensive guideline on transportation. This guideline is not intended to govern the movement of waste over the national system of highways and railroads; regulations of the NRC (10 CFR Part 71) and the Department of Transportation (49 CFR Parts 171–178) govern that part of waste transportation. The guideline is intended to govern only the transportation issues that are important in choosing sites for characterization and development. The guideline now makes clear that it is concerned primarily with site-specific conditions. It does not address the nationwide transportation of waste, beyond the comparative assessment of costs and risks for the considered sites.

A number of comments stated that there are transportation-related factors that would disqualify a site and called for specific disqualifying conditions in the guideline. The examples cited included transport over rivers, watersheds, reservoirs, high bridges, and through Indian reservations; rail access routes that are too long; concentration of routes through population centers; transport over routes that do not comply with DOT regulations; and the lack of direct rail access. Also cited were increased risk or environmental impact relative to other sites or radiation doses from transportation over local highways in excess of the EPA limit in 40 CFR Part 191.

The DOE does not feel justified in defining explicit disqualification thresholds, because transportation costs, risks, and impacts must be evaluated in relation to the repository system as a whole. None of the suggested disqualifying conditions would make the construction of a satisfactory repository system so difficult that a site should be eliminated simply because the condition is present. Consequently, no disqualifying conditions have been added to the transportation guideline. Furthermore, EPA standards cited above are not applicable to transportation, nor is it appropriate for the DOE to include such standards in its transportation exposure assessments. However, the maximum individual exposure along local access routes is expected to be a very small fraction of that due to natural background radiation.

Some comments cited as adverse conditions (1) transport over bridges whose height above the terrain below exceeds the conditions of the NRC hypothetical accident tests or (2) local highways and railroads that are in poor condition. These considerations are included in the revised guideline under potentially adverse conditions that would require further evaluation or possibly mitigation measures.

Several comments cited transportation-related conditions that should be considered in siting the repository. Examples are access to the site; the feasibility of access route construction, cost and environmental impacts; visual impacts, air pollution, and noise impacts; adverse weather conditions; extremely heavy loads on railroads; and the availability of air and water transportation modes. Extremely heavy loading is not included because the loaded railroad cars serving the repository will meet standard railroad requirements on wheel loading and spacing and gross loadings.

Two commenters discussed the assumptions made by the DOE in previous transportation assessments and pointed out that the current assumption about the fraction of waste transported by rail (90 percent) contradicts the current practices of nuclear-reactor facilities. They also suggested that rail access is a primary qualifying condition and that the DOE should use dedicated trains for transporting waste to the repository.

Various assumptions about the fractions of waste transported by rail and truck have been and will continue to be used by the DOE in assessing the risks, costs, and environmental impacts of transporting waste to a repository. It is neither necessary nor desirable to fix on this set of assumptions now; analyses will be done to cover a range of reasonable values. The actual values that will pertain 15 to 20 years hence, when operations begin, are difficult to predict now. Many logistic, economic, and service factors will be involved in the choice between rail and truck transport. The use of dedicated trains has been studied by the Interstate Commerce Commission. Whether they will be used is still under consideration, but is not an issue for siting guidelines to specify.

One commenter cited the cost of access-route construction as a major factor and suggested that a limit be placed on transportation-related costs in terms of a maximum percentage of the total disposal cost; exceeding this value would disqualify the site. The DOE does not agree that any minimum level of transportation-related cost alone should disqualify a site, because such costs may be offset by other site-specific factors, including the costs of the repository itself. Transportation-related costs, including access-route construction, will be included in the total system cost for comparison with the costs of other siting options.

One commenter stated that the guideline does not offer an adequate method for comparing transportation costs and risks and the DOE must develop such methods for accurately making such comparisons among siting options. The comment goes on to say that specific origin-and-destination pairs, specific routes, and route-specific data on population density, accident rates, travel restrictions, and the site should be considered.

The DOE contends that current methods and analytical tools are adequate, but is nevertheless continuing to make improvements in them. General guidelines for siting purposes are, in any case, not an appropriate place to require the development of improved methods.

A number of comments emphasized the importance of waste-shipment routing and the population density along such routes. This is largely a generic issue, inappropriate for siting guidelines, that the Department of Transportation (DOT) has addressed in its recent final rule (49 CFR 177.825). The DOT has defined preferred routes but given to the States the opportunity to identify and analyze alternative routes, in accordance with DOT guidelines, and designate such routes that they may deem necessary to accommodate local conditions. This may include routes in the vicinity of the repository if considered necessary by State officials. Thus, no specific treatment of this subject appears in the guidelines.

Several comments requested greater emphasis on the proximity of repositories to waste sources for both the first and subsequent repositories. A favorable condition in the transportation guideline requires the evaluation and comparison of total life-cycle waste-transportation costs and risks for each siting option. The guideline on regionality (§ 960.3–1–3) requires consideration of the proximity of the second repository to locations where radioactive waste is generated or temporarily stored.

A number of comments addressed such generic issues as the role of the States in regulating the transportation of nuclear materials, the adequacy of shipping casks, the applicability of specific EPA standards, and defense-waste shipments to a commercial repository. In the opinion of the DOE, these comments did not address issues that would allow differentiation among proposed sites, since the same conditions exist for the various siting options. In addition, many of these comments raised issues that are either not related to the guidelines or are covered under other applicable Federal regulations that are the responsibility of other Federal agencies. Consequently, these comments are not reflected in the final guidelines.

In editing the final guidelines, the statement of the qualifying condition (§ 960.5–2–7(a)) was revised by simplifying the phrase "radiological or non-radiological risk to the public health and safety" to "risk to the public" and by inserting the phrase "taking into account programmatic, technical, social, economic, and environmental factors."

Ease and Cost of Siting, Construction, Operation, and Closure

Section 960.5–2–8 Surface Characteristics. The preclosure guideline on surface characteristics is concerned with conditions that are important to the ease and cost of siting, constructing, operating, and closing a repository. In sites that are prone to periodic flooding, are located in a rugged terrain, or have other adverse surface features, special measures may be necessary for repository construction, operation, and closure. The cost of repository construction, operation, and closure could rise to prohibitive levels if a large number of special measures were necessary for these phases. However, other features of the site—those that would significantly enhance waste isolation—could be more important than the higher costs associated with adverse surface characteristics.

Four commenters expressed concern about repository flooding through the possible failure of shafts, shaft liners, seals, or other engineered components of the repository; they suggested that such failures be added to the first potentially adverse condition in the alternative guideline, which dealt specifically with flooding (§ 960.5.2.8(b)(1)). The DOE agrees with this suggestion because the flooding of surface or subsurface facilities could endanger the safety of personnel and interrupt repository operations. The phrase "or the failure of engineered components of the repository" was therefore added to the potentially adverse condition in the final guideline. This phrase was selected because it is a general statement that encompasses all of the concerns raised by the commenter.

One commenter requested that the potentially adverse condition concerned with flooding be elevated to a disqualifying condition. The DOE decided against this approach because the existence of surface characteristics with a significant potential for flooding does not necessarily mean that the repository will be flooded. Simple engineering measures, such as dikes or berms, could reduce the risk of flooding to an acceptable level that would meet applicable licensing requirements. Such measures have been used for both nuclear and nonnuclear facilities for many years.

Two commenters pointed out that in some specific instances the favorable condition of "generally flat terrain" would be unfavorable. One felt that slow and uniform drainage in flat areas might affect the hydrologic performance of the repository; the other felt that waste disposal in the side of a mountain (above surrounding floodplains) would not meet the favorable condition. After evaluating these concerns, the DOE still contends that a generally flat terrain is a favorable condition because it facilitates construction, operation, and closure; however, a favorable condition that specifically addresses the drainage question was added to the final guideline. The second commenter is correct in stating that a repository located in rugged terrain or in the side of a mountain may not be able to meet this favorable condition, but not meeting a favorable condition does not disqualify a site. It would, however, indicate the need for special measures, and hence potential increases in costs during construction, operation, and closure.

Three commenters requested that, in the alternative guideline, the statement "compliance with applicable non-radiological regulations" be expanded to include air-quality standards and radiological requirements. The DOE modified the guideline by deleting the reference to applicable non-radiological regulations because they are already generally covered by the final guideline on environmental quality (§ 960.5–2–5). The DOE believes that, for these general guidelines, a general treatment of non-radiological requirements is more appropriate than specific examples of such requirements. Similarly, air quality standards were already covered by the first two potentially adverse conditions and the first disqualifying condition of the alternative guideline on environmental quality. Preclosure radiological requirements are specifically addressed in the first preclosure system guideline (§ 960.5–1(a)(3)) by invoking the requirements of 10 CFR Part 20, 10 CFR Part 60, and proposed 40 CFR Part 191, Subpart A.

Three commenters requested additions to the surface-characteristics guideline that are already covered in other preclosure guidelines—namely, personnel safety, the standards the Occupational Safety and Health Administration (OSHA), and the offsite disposal of salt. Personnel safety and OSHA requirements are covered by the preclosure guideline on rock characteristics (§ 960.5–2–9). The offsite disposal of salt is covered by the constraints imposed under the preclosure guideline on environmental quality (§ 960.5–2–5).

Among the suggestions for the surface-characteristics guideline was the addition of favorable soil characteristics and conditions. Even though favorable soil characteristics and conditions might make construction and site restoration slightly easier, the DOE does not believe that these features should be significant in selecting a repository site. Two issues raised in the comments on the preclosure guideline on rock characteristics are not pertinent to this siting guideline: preclosure monitoring and reliance on engineered barriers (see Section III.A for DOE responses to the engineered-barrier issue).

Section 960.5–2–9 Rock Characteristics. The objective of the preclosure guideline on rock characteristics is to ensure that due consideration is given to those characteristics of the host rock that may affect (1) the ease and cost of repository construction, operation, and closure and (2) the safety of repository workers. Among those characteristics are the thickness and lateral extent of the host rock, geomechanical properties that are favorable for the maintenance of underground openings, and conditions that would allow the construction of shafts and the underground facility with reasonably available technology.

Ten commenters were concerned that the disqualifying condition in the draft revised guideline did not specifically include the safety requirements of the Occupational Safety and Health Administration and the Mine Safety and Health Administration. This concern arose because the proposed disqualifying condition stated that "the site shall be *disqualified* if the applicable nonradiological safety requirements of the DOE could not be met." To eliminate this concern, the DOE rewrote the disqualifying condition as follows: "The site shall be disqualified if the rock characteristics are such that the activities associated with repository construction, operation, or closure are predicted to cause significant risk to the health and safety of personnel, taking into account mitigating measures that use reasonably available technology."

Five commenters objected to the phrase "engineering measures beyond the state of the art" in the second potentially adverse condition in the alternative guideline. As explained in the discussion of the postclosure guideline on rock characteristics, this phrase was changed to "engineering measures beyond reasonably available technology."

Four comments asked the DOE to reclassify the potentially adverse conditions as disqualifying ones. This was not done because, by itself, none of the potentially adverse conditions are necessarily unacceptable and hence should not disqualify a site. Their designation as potentially adverse ensures that these conditions will be given due consideration. Another comment suggested that the converse of favorable condition 960.5.2.9(a)(1) be used as a disqualifying condition. The converse of this condition would not be disqualifying, because, while the flexibility of designing and locating a repository would be reduced, the ability of the host rock to contain a respository would not be eliminated.

Three commenters expressed concern that retrievability was not adequately addressed in the alternative guidelines and felt that preclosure rock characteristics were important to ensuring retrievability. The DOE agrees that rock characteristics are important to retrievability, but feels that many other guidelines are also important in this regard. However, the retrievability issue is more pertinent to repository design than to site selection, and, if the requirements of the final guidelines taken as a whole are met, retrievability will be ensured. Furthermore, the DOE is required by 10 CFR Part 60 to maintain retrieval as an option for 50 years if unforeseen circumstances would require the removal of emplaced wastes.

Among the issues raised in the comments was that of thermal effects on in-situ stresses. In response to this concern, the DOE added a potentially adverse condition, § 960.4-2-3(c)(3), to specifically address thermal effects.

One commenter was concerned that the available data might not allow a complete analysis of the disqualifier contained in the proposed guidelines. This issue is covered by one of the implementation guidelines, "Basis for Site Evaluations" (§ 960.3-1-5), and Appendix III to the siting guidelines, which specifies what type of finding the DOE is to make at major decision points in the site-selection process.

Section 960.5-2-10 Hydrology. The preclosure technical guideline on hydrology is concerned with (1) the potential effects of ground water on the construction and sealing of shafts and other underground openings, including the repository itself; (2) the potential for flooding of underground workings by surface-water; and (3) the availability of water for repository construction and operation. Its objectives are to ensure that the geohydrologic setting will (1) be compatible with repository construction, operation, and closure and (2) not compromise the functions of shaft liners and seals.

Eleven commenters objected to the term "state of the art" in the potentially adverse condition of the alternative guideline. Some argued that the potentially adverse condition, as written with the "state-of-the-art" phrase included, should be disqualifying. Others suggested that the phrase should be replaced by "reasonably available technology" or similar words. The DOE agrees that "state of the art" is inappropriate because it suggests technology that may not have been fully demonstrated and tested and substituted the term "reasonably available technology," which is defined in § 960.2 of the guidelines.

The presence or absence of aquifers within or above the host rock was an issue raised by eight commenters. The absence of aquifers between the host rock and the land surface is recognized as a favorable condition in the preclosure guideline. Some commenters suggested that the presence of aquifers between the host rock and the land surface should be explicitly stated as a potentially adverse condition; others recommended that the absence of aquifers be a qualifying condition or, conversely, that the presence of aquifers be a disqualifying condition. The presence of aquifers between the host rock and the land surface must be carefully considered in repository design and construction. However, many mines and other underground facilities have been successfully constructed below aquifers, and accepted and proved engineering measures are available to allow underground construction and operation under many types of ground-water conditions. That is not to say that some ground-water conditions may not require very costly engineering measures, or that some ground-water conditions may not be so severe as to preclude construction. For these reasons, the DOE did not stipulate the absence or presence of aquifers between the host rock in the qualifying condition of the preclosure hydrology guideline, but a potentially adverse condition deals with aquifers whose presence would raise serious questions about the feasibility of construction.

Four comments recommended that the converse of the favorable condition pertaining to the availability of potable and construction water be explicitly stated as a disqualifying condition; they believe that the unavailability of water for construction and operation should disqualify a site. The issue lies in the meaning of the words "available" and "unavailable." Water might not be available locally at a site, but it might be available from a source some distance away. Water must be available for construction and operation, and locally available water would presumably be less expensive than water obtained from a more distant source. Thus in the preclosure hydrology guideline the DOE assumes that water can be made available and regards ready availability as a favorable condition.

One commenter suggested the addition of a potentially adverse condition pertaining to a geohydrologic system that would not allow predictive modeling before construction. The rationale for this suggestion is related to the potential for adverse effects on the hydrologic system caused by construction activities. The difficulty of modeling is addressed in the postclosure geohydrology guideline as a potentially adverse condition, and the DOE believes it would be redundant to include a similar statement in the preclosure guideline.

In consideration of the NRC's request, in preliminary concurrence condition 7, for additional disqualifying conditions that address the factors specified in Section 112(a) of the Act, the DOE agreed to develop a disqualifier for the final preclosure guideline on hydrology. This condition, § 960.5-2-10(d), is concerned with the need to use engineering measures that are beyond reasonably available technology for exploratory-shaft construction or for repository construction, operation, or closure.

Section 960.5-2-11 Tectonics. The objective of the preclosure guideline on tectonics is to ensure that the selected site is in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity will be such that the requirements of system guideline § 960.5-1(a)(3) can be met.

Five commenters complained that no disqualifying conditions were proposed for the preclosure tectonics guideline. Some recommended that the opposite of the qualifying condition should be used, while others recommended that some of the potentially adverse conditions be changed to disqualifying ones. The DOE believed that the existence of a potentially adverse condition does not mean that the site is disqualified. The existence of any such condition would require an understanding of the condition to ensure that repository design and operation could adequately accommodate its effects. Using the converse of the qualifying conditions adds nothing to the guidelines since all acceptable sites must meet the requirements of the qualifying conditions. The guideline was therefore not changed to reflect these recommendations.

Two commenters felt that the historical record of earthquakes should be based solely on instrument recordings. This approach would severely limit the amount of historical data that could be considered because seismic recording equipment has been available for a relatively short period of time (20th century). In developing a historical record for seismicity, it is important to look as far back into the recorded past as can be done for a particular area of the country. While the DOE agrees that seismic-instrument recording should be included in the historical record, other historical records must also be used. For this reason the suggestion was not accepted.

One commenter recommended that "man-induced seismicity," a particular tectonic phenomenon, be added to the qualifying condition. The DOE believes that this particular aspect of tectonics is no more important than the other aspects and should not be called out separately. No change was made.

In response to the NRC's preliminary concurrence condition 7, the DOE reevaluated the preclosure guideline on tectonics and added a disqualifying condition. This condition is concerned with the need to use engineering measures beyond reasonably available technology to ensure that tectonic ground motion will not adversely affect exploratory-shaft construction or repository construction, operation, or closure. As shown in Appendix III to the siting guidelines, this disqualifying condition can be used early in the siting process (i.e., in the identification of potentially acceptable sites).

V. References

1. U.S. Department of Energy, Final Environmental Impact Statement—Management of Commercially Generated Radioactive Waste, DOE/EIS-0046F, October 1980.

2. U.S. Department of Energy, Mission Plan for the Civilian Radioactive Waste Management Program, draft, DOE/RW-0005, 1984.

3. U.S. Department of Energy, Program Objectives, Functional Requirements, and System Performance Criteria, NWTS-33(1), National Waste Terminal Storage Program, 1982.

4. U.S. Department of Energy, Site Performance Criteria, NWTS-33(2), National Waste Terminal Storage Program, 1981.

5. National Research Council–National Academy of Sciences, Geological Criteria for Repositories for High-Level Radioactive Waste, August 1978.

6. International Atomic Energy Agency, Site Selection Factors for Repositories of Solid High-Level and Alpha-Bearing Wastes in Geologic Formations, Technical Report No. 177, October 1977.

7. G.D. Brunton and W.C. McClain, Geological Criteria for Radioactive Waste Repositories, Y/OWI/TM-47, Office of Waste Isolation, Union Carbide Corporation, November 28, 1977.

8. U.S. Department of Energy, Final Environmental Impact Statement—Waste Isolation Pilot Plant, DOE/EIS-0026, October 1980.

9. Comptroller General of the United States, The Nation's Nuclear Waste—Proposals for Organization and Siting, EMD-79-77, General Accounting Office, June 21, 10079.

10. Congressional Record—House, October 18, 1979, p. H 9367 to H 9371.

11. U.S. Nuclear Regulatory Commission, "Advance Notice of Rulemaking on Technical Criteria for Regulating Geologic Disposal of High-Level Radioactive Waste," 10 CFR Part 60, May 1980.

12. U.S. Environmental Protection Agency, "Environmental Radiation Protection Standards for Nuclear Power Operations," 40 CFR Part 190.

13. U.S. Nuclear Regulatory Commission, "Standards for Protection Against Radiation," 10 CFR Part 20.

14. U.S. Nuclear Regulatory Commission, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," 10 CFR Part 60, Subpart E (final draft), November 18, 1982.

15. U.S. Environmental Protection Agency, "Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," 40 CFR Part 191, Federal Register, Vol. 47, pp. 58196–58206, December 29, 1982 (proposed rule).

16. U.S. Department of Energy, Record of Responses to Public Comments on Proposed General Guidelines for Recommendation of Sites for Nuclear Waste Repositories, DOE/RW-0001, Washington, D.C., 1983.

17. U.S. Nuclear Regulatory Commission, "Disposal of High-Level Radioactive Wastes in Geologic Repositories—Technical Criteria," 10 CFR Part 60, July 1983.

18. S.W. Lohman et al., Definitions of Selected Ground Water Terms—Revisions and Conceptual Refinements, U.S. Geological Survey Water-Supply Paper 1988, U.S. Geological Survey, 1972, p.21.

19. R.L. Bates and J.A. Jackson, eds., Glossary of Geology, 2nd edition, American Geological Institute, 1980.

VI. Compliance With the National Environmental Policy Act (NEPA)

The issuance of these guidelines is a preliminary decision making activity pursuant to Section 112(e) of the Nuclear Waste Policy Act of 1982 and therefore does not require the preparation of an environmental impact statement pursuant to Section 102(2)(C) of NEPA or any other environmental review under Section 102(2) (E) or (F) of NEPA.

VII. Regulatory Flexibility Analysis

The DOE certifies that these guidelines will not have a significant economic impact on a substantial number of small entities, since they merely articulate the proposed considerations for the Secretary of Energy's recommendations to the President of proposed sites for repositories. Accordingly, no regulatory flexibility analysis is required under the Regulatory Flexibility Act (5 U.S.C. 601 et seq.).

VIII. Paperwork Reduction Analysis

This rule contains no new or amended recordkeeping, reporting, or application requirement, or any other type of information collection requirement subject to the Paperwork Reduction Act (Pub. L. 96-511).

IX. Executive Order No. 12291

These final guidelines were reviewed under Executive Order 12291 (46 FR 13193). The DOE has concluded that the guidelines are not a "major rule" under the Executive Order, because they will not result in (1) an annual effect on the economy of $100 million or more; (2) a major increase in costs or prices for consumers, individual industries, and Federal, State, or local government agencies, or geographic regions; or (3) significant adverse effects on competition, employment, investment, productivity, innovation, or the ability of United States-based enterprises to compete with foreign-based enterprises in domestic or export markets. Pursuant to Section 3(c)(3) of the Executive Order, the final guidelines were submitted to the Director of the Office of Management and Budget for a 10-day review. The Director has concluded his review and had no comments.

List of Subjects in 10 CFR Part 960

Environmental protection, Geologic repositories, Nuclear energy, Nuclear materials, Radiation protection, Waste disposal.

(The Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 *et seq.*); Energy Reorganization Act of 1974 (42 U.S.C. 5801 *et seq.*); Department of Energy Organization Act of 1977 (42 U.S.C. 7101 *et seq.*); Nuclear Waste Policy Act of 1982 (Pub. L. 97-425, 96 Stat. 2201))

For the reasons set out in the preamble, Chapter III of Title 10 of the Code of Federal Regulations is amended as follows:

Issued at Washington, D.C., November 30, 1984.

Donald Paul Hodel,

Secretary of Energy.

Part 960 is added to 10 CFR Chapter III to read as follows:

PART 960—GENERAL GUIDELINES FOR THE RECOMMENDATION OF SITES FOR NUCLEAR WASTE REPOSITORIES

Authority: The Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 *et seq.*); Energy Reorganization Act of 1974 (42 U.S.C. *et seq.*); Department of Energy Organization Act of 1977 (42 U.S.C. 7101 *et seq.*); Nuclear Waste Policy Act of 1982 (Pub. L. 97-425, 96 Stat. 2201).

Subpart A—General Provisions

§ 960.1 Applicability.

These guidelines were developed in accordance with the requirements of Section 112(a) of the Nuclear Waste Policy Act of 1982 for use by the Secretary of Energy in evaluating the suitability of sites for the development of repositories. The guidelines will be used for suitability evaluations and determinations made pursuant to Section 112(b) and any preliminary suitability determinations required by Section 114(f). The guidelines set forth in this Part are intended to complement the requirements set forth in the Act, 10 CFR Part 60, and 40 CFR Part 191. The DOE recognizes NRC jurisdiction for the resolution of differences between the guidelines and 10 CFR Part 60. The guidelines have received the concurrence of the NRC. The DOE contemplates revising the guidelines from time to time, as permitted by the Act, to take into account revisions made to the above regulations and to otherwise update the guidelines as necessary. The DOE will submit the revisions to the NRC and obtain its concurrence before issuance.

§ 960.2 Definitions.

As used in this part:

"Accessible environment" means the atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere that is outside the controlled area.

"Act" means the Nuclear Waste Policy Act of 1982.

"Active fault" means a fault along which there is recurrent movement, which is usually indicated by small, periodic displacements or seismic activity.

"Affected area" means either the area of socioeconomic impact or the area of environmental impact, each of which will vary in size among potential repository sites.

"Affected Indian tribe" means any Indian tribe (1) within whose reservation boundaries a repository for radioactive waste is proposed to be located or (2) whose federally defined possessory or usage rights to other lands outside the reservation's boundaries arising out of congressionally ratified treaties may be substantially and adversely affected by the locating of such a facility: *Provided* That the Secretary of the Interior finds, upon the petition of the appropriate governmental officials of the tribe, that such effects are both substantial and adverse to the tribe.

"Affected State" means any State that (1) has been notified by the DOE in accordance with Section 116(a) of the Act as containing a potentially acceptable site; (2) contains a candidate site for site characterization or repository development; or (3) contains a site selected for repository development.

"Application" means the act of making a finding of compliance or noncompliance with the qualifying or disqualifying conditions specified in the guidelines of Subparts C and D, in accordance with the types of findings specified in Appendix III.

"Aquifer" means a formation, a group of formations, or a part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

"Barrier" means any material or structure that prevents or substantially delays the movement of water or radionuclides.

"Candidate site" means an area, within a geohydrologic setting, that is recommended by the Secretary of

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Energy under Section 112 of the Act for site characterization, approved by the President under Section 112 of the Act for characterization, or undergoing site characterization under Section 113 of the Act.

"Closure" means final backfilling of the remaining open operational areas of the underground facility and boreholes after the termination of waste emplacement, culminating in the sealing of shafts.

"Confining unit" means a body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.

"Containment" means the confinement of radioactive waste within a designated boundary.

"Controlled area" means a surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers 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.

"Cumulative releases of radionuclides" means the total number of curies of radionuclides entering the accessible environment in any 10,000-year period, normalized on the basis of radiotoxicity in accordance with 40 CFR Part 191. The peak cumulative release of radionuclides refers to the 10,000-year period during which any such release attains its maximum predicted value.

"Decommissioning" means the permanent removal from service of surface facilities and components necessary for preclosure operations only, after repository closure, in accordance with regulatory requirements and environmental policies.

"Determination" means a decision by the Secretary that a site is suitable for site characterization for the selection of a repository site or that a site is suitable for the development of a repository, consistent with applications of the guidelines of Subparts C and D in accordance with the provisions set forth in Subpart B.

"Disposal" means 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.

"Disqualifying condition" means a condition that, if present at a site, would eliminate that site from further consideration.

"Disturbed zone" means that portion of the controlled area, excluding shafts, whose physical or chemical properties are predicted to change as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change of properties could have a significant effect on the preformance of the geologic repository.

"DOE" means the U.S. Department of Energy or its duly authorized representatives.

"Effective porosity" means the amount of interconnected pore space and fracture openings available for the transmission of fluids, expressed as the ratio of the volume of interconnected pores and openings to the volume of rock.

"Engineered-barrier system" means the manmade components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. Such term includes the radioactive-waste form, radioactive-waste canisters, materials placed over and around such canisters, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility.

"Environmental assessment" means the document required by Section 112(b)(1)(E) of the Nuclear Waste Policy Act of 1982.

"Environmental impact statement" means the document required by Section 102(2)(C) of the National Environmental Policy Act of 1969. Sections 114(a) and 114(f) of the Nuclear Waste Policy Act of 1982 include certain limitations on the National Environmental Policy Act requirements as they apply to the preparation of an environmental impact statement for the development of a repository at a characterized site.

"EPA" means the U.S. Environmental Protection Agency or its duly authorized representatives.

"Evaluation" means the act of carefully examining the characteristics of a site in relation to the requirements of the qualifying or disqualifying conditions specified in the guidelines of Subparts C and D. Evaluation includes the consideration of favorable and potentially adverse conditions.

"Excepted" means assumed to be probable or certain on the basis of existing evidence and in the absence of significant evidence to the contrary.

"Expected repository performance" means the manner in which the repository is predicted to function, consideration those conditions, processes, and events that are likely to prevail or may occur during the time period of interest.

"Facility" means any structure, system, or system component, including engineered barriers, created by the DOE to meet repository-performance or functional objectives.

"Fault" means a fracture or a zone of fractures along which there has been displacement of the side relative to one another parallel to the fracture or zone of fractures.

"Faulting" means the process of fracturing and displacement that produces a fault.

"Favorable condition" means a condition that, though not necessary to qualify a site, is presumed, if present, to enhance confidence that the qualifying condition of a particular guideline can be met.

"Finding" means a conclusion that is reached after evaluation.

"Geohydrologic setting" means the system of geohydrologic units that is located within a given geologic setting.

"Geohydrologic system" means the geohydrologic units within a geologic setting, including any recharge, discharge, interconnections between units, and any natural or man-induced processes or events that could affect ground-water flow within or among those units.

"Geohydrologic unit" means an aquifer, a confining unit, or a combination of aquifers and confining units comprising a framework for a reasonably distinct geohydrologic system.

"Geologic repository" means a system, requiring licensing by the NRC, that is intended to be used, or may be used, for the disposal of radioactive waste in excavated geologic media. A geologic repository includes (1) the geologic-repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactiv waste and is located within the controlled area.

"Geologic-repository operations area" means a radioactive-waste facility that is part of the geologic repository, including both surface and subsurface areas and facilities where waste-handling activities are conducted.

"Geologic setting" means the geologi hydrologic, and geochemical systems o the region in which a geologic-repositor operations area is or may be located.

"Geomorphic processes" means geologic processes that are responsible for the general configuration of the Earth's surface, including the development of present landforms and their relationships to underlying structures, and are responsible for the geologic changes recorded by these surface features.

"Ground water" means all subsurface water as distinct from surface water.

"Ground-water flux" means the rate of ground-water flow per unit area of porous or fractured media measured perpendicular to the direction of flow.

"Ground-water sources" means aquifers that have been or could be economically and technologically developed as sources of water in the foreseeable future.

"Ground-water travel time" means the time required for a unit volume of ground water to travel between two locations. The travel time is the length of the flow path divided by the velocity, where velocity is the average ground-water flux passing through the cross-sectional area of the geologic medium through which flow occurs, perpendicular to the flow direction, divided by the effective porosity along the flow path. If discrete segments of the flow path have different hydrologic properties, the total travel time will be the sum of the travel times for each discrete segment.

"Guideline" means a statement of policy or procedure that may include, when appropriate, qualifying, disqualifying, favorable, or potentially adverse conditions as specified in the "guidelines."

"Guidelines" means Part 960 of Title 10 of the Code of Federal Regulations—General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories.

"High-level radioactive waste" means (1) the highly radioactive material resulting 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 and (2) other highly radioactive material that the NRC, consistent with existing law, determines by rule requires permanent isolation.

"Highly populated area" means any incoporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2,500 or more persons, or any census designated place (as defined and delineated by the Bureau) of 2,500 or more persons, unless it can be demonstrated that any such place has a lower population density than the mean value for the continental United States. Counties or county equivalents, whether incorporated or not, are specifically excluded form the definition of "place" as used herein.

"Host rock" means the geologic medium in which the waste is emplaced, specifically the geologic materials that directly encompass and are in close proximity to the underground facility.

"Hydraulic conductivity" means the volume of water that will move through a medium in a unit of time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow.

"Hydraulic gradient" means a change in the static pressure of ground water, expressed in terms of the height of water above a datum, per unit of distance in a given direction.

"Hydrologic process" means any hydrologic phenomenon that exhibits a continuous change in time, whether slow or rapid.

"Hydrologic properties" means those properties of a rock that govern the entrance of water and the capacity to hold, transmit, and deliver water, such as porosity, effective porosity, specific retention, permeability, and the directions of maximum and minimum permeabilities.

"Igneous activity" means the emplacement (intrusion) of molten rock material (magma) into material in the Earth's crust or the expulsion (extrusion) of such material onto the Earth's surface or into its atmosphere or surface water.

"Isolation" means inhibiting the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.

"Likely" means processing or displaying the qualities, characteristics, or attributes that provide a reasonable basis for confidence that what is expected indeed exists or will occur.

"Lithosphere" means the solid part of the Earth, including any ground water contained within it.

"Member of the public" means any individual who is not engaged in operations involving the management, storage, and disposal of radioactive waste. A worker so engaged is a member of the public except when on duty at the geologic-repository operations area.

"Mitigation" means (1) avoiding the impact altogether by not taking a certain action or parts of an action; (2) minimizing impacts by limiting the degree or magnitude of the action and its implementation; (3) rectifying the impact by repairing, rehabilitating, or restoring the affected environment; (4) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; or (5) compensating for the impact by replacing or providing substitute resources or environments.

"Model" means a conceptual description and the associated mathematical representation of a system, subsystem, component, or condition that is used to predict changes from a baseline state as a function of internal and/or external stimuli and as a function of time and space.

"NRC" means the U.S. Nuclear Regulatory Commission or its duly authorized representatives.

"Perched ground water" means unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Its water table is a perched water table. Perched ground water is held up by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.

"Performance assessment" means any analysis that predicts the behavior of a system or system component under a given set of constant and/or transient conditions. Performance assessments will include estimates of the effects of uncertainties in data and modeling.

"Permanent closure" is synonymous with "closure."

"Postclosure" means the period of time after the closure of the geologic repository.

"Potentially acceptable site" means any site at which, after geologic studies and field mapping but before detailed geologic data gathering, the DOE undertakes preliminary drilling and geophysical testing for the definition of site location.

"Potentially adverse condition" means a condition that is presumed to detract from expected system performance, but further evaluation, additional data, or the identification of compensating or mitigating factors may indicate that its effect on the expected system performance is acceptable.

"Preclosure" means the period of time before and during the closure of the geologic repository.

"Pre-waste-emplacement" means before the authorization of repository construction by the NRC.

"Qualifying condition" means a condition that must be satisfied for a site to be considered acceptable with respect to a specific guideline.

"Quaternary Period" means the second period of the Cenozoic Era, following the Tertiary, beginning 2 to 3 million years ago and extending to the present.

"Radioactive waste" or "waste" means high-level radioactive waste and other radioactive materials, including spent nuclear fuel, that are received for emplacement in a geologic repository.

"Radioactive-waste facility" means a facility subject to the licensing and related regulatory authority of the NRC pursuant to Sections 202(3) and 202(4) of the Energy Reorganization Act of 1974 (88 Stat. 1244).

"Radionuclide retardation" means the process or processes that cause the time required for a given radionuclide to move between two locations to be greater than the ground-water travel time, because of physical and chemical interactions between the radionuclide and the geohydrologic unit through which the radionuclide travels.

"Reasonably available technology" means technology which exists and has been demonstrated or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time period.

"Repository" is synonymous with "geologic repository."

"Repository closure" is synonymous with "closure."

"Repository construction" means all excavation and mining activities associated with the construction of shafts, shaft stations, rooms, and necessary openings in the underground facility, preparatory to radioactive-waste emplacement, as well as the construction of necessary surface facilities, but excluding site-characterization activities.

"Repository operation" means all of the functions at the site leading to and involving radioactive-waste emplacement in the underground facility, including receiving, transportation, handling, emplacement, and, if necessary, retrieval.

"Repository support facilities" means all permanent facilities constructed in support of site-characterization activities and repository construction, operation, and closure activities, including surface structures, utility lines, roads, railroads, and similar facilities, but excluding the underground facility.

"Restricted area" means any area access to which is controlled by the DOE for purposes of protecting individuals from exposure to radiation and radioactive materials before repository closure, but not including any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

"Retrieval" means the act of intentionally removing radioactive waste before repository closure from the underground location at which the waste had been previously emplaced for disposal.

"Saturated zone" means that part of the Earth's crust beneath the water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

"Secretary" means the Secretary of Energy.

"Site" means a potentially acceptable site or a candidate site, as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same.

"Site characterization" means activities, whether in the laboratory or in 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, including borings, surface excavations, excavations of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing needed to evaluate the suitability of a candidate site for the location of a repository, but not including preliminary borings and geophysical testing needed to assess whether site characterization should be undertaken.

"Siting" means the collection of exploration, testing, evaluation, and decision-making activities associated with the process of site screening, site nomination, site recommendation, and site approval for characterization or repository development.

"Source term" means the kinds and amounts of radionuclides that make up the source of a potential release of radioactivity.

"Spent nuclear fuel" means fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

"Surface facilities" means repository support facilities within the restricted area.

"Surface water" means any waters on the surface of the Earth, including fresh and salt water, ice, and snow.

"System" means the geologic setting at the site, the waste package, and the repository, all acting together to contain and isolate the waste.

"System performance" means the complete behavior of a repository system in response to the conditions, processes, and events that may affect it.

"Tectonic" means of, or pertaining to, the forces involved in, or the resulting structures or features of, "tectonics."

"Tectonics" means the branch of geology dealing with the broad architecture of the outer part of the Earth, that is, the regional assembling of structural or deformational features and the study of their mutual relations, origin, and historical evolution.

"To the extent practicable" means the degree to which an intended course of action is capable of being effected in a manner that is reasonable and feasible within a framework of constraints.

"Underground facility" means the underground structure and the rock required for support, including mined openings and backfill materials, but excluding shafts, boreholes, and their seals.

"Unsaturated zone" means the zone between the land surface and the water table. Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric.

"Waste form" means the radioactive waste materials and any encapsulating or stabilizing matrix.

"Waste package" means the waste form and any containers, shielding, packing, and other sorbent materials immediately surrounding an individual waste container.

"Water table" means that surface in a body of ground water at which the water pressure is atmospheric.

Subpart B—Implementation Guidelines

§ 960.3 Implementation guidelines.

The guidelines of this Subpart establish the procedure and basis for applying the postclosure and the preclosure guidelines of Subparts C and D, respectively, to evaluations of the suitability of sites for the development of repositories. As may be appropriate during the siting process, this procedure requires consideration of a variety of geohydrologic settings and rock types, regionality, and environmental impacts and consultation with affected States, affected Indian tribes, and Federal agencies.

§ 960.3-1 Siting provisions.

The siting provisions establish the framework for the implementation of the siting process specified in § 960.3-2. Sections 960.3-1-1 and 960.3-1-2 require that consideration be given to sites situated in different geohydrologic settings and different types of host rock, respectively. These diversity guidelines are intended to balance the process of site selection by requiring consideration of a variety of geologic conditions and media, and thereby enhance confidence in the technical suitability of sites selected for the development of repositories. As required by the Act, § 960.3-1-3 specifies consideration of a regional distribution of repositories after recommendation of a site for development of the first repository. Section 960.3-1-4 describes the evidence that is required to support siting decisions. Section 960.3-1-5 establishes the basis for site evaluations against the postclosure and the preclosure guidelines of Subparts C and D during the various phases of the siting process.

§ 960.3-1-1 Diversity of geohydrologic settings.

Consideration shall be given to a variety of geohydrologic settings in which sites for the development of repositories may be located. To the extent practicable, sites recommended as candidate sites for characterization shall be located in different geohydrologic settings.

§ 960.3-1-2 Diversity of rock types.

Consideration shall be given to a variety of geologic media in which sites for the development of repositories may be located. To the extent practicable, and with due consideration of candidate sites characterized previously or approved for such characterization if the circumstances apply, sites recommended as candidate sites for characterization shall have different types of host rock.

§ 960.3-1-3 Regionality.

In making site recommendations for repository development after the site for the first repository has been recommended, the Secretary shall give due consideration to the need for, and the advantages of, a regional distribution in the siting of subsequent repositories. Such consideration shall take into account the proximity of sites to locations at which waste is generated or temporarily stored and at which other repositories have been or are being developed.

§ 960.3-1-4 Evidence for siting decisions.

The siting process involves a sequence of four decisions: The identification of potentially acceptable sites; the nomination of sites as suitable for characterization; the recommendation of sites as candidate sites for site characterization; and after the completion of site characterization and nongeologic data gathering, the recommendation of a candidate site for the development of a repository. Each of these decisions will be supported by the evidence specified below.

§ 960.3-1-4-1 Site identification as potentially acceptable.

The evidence for the identification of a potentially acceptable site shall be the types of information specified in Appendix IV of this part. Such evidence will be relatively general and less detailed than that required for the nomination of a site as suitable for characterization. Because the gathering of detailed geologic data will not take place until after the recommendation of a site for characterization, the levels of information may be relatively greater for the evaluation of those guidelines in Subparts C and D that pertain to surface-identifiable factors for such site. The sources of information shall include the literature in the public domain and the private sector, when available, and will be supplemented in some instances by surface investigations and conceptual engineering design studies conducted by the DOE. Geologic surface investigations may include the mapping of identifiable rock masses, fracture and joint characteristics, and fault zones. Other surface investigations will consider the aquatic and terrestrial ecology; water rights and uses; topography; potential offsite hazards; natural resource concentrations; national or State protected resources; existing transportation systems; meteorology and climatology; population densities, centers, and distributions; and general socioeconomic characteristics.

§ 960.3-1-4-2 Site nomination for characterization.

The evidence required to support the nomination of a site as suitable for characterization shall include the types of information specified in Appendix IV of this part and shall be contained or referenced in the environmental assessments to be prepared in accordance with the requirements of the Act. The source of this information shall include the literature and related studies in the public domain and the private sector, when available, and various meteorological, environmental, socioeconomic, and transportation studies conducted by the DOE in the affected area; exploratory boreholes in the region of such site, including lithologic logging and hydrologic and geophysical testing of such boreholes, laboratory testing of core samples for the evaluation of geochemical and engineering rock properties, and chemical analyses of water samples from such boreholes; surface investigations, including geologic mapping and geophysical surveys, and compilations of satellite imagery data; in situ or laboratory testing of similar rock types under expected repository conditions; evaluations of natural and man-made analogs of the repository and its subsystems, such as geothermally active areas, underground excavations, and case histories of socioeconomic cycles in areas that have experienced intermittent large-scale construction and industrial activities; and extrapolations of regional data to estimate site-specific characteristics and conditions. The exact types and amounts of information to be collected within the above categories, including such details as the specific types of hydrologic tests, combinations of geophysical tests, or number of exploratory boreholes, are dependent on the site-specific needs for the application of the guidelines of Subparts C and D, in accordance with the provisions of this Subpart and the application requirements set forth in Appendix III of this part. The evidence shall also include those technical evaluations that use the information specified above and that provide additional bases for evaluating the ability of a site to meet the qualifying conditions of the guidelines of Subparts C and D. In developing the above-mentioned bases for evaluation, as may be necessary, assumptions that approximate the characteristics or conditions considered to exist at a site, or expected to exist or occur in the future, may be used. These assumptions will be realistic but conservative enough to underestimate the potential for a site to meet the qualifying condition of a guideline; that is, the use of such assumptions should not lead to an exaggeration of the ability of a site to meet the qualifying condition.

§ 960.3-1-4-3 Site recommendation for characterization.

The evidence required to support the recommendation of a site as a candidate site for characterization shall consist of the evaluations and data contained or referenced in the environmental assessment for such site, unless the Secretary certifies that such information, in the absence of additional preliminary borings or excavations, will not be adequate to satisfy applicable requirements of the Act.

§ 960.3-1-4-4 Site recommendation for repository development.

The evidence required to support the recommendation of a candidate site for the development of a repository, after the completion of characterization activities at such site, shall consist of the information specified in Section 114(a) of the Act for the comprehensive statement of the basis for such recommendation and Section 114(f) of the Act for the environmental impact statement. This evidence shall be obtained by the characterization of such site, according to the requirements specified in Section 113(b) of the Act and in 10 CFR 60.11, and by nongeologic data gathering.

§ 960.3-1-5 Basis for site evaluations.

Evaluations of individual sites and comparisons between and among sites shall be based on the postclosure and preclosure guidelines specified in Subparts C and D, respectively. Except for screening for potentially acceptable sites as specified in § 960.3-2-1, such evaluations shall place *primary significance* on the postclosure guidelines and *secondary significance* on the preclosure guidelines, with each set of guidelines considered collectively for such purposes. Both the postclosure and the preclosure guidelines consist of a system guideline or guidelines and corresponding groups of technical guidelines. The postclosure guidelines of Subpart C contain eight technical guidelines in one group. The preclosure guidelines of Subpart D contain eleven technical guidelines separated into three groups that represent, *in decreasing order of importance*, preclosure radiological safety; environment, socioeconomics, and transportation; and ease and cost of siting, construction, operation, and closure. The relative significance of any technical guideline to its corresponding system guideline is site specific. Therefore, for each technical guideline, an evaluation of compliance with the qualifying condition shall be made in the context of the collection of system elements and the evidence related to that guideline, considering on balance the favorable conditions and the potentially adverse conditions identified at a site. Similarly, for each system guideline, such evaluation shall be made in the context of the group of technical guidelines and the evidence related to that system guideline. For purposes of recommending sites for development as respositories, such evidence shall include analyses of expected respository performance to assess the likelihood of demonstrating compliance with 40 CFR Part 191 and 10 CFR Part 60, in accordance with § 960.4-1. A site shall be disqualified at any time during the siting process if the evidence supports a finding by the DOE that a disqualifying condition exists or the qualifying condition of any system or technical guideline cannot be met. Comparisons between and among sites shall be based on the system guidelines, to the extent practicable and in accordance with the levels of relative significance specified above for the postclosure and the preclosure guidelines. Such comparisons are intended to allow comparative evaluations of sites in terms of the capabilities of the natural barriers for waste isolation and to identify innate deficiencies that could jeopardize compliance with such requirements. If the evidence for the sites is not adequate to substantiate such comparisons, then the comparisons shall be based on the groups of technical guidelines under the postclosure and the preclosure guidelines, considering the levels of relative significance appropriate to the postclosure and the preclosure guidelines and the order of importance appropriate to the subordinate groups within the preclosure guidelines. Comparative site evaluations shall place primary importance on the natural barriers of the site. In such evaluations for the postclosure guidelines of Subpart C, engineered barriers shall be considered only to the extent necessary to obtain realistic source terms for comparative site evaluations based on the sensitivity of the natural barriers to such realistic engineered barriers. For a better understanding of the potential effects of engineered barriers on the overall performance of the repository system, these comparative evaluations shall consider a range of levels in the performance of the engineered barriers. That range of performance levels shall vary by at least a factor of 10 above and below the engineered-barrier performance requirements set forth in 10 CFR 60.113, and the range considered shall be identical for all sites compared. The comparisons shall assume equivalent engineered-barrier performance for all sites compared and shall be structured so that engineered barriers are not relied upon to compensate for deficiencies in the geologic media. Furthermore, engineered barriers shall not be used to compensate for an inadequate site; mask the innate deficiencies of a site; disguise the strengths and weaknesses of a site and the overall system; and mask differences between sites when they are compared. Site comparisons performed to support the recommendation of sites for the development of repositories in § 960.3-2-4 shall evaluate predicted releases of radionuclides to the accessible environment. For the purposes of such comparison, the accessible environment shall consist of the atmosphere, the land surface, any nearby surface water, and those portions of the lithosphere that are situated more than 10 kilometers in a horizontal direction from the outer boundary of the original location of the waste emplacement in the geologic repository. Releases of different radionuclides shall be combined by the methods specified in Appendix A of 40 CFR Part 191. The comparisons specified above shall consist of two comparative evaluations that predict radionuclide releases for 100,000 years after repository closure and shall be conducted as follows. First, the sites shall be compared by means of evaluations that emphasize the performance of the natural barriers at the site. Second, the sites shall be compared by means of evaluations that emphasize the performance of the total repository system. These second evaluations shall consider the expected performance of the repository system; be based on the expected performance of waste packages and waste forms, in compliance with the requirements of 10 CFR 60.113, and on the expected hydrologic and geochemical conditions at each site; and take credit for the expected performance of all other engineered components of the repository system. The comparison of isolation capability shall be one of the significant considerations in the recommendation of sites for the development of repositories. The first of the two comparative evaluations specified in the preceding paragraph shall take precedence unless the second comparative evaluation would lead to substantially different recommendations. In the latter case, the two comparative evaluations shall receive comparable consideration. Sites with predicted isolation capabilities that differ by less than a factor of 10, with similar uncertainties, may be assumed to provide equivalent isolation.

§ 960.3-2 Siting process.

The siting process begins with site screening for the identification of potentially acceptable sites. This process was completed for purposes of the first repository before the enactment of the Act, and the identification of such sites was made after enactment in accordance with the provisions of section 116(a) of the Act. The screening process for the identification of potentially acceptable sites for the second and subsequent repositories shall be conducted in accordance with the requirements specified in § 960.3-2-1 of this Subpart. The nomination of any site as suitable for characterization shall follow the process specified in § 960.3-2-2, and such nomination shall be accompanied by an environmental assessment as specified in section 112(b)(1)(E) of the Act. The recommendation of sites as candidate sites for characterization and the recommendation of a characterized site for the development of a repository shall be accomplished in accordance with the requirements specified in §§960.3-2-3 and 960.3-2-4, respectively.

§ 960.3-2-1 Site screening for potentially acceptable sites.

To identify potentially acceptable sites for the development of other than the first repository, the process shall begin with site-screening activities that consider large land masses that contain rock formations of suitable depth, thickness, and lateral extent and have structural, hydrologic, and tectonic features favorable for waste containment and isolation. Within those large land masses, subsequent site-screening activities shall focus on successively smaller and increasingly more suitable land units. This process shall be developed in consultation with the States that contain land units under consideration. It shall be implemented in a sequence of steps that first applies the applicable disqualifying conditions to eliminate land units on the basis of the evidence specified in § 960.3-1-4-1 and in accordance with the application requirements set forth in Appendix III of this Part. After the disqualifying conditions have been applied, the favorable and potentially adverse conditions, as identified for each remaining land unit, shall be evaluated. The presence of favorable conditions shall favor a given land unit, while the presence of potentially adverse conditions shall penalize that land unit. Recognizing that favorable conditions and potentially adverse conditions for different technical guidelines can exist in the same land unit, the DOE shall seek to evaluate the composite favorability of each land unit. Land units that, in the aggregrate, exhibit potentially adverse conditions shall be deferred in favor of land units that exhibit favorable conditions. The siting provisions that require diversity of geohydrologic settings and rock types and consideration of regionality, as specified in §§ 960.3-1-1, 960.3-1-2, and 960.3-1-3, respectively, may be used to discriminate between land units and to establish the range of options in site screening. To identify a site as potentially acceptable, the evidence shall support a finding that the site is not disqualified in accordance with the application requirements set forth in Appendix III of this Part and shall support the decision by the DOE to proceed the continued investigation of the site on the basis of the favorable and potentially adverse conditions identified to date. In continuation of the screening process after such identification and before site nomination, the DOE may defer from further consideration land units or potentially acceptable sites or portions thereof on the basis of additional information or by the application of the siting provisions for diversity of geohydrologic settings, diversity of rock types, and regionality (§§ 960.3-1-1, 960.3-1-2, and 960.3-1-3, respectively). The deferral of potentially acceptable sites will be described in the environmental assessments that accompany the nomination of at least five sites as suitable for characterization. In order to identify potentially acceptable sites for the second and subsequent repositories, the Secretary shall *first* identify the State within which the site is located in a decision-basis document that describes the process and the considerations that led to the identification of such site and that has been issued previously in draft for review and comment by such State. *Second,* when such document is final, the Secretary shall notify the Governor and the legislature of that State and the tribal council of any affected Indian tribe of the potentially acceptable site.

§ 960.3-2-2 Nomination of sites as suitable for characterization.

From the sites identified as potentially acceptable, the Secretary shall nominate at least five sites determined suitable for site characterization for the selection of each repository site. For the second repository, at least three of the sites shall not have been nominated previously. Any site nominated as suitable for characterization for the first repository, but not recommended as a candidate site for characterization, may not be nominated as suitable for characterization for the second repository. The nomination of a site as suitable for characterization shall be accompanied by an environmental assessment as specified in section 112(b)(1)(E) of the Act. Such nomination shall be based on evaluations in accordance with the guidelines of this Part, and the bases and relevant details of those evaluations and of the decision processes involved therein shall be contained in the environmental assessment for the site in the manner specified in this Subpart. The evidence required to support such evaluations and siting decisions is specified in § 960.3-1-4-2.

§ 960.3-2-2-1 Evaluation of all potentially acceptable sites.

First, in considering sites for nomination, each of the potentially acceptable sites shall be evaluated on the basis of the disqualifying conditions specified in the technical guidelines of Subparts C and D, in accordance with the application requirements set forth in Appendix III of this part. This evaluation shall support a finding by the DOE that such sites is not disqualified.

§ 960.3-2-2-2 Selection of sites within geohydrologic settings.

Second, the siting provision requiring diversity of geohydrologic settings, as specified in § 960.3-1-1, shall be applied to group all potentially acceptable sites according to their geohydrologic settings. *Third,* for those geohydrologic settings that contain more than one potentially acceptable site, the preferred site shall be selected on the basis of a comparative evaluation of all potentially acceptable sites in that setting. This evaluation shall consider the distinguishing characteristics displayed by the potentially acceptable sites within the setting and the related guidelines from Subparts C and D. That is, the appropriate guidelines shall be selected primarily on the basis of the kinds of evidence among sites for which distinguishing characteristics can be identified. Such comparative evaluation shall be made on the basis of the qualifying conditions for those guidelines, considering, on balance, the favorable conditions and potentially adverse conditions identified at each site. Due consideration shall also be given to the siting provisions specifying the basis for site evaluations in § 960.3-1-5, to the extent practicable, and diversity of rock types in § 960.3-1-2, if the circumstances so apply. If less than five geohydrologic settings are available for consideration, the above process shall be used to select two or more preferred sites from those settings that contain more than one potentially acceptable site, as required to obtain the number of sites to be nominated as suitable for characterization. For purposes of the second and subsequent repositories, due consideration shall also be given to the siting provision for regionality as specified in § 960.3-1-3. *Fourth,* each preferred site within a geohydrologic setting shall be evaluated as to whether such site is suitable for the development of a repository under the qualifying condition of each guideline specified in Subparts C and D that does not require site characterization as a prerequisite for the application of such guideline. The guidelines considered appropriate to this evaluation have been selected on the basis of their exclusion under the definition of site characterization as specified in § 960.2. Although the final application of these guidelines, in accordance with the provisions set forth in Appendix III of this Part, does not require geologic data from site-characterization activities, such application will require additional data beyond those specified in Appendix IV of this part, which will be obtained concurrently with site characterization. Such guidelines include those specified in § 960.4-2-8-2 (Site Ownership and Control) of Subpart C; §§ 960.5-1(a)(1) and 960.5-1(a)(2) of Subpart D (preclosure system guidelines for radiological safety and environmental quality, socioeconomics, and transportation); and §§ 960.5-2-1 through 960.5-2-7 of Subpart D (Population Density and Distribution, Site Ownership and Control, Meteorology, Offsite Installations and Operations, Environmental Quality, Socioeconomic Impacts, and Transportation). This evaluation shall consider on balance those favorable conditions and potentially adverse conditions identified as such at a preferred site in relation to the qualifying condition of each such guideline. For each such guideline, this evaluation shall focus on the suitability of the site for the development of a repository by considering the activities from the start of site characterization through decommissioning and shall support a finding by the DOE in accordance with the application requirements set forth in Appendix III of this part. *Fifth*, each preferred site within a geohydrologic setting shall be evaluated as to whether such site is suitable for site characterization under the qualifying conditions of those guidelines specified in Subparts C and D that require characterization (i.e., subsurface geologic, hydrologic, and geochemical data gathering). Such guidelines include those specified in § 960.4-1(a) (postclosure system guideline); §§ 960.4-2-1 through 960.4-2-8-1 of Subpart C (Geohydrology, Geochemistry, Rock Characteristics, Climatic Changes, Erosion, Dissolution, Tectonics, Human Interference, and Natural Resources); §960.5-1(a)(3) (preclosure system guideline for ease and cost of siting, construction, operation, and closure); and, § 960.5-2-8 through 960.5-2-11 of Subpart D (Surface Characteristics, Rock Characteristics, Hydrology, and Tectonics). This evaluation shall consider on balance the favorable conditions and potentially adverse conditions identified as such at a preferred site in relation to the qualifying condition of each such guideline. For each such guideline, this evaluation shall focus on the suitability of the site for characterization and shall support a finding by the DOE in accordance with the application requirements set forth in Appendix III of this part.

§ 960.3-2-2-3 Comparative evaluation of all sites proposed for nomination.

Sixth, for those potentially acceptable sites to be proposed for nomination, as determined by the process specified in § 960.3-2-2-2, a reasonable comparative evaluation of each such site with all other such sites shall be made. For each site and for each guideline specified in Subparts C and D, the DOE shall summarize the evaluations and findings specified under § 960.3-2-2-1 and under the fourth and fifth provisions of § 960.3-2-2-2. Each such summary shall allow comparisons to be made among sites on this basis of each guideline.

§ 960.3-2-2-4 The environmental assessment.

To document the process specified above, and in compliance with section 112(b)(1)(E) of the Act, an environmental assessment shall be prepared for each site proposed for nomination as suitable for characterization. Each such environmental assessment shall describe the decision process by which such site was proposed for nomination as described in the preceding six steps and shall contain or reference the evidence that supports such process according to the requirements of § 960.3-1-4-2 and Appendix IV of this part. As specified in the Act, each environmental assessment shall include an evaluation of the effects of the site-characterization activities at the site on public health and safety and the environment; a discussion of alternative activities related to site characterization that may be taken to avoid such impact; and an assessment of the regional and local impacts of locating a repository at the site. The draft environmental assessment for each site proposed for nomination as suitable for characterization shall be made available by the DOE for public comment after the Secretary has notified the Governor and legislature of the State in which the site is located, and the governing body of the affected Indian tribe where such site is located, of such impending availability.

§ 960.3-2-2-5 Formal site nomination.

After the final environmental assessments have been prepared, the Secretary shall nominate at least five sites that he determines suitable for site characterization for the selection of a repository site, and, in so doing, he shall cause to have published in the Federal Register a notice specifying the sites so nominated and announcing the availability of the final environmental assessments for such sites. This determination by the Secretary shall be based on the final environmental assessments for such sites, including, in particular, consideration of the available evidence, evaluations, and the resultant findings for the guidelines of Subparts C and D so specified under the fourth and fifth provisions of § 960.3-2-2-2. Before nominating a site, the Secretary shall notify the Governor and legislature of the State in which the site is located, and the governing body of the affected Indian tribe where such site is located, of such nomination and the basis for such nomination.

§ 960.3-2-3 Recommendation of sites for characterization.

After the nomination of at least five sites as suitable for site characterization for the selection of the first repository, the Secretary shall recommend in writing to the President not less than three candidate sites for such characterization. The recommendation decision shall be based on the available geophysical, geologic, geochemical, and hydrologic data; other information; associated evaluations and findings reported in the environmental assessments accompanying the nominations; and the considerations specified below, unless the Secretary certifies that such available data will not be adequate to satisfy applicable requirements of the Act in the absence of further preliminary borings or excavations. On the basis of the evidence and in accordance with the siting provision specifying the basis for site evaluations in § 960.3-1-5, the sites nominated as suitable for characterization shall be considered as to their order of preference as candidate sites for characterization. Subsequently, the siting provisions specifying diversity of geohydrologic settings, diversity of rock types, and, after the first repository, consideration of regionality in §§ 960.3-1-1, 960.3-1-2, and 960.3-1-3, respectively, shall be considered to determine a final order of preference for the characterization of such sites. Considering this order of preference together with the available siting alternatives specified in the Act, the sites recommended as candidate sites for characterization shall offer, on balance, the most advantageous combination of characteristics and conditions for the successful development of repositories at such sites. The process for the recommendation of sites as candidate sites for characterization for the selection of any subsequent repository shall be the same as that specified above for the first repository.

§ 960.3-2-4 Recommendation of sites for the development of repositories.

After completion of site characterization and nongeologic data gathering activities at the candidate sites for the development of the first repository, or from all of the characterized sites for the development of subsequent repositories, the candidate sites shall be compared with each other on the basis of the guidelines specified in Subparts C and D according to the siting provision specifying the basis for site evaluations in § 960.3-1-5. This comparison shall lead to a recommendation by the Secretary to the President of a site for the development of a repository. Together with any recommendation to the President to approve a site for the development of a repository, the Secretary shall make available to the public, and submit to the President, a comprehensive statement of the basis of such recommendation pursuant to the requirements specified in section 114(a)(1) of the Act, including an environmental impact statement prepared in accordance with the provisions of sections 114(a)(1)(D) and 114(f) of the Act. The environmental impact statement shall include the results of the comparative evaluation specified above and a description of the decision process that resulted in the selection of the candidate site recommended for the development of such repository.

§ 960.3-3 Consultation.

The DOE shall provide to designated officials of the affected States and to the governing bodies of any affected Indian tribe timely and complete information regarding determinations or plans made with respect to the siting, site characterization, design, development, construction, operation, closure, decommissioning, licensing, or regulation of a repository. Written responses to written requests for information from the designated officials of affected States or affected Indian tribes will be provided within 30 days after receipt of the written requests. In performing any study of an area for the purpose of determining the suitability of such area for the development of a repository, the DOE shall consult and cooperate with the Governor and the legislature of an affected State and the governing body of an affected Indian tribe in an effort to resolve concerns regarding public health and safety, environmental impacts, socioeconomic impacts, and technical aspects of the siting process. After notifying affected States and affected Indian tribes that potentially acceptable sites have been identified, or that a site has been approved for characterization, the DOE shall seek to enter into binding written agreements with such affected States or affected Indian tribes in accordance with the requirements of the Act. The DOE shall also consult, as appropriate, with other Federal agencies.

§ 960.3-4 Environmental impacts.

Environmental impacts shall be considered by the DOE throughout the site characterization, site selection, and repository development process. The DOE shall mitigate significant adverse environmental impacts, to the extent practicable, during site characterization and repository construction, operation, closure, and decommissioning.

Subpart C—Postclosure Guidelines

§ 960.4 Postclosure guidelines.

The guidelines in this Subpart specify the factors to be considered in evaluating and comparing sites on the basis of expected repository performance after closure. The postclosure guidelines are separated into a system guideline and eight technical guidelines. The system guideline establishes waste containment and isolation requirements that are based on NRC and EPA regulations. These requirements must be met by the repository system, which contains natural barriers and engineered barriers. The engineered barriers will be designed to complement the natural barriers, which provide the primary means for waste isolation.

§ 960.4-1 System guideline.

(a) *Qualifying Condition.* The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subpart B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60 (see Appendix I of this Part).

§ 960.4-2 Technical guidelines.

The technical guidelines in this Subpart set forth qualifying, favorable, potentially adverse, and, in five guidelines, disqualifying conditions on the characteristics, processes, and events that may influence the performance of a repository system after closure. The favorable conditions and the potentially adverse conditions under each guideline are *not* listed in any assumed order of importance. Potentially adverse conditions will be considered if they affect waste isolation within the controlled area even though such conditions may occur outside the controlled area. The technical guidelines that follow establish conditions that shall be considered in determining compliance with the qualifying condition of the postclosure system guideline. For each technical guideline, an evaluation of qualification or disqualification shall be made in accordance with the requirements specified in Subpart B.

§ 960.4-2-1 Geohydrology.

(a) *Qualifying Condition.* The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in § 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

(b) *Favorable Conditions.* (1) Site conditions such that the pre-waste-emplacement ground-water travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years.

(2) The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

(3) Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty.

(4) For disposal in the saturated zone, at least one of the following pre-waste-emplacement conditions exists:

(i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities.

(ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units.

(iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units.

(iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment.

(5) For disposal in the unsaturated zone, at least one of the following pre-waste-emplacement conditions exists:

(i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units.

(ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock.

(iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste.

(iv) A host rock that provides for free drainage.

(v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration.

Note.—The DOE will, in accordance with the general principles set forth in § 960.1 of these regulations, revise the guidelines as necessary, to ensure consistency with the final NRC regulations on the unsaturated zone, which were published as a proposed rule on February 16, 1984, in 49 FR 5934.

(c) *Potentially Adverse Conditions.* (1) Expected changes in geohydrologic conditions—such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity, and the ground-water flux through the host rock and the surrounding geohydrologic units—sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions.

(2) The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water flow paths from the host rock to the accessible environment.

(3) The presence in the geologic setting of stratigraphic or structural features—such as dikes, sills, faults, shear zones, folds, dissolution effects, or brine pockets—if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system.

(d) *Disqualifying Condition.* A site shall be disqualified if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years along any pathway of likely and significant radionuclide travel.

§ 960.4-2-2 Geochemistry.

(a) *Qualifying Condition.* The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in § 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

(b) *Favorable Conditions.* (1) The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years.

(2) Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes.

(3) Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport.

(4) A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved.

(5) Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation.

(c) *Potentially Adverse Conditions.* (1) Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered-barrier system to the extent that the expected repository performance could be compromised.

(2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength.

(3) Pre-waste-emplacement ground-water conditions in the host rock that are chemically oxidizing.

§ 960.4-2-3 Rock characteristics.

(a) *Qualifying condition.* The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in § 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

(b) *Favorable Conditions.* (1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation.

(2) A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components.

(c) *Potentially Adverse Conditions.* (1) Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation.

(2) Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation.

(3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with pre-waste-emplacement conditions.

§ 960.4-2-4 Climatic changes.

(a) *Qualifying Condition.* The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4-1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting.

(b) *Favorable Conditions.* (1) A surface-water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation.

(2) A geologic setting in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period

(c) *Potentially Adverse Conditions.* (1) Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock.

(2) Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.

§ 960.4-2-5 Erosion.

(a) *Qualifying Condition.* The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4-1. In predicting the likelihood of potentially disruptive erosional processes, the DOE will consider the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period.

(b) *Favorable Conditions.* (1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the directly overlying ground surface.

(2) A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than one chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment.

(3) Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure.

(c) *Potentially Adverse Conditions.* (1) A geologic setting that shows evidence of extreme erosion during the Quaternary Period.

(2) A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste.

(d) *Disqualifying Condition.* The site shall be *disqualified* if site conditions do not allow all portions of the underground facility to be situated at least 200 meters below the directly overlying ground surface.

§ 960.4-2-6 Dissolution.

(a) *Qualifying Condition.* The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4-1. In predicting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified.

(b) *Favorable Condition.* No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period.

(c) *Potentially Adverse Condition.* Evidence of dissolution within the geologic setting—such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse—such that a hydraulic interconnection leading to a loss of waste isolation could occur.

(d) *Disqualifying Condition.* The site shall be *disqualified* if it is likely that, during the first 10,000 years after closure, active dissolution, as predicted on the basis of the geologic record, would result in a loss of waste isolation.

§ 960.4-2-7 Tectonics.

(a) *Qualifying Condition.* The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4-1. In predicting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, stratigraphic, geophysical, and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period.

(b) *Favorable Condition.* The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than one chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment.

(c) *Potentially Adverse Conditions.* (1) Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period.

(2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation.

(3) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase.

(4) More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located.

(5) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface-water impoundments that could change the regional ground-water flow system.

(6) Potential for tectonic deformations—such as uplift, subsidence, folding, or faulting—that could adversely affect the regional ground-water flow system.

(d) *Disqualifying Condition.* A site shall be disqualified if, based on the geologic record during the Quaternary Period, the nature and rates of fault movement or other ground motion are expected to be such that a loss of waste isolation is likely to occur.

§ 960.4-2-8 Human interference.

The site shall be located such that activities by future generations at or near the site will not be likely to affect waste containment and isolation. In assessing the likelihood of such activities, the DOE will consider the estimated effectiveness of the permanent markers and records required by 10 CFR Part 60, taking into account site-specific factors, as stated in §§ 960.4-2-8-1 and 960.4-2-8-2, that could compromise their continued effectiveness.

§ 960.4-2-8-1 Natural resource.

(a) *Qualifying Condition.* This site shall be located such that—considering permanent markers and records and reasonable projections of value, scarcity, and technology—the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4-1.

(b) *Favorable Conditions.* (1) No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource.

(2) Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel from the host rock to the accessible environment.

(c) *Potentially Adverse Conditions.* (1) Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or (ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting.

(2) Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation.

(3) Evidence of drilling within the site for any purpose other than repository-site evaluation to a depth sufficient to affect waste containment and isolation.

(4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources.

(5) Potential for foreseeable human activities—such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface-water impoundments—that could adversely change portions of the ground-water flow system important to waste isolation.

(d) *Disqualifying Conditions.* A site shall be disqualified if—

(1) Previous exploration, mining, or extraction activities for resources of commercial importance at the site have created significant pathways between the projected underground facility and the accessible environment; or

(2) Ongoing or likely future activities to recover presently valuable natural mineral resources outside the controlled area would be expected to lead to an inadvertent loss of waste isolation.

§ 960.4-2-8-2 Site ownership and control.

(a) *Qualifying Condition.* The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60, ownership, surface and subsurface rights, and control of access that are required in order that potential surface and subsurface activities as the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4-1.

(b) *Favorable Condition.* Present ownership and control of land and all surface and subsurface rights by the DOE.

(c) *Potentially Adverse Condition.* Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

Subpart D—Preclosure Guidelines

§ 960.5 Preclosure guidelines.

The guidelines in this Subpart specify the factors to be considered in evaluating and comparing sites on the basis of expected repository performance before closure. The preclosure guidelines are separated into three system guidelines and eleven technical guidelines.

§ 960.5-1 System guidelines.

(a) *Qualifying Conditions*—(1) *Preclosure Radiological Safety.* Any projected radiological exposures of the general public and any projected releases of radioactive materials to restricted and unrestricted areas during repository operation and closure shall meet the applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A (see Appendix II of this part).

(2) *Environment, Socioeconomics, and Transportation.* During repository siting, construction, operation, closure, and decommissioning the public and the environment shall be adequately protected from the hazards posed by the disposal of radioactive waste.

(3) *Ease and Cost of Siting, Construction, Operation, and Closure.* Repository siting, construction, operation, and closure shall be demonstrated to be technically feasible on the basis of reasonably available technology, and the associated costs shall be demonstrated to be reasonable relative to other available and comparable siting options.

§ 960.5-2 Technical guidelines.

The technical guidelines in this Subpart set forth qualifying, favorable, potentially adverse, and, in seven guidelines, disqualifying conditions for the characteristics, processes, and events that influence the suitability of a site relative to the preclosure system guidelines. These conditions are separated into three main groups: Preclosure radiological safety; environment, socioeconomics, and transportation; and ease and cost of siting, construction, operation, and closure. The first group includes conditions on population density and distribution, site ownership and control, meteorology, and offsite installations and operations. The second group includes conditions related to environmental quality and socioeconomic impacts in areas potentially affected by a repository and to the transportation of waste to a repository site. The third group includes conditions on the surface characteristics of the site, the characteristics of the host rock and surrounding strata, hydrology, and tectonics. The individual technical guidelines within each group, as well as the favorable conditions and the potentially adverse conditions under each guideline, are not listed in any assumed order of importance. The technical guidelines that follow establish conditions that shall be considered in determining compliance with the qualifying conditions of the preclosure system guidelines. For each technical guideline, an evaluation of qualification or disqualification shall be made in accordance with the requirements specified in Subpart B.

Preclosure Radiological Safety

§ 960.5-2-1 Population Density and Distribution.

(a) *Qualifying Condition.* The site shall be located such that, during repository operation and closure, (1) the expected average radiation dose to members of the public within any highly populated area will not be likely to exceed a small fraction of the limits allowable under the requirements specified in § 960.5-1(a)(1), and (2) the expected radiation dose to any member of the public in an unrestricted area will not be likely to exceed the limit allowable under the requirements specified in § 960.5-1(a)(1).

(b) *Favorable Conditions.* (1) A low population density in the general region of the site.

(2) Remoteness of site from highly populated areas.

(c) *Potentially Adverse Conditions.* (1) High residential, seasonal, or daytime population density within the projected site boundaries.

(2) Proximity of the site to highly populated areas, or to areas having at least 1,000 individuals in an area 1 mile

by 1 mile as defined by the most recent decennial count of the U.S. census.

(d) *Disqualifying Conditions.* A site shall be *disqualified* if—

(1) Any surface facility of a repository would be located in a highly populated area; or

(2) Any surface facility of a repository would be located adjacent to an area 1 mile by 1 mile having a population of not less than 1,000 individuals as enumerated by the most recent U.S. census; or

(3) The DOE could not develop an emergency preparedness program which meets the requirements specified in DOE Order 5500.3 (Reactor and Non-Reactor Facility Emergency Planning, Preparedness, and Response Program for Department of Energy Operations) and related guides or, when issued by the NRC, in 10 CFR Part 60, Subpart I, "Emergency Planning Criteria."

§ 960.5-2-2 Site Ownership and Control.

(a) *Qualifying Condition.* The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR 60.121, ownership, surface and subsurface rights, and control of access that are required in order that surface and subsurface activities during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in § 960.5-1(a)(1).

(b) *Favorable Condition.* Present ownership and control of land and all surface and subsurface mineral and water rights by the DOE.

(c) *Potentially Adverse Condition.* Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

§ 960.5-2-3 Meteorology.

(a) *Qualifying Condition.* The site shall be located such that expected meteorological conditions during repository operation and closure will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in § 960.5-1(a)(1).

(b) *Favorable Condition.* Prevailing meteorological conditions such that any radioactive releases to the atmosphere during repository operation and closure would be effectively dispersed, thereby reducing significantly the likelihood of unacceptable exposure to any member of the public in the vicinity of the repository.

(c) *Potentially Adverse Conditions.* (1) Prevailing meteorological conditions such that radioactive emissions from repository operation of closure could be preferentially transported toward localities in the vicinity of the repository with higher population densities than are the average for the region.

(2) History of extreme weather phenomena—such as hurricanes, tornadoes, severe floods, or severe and frequent winter storms—that could significantly affect repository operation or closure.

§ 960.5-2-4 Offsite installations and operations.

(a) *Qualifying Condition.* The site shall be located such that present projected effects from nearby industrial, transportation, and military installations and operations, including atomic energy defense activities, (1) will not significantly affect repository siting, construction, operation, closure, or decommissioning or can be accommodated by engineering measures and (2), when considered together with emissions from repository operation and closure, will not be likely to lead to radionuclide releases to an unrestricted area greater than those allowable under the requirements specified in § 960.5-1(a)(1).

(b) *Favorable Condition.* Absence of contributing radioactive releases from other nuclear installations and operations that must be considered under the requirements of 40 CFR 191, Subpart A.

(c) *Potentially Adverse Conditions.* (1) The presence of nearby potentially hazardous installations or operations that could adversely affect repository operation or closure.

(2) Presence of other nuclear installations and operations, subject to the requirements of 40 CFR Part 190 or 40 CFR 191, Subpart A, with actual or projected releases near the maximum value permissible under those standards.

(d) *Disqualifying Condition.* A site shall be disqualified if atomic energy defense activities in proximity to the site are expected to conflict irreconcilably with repository siting, construction, operation, closure, or decommissioning.

Environment, Socioeconomics, and Transportation

§ 960.5-2-5 Environmental quality.

(a) *Qualifying Condition.* The site shall be located such that (1) the quality of the environment in the affected area during this and future generations will be adequately protected during repository siting, construction, operation, closure, and decommissioning, and projected environmental impacts in the affected area can be mitigated to an acceptable degree, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements specified in § 960.5-1(a)(2) can be met.

(b) *Favorable Conditions.* (1) Projected ability to meet, within time constraints, all Federal, State, and local procedural and substantive environmental requirements applicable to the site and the activities proposed to take place thereon.

(2) Potential significant adverse environmental impacts to present and future generations can be mitigated to an insignificant level through the application of reasonable measures, taking into account programmatic, technical, social, economic, and environmental factors.

(c) *Potentially Adverse Conditions.* (1) Projected major conflict with applicable Federal, State, or local environmental requirements.

(2) Projected significant adverse environmental impacts that cannot be avoided or mitigated.

(3) Proximity to, or projected significant adverse environmental impacts of the repository or its support facilities on, a component of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.

(4) Proximity to, and projected significant adverse environmental impacts of the repository or its support facilities on, a significant State or regional protected resource area, such as a State park, a wildlife area, or a historical area.

(5) Proximity to, and projected significant adverse environmental impacts of the repository and its support facilities on, a significant Native American resource, such as a major Indian religious site, or other sites of unique cultural interest.

(6) Presence of critical habitats for threatened or endangered species that may be compromised by the repository or its support facilities.

(d) *Disqualifying Conditions.* Any of the following conditions shall *disqualify* a site:

(1) During repository siting, construction, operation, closure, or decommissioning the quality of the environment in the affected area could not be adequately protected or projected environmental impacts in the affected area could not be mitigated to an acceptable degree, taking into account

programmatic, technical, social, economic, and environmental factors.

(2) Any part of the restricted area or repository support facilities would be located within the boundaries of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, or the National Wild and Scenic Rivers System.

(3) The presence of the restricted area or the repository support facilities would conflict irreconcilably with the previously designated resource-preservation use of a component of the National Park System, the National Wildlife Refuge System, the National Wilderness Preservation System, the National Wild and Scenic Rivers System, or National Forest Lands, or any comparably significant State protected resource that was dedicated to resource preservation at the time of the enactment of the Act.

§ 960.5-2-6 Socioeconomic impacts.

(a) *Qualifying Condition.* The site shall be located such that (1) any significant adverse social and/or economic impacts induced in communities and surrounding regions by repository siting, construction, operation, closure, and decommissioning can be offset by reasonable mitigation or compensation, as determined by a process of analysis, planning, and consultation among the DOE, affected State and local government jurisdictions, and affected Indian tribes; and (2) the requirements specified in § 960.5-1(a)(2) can be met.

(b) *Favorable Conditions.* (1) Ability of an affected area to absorb the project-related population changes without significant disruptions of community services and without significant impacts on housing supply and demand.

(2) Availability of an adequate labor force in the affected area.

(3) Projected net increases in employment and business sales, improved community services, and increased government revenues in the affected area.

(4) No projected substantial disruption of primary sectors of the economy of the affected area.

(c) *Potentially Adverse Conditions.* (1) Potential for significant repository-related impacts on community services, housing supply and demand, and the finances of State and local government agencies in the affected area.

(2) Lack of an adequate labor force in the affected area.

(3) Need for repository-related purchase or acquisition of water rights, if such rights could have significant adverse impacts on the present or future development of the affected area.

(4) Potential for major disruptions of primary sectors of the economy of the affected area.

(d) *Disqualifying Condition.* A site shall be disqualified if repository construction, operation, or closure would significantly degrade the quality, or significantly reduce the quantity, of water from major sources of offsite supplies presently suitable for human consumption or crop irrigation and such impacts cannot be compensated for, or mitigated by, reasonable measures.

§ 960.5-2-7 Transportation.

(a) *Qualifying Condition.* The site shall be located such that (1) the access routes constructed from existing local highways and railroads to the site (i) will not conflict irreconcilably with the previously designated use of any resource listed in § 960.5-2-5(d) (2) and (3); (ii) can be designed and constructed using reasonably available technology; (iii) will not require transportation system components to meet performance standards more stringent than those specified in the applicable DOT and NRC regulations, nor require the development of new packaging containment technology; (iv) will allow transportation operations to be conducted without causing an unacceptable risk to the public or unacceptable environmental impacts, taking into account programmatic, technical, social, economic, and environmental factors; and (2) the requirements of § 960.5-1(a)(2) can be met.

(b) *Favorable Conditions.* (1) Availability of access routes from local existing highways and railroads to the site which have any of the following characteristics:

(i) Such routes are relatively short and economical to construct as compared to access routes for other comparable siting options.

(ii) Federal condemnation is not required to acquire rights-of-way for the access routes.

(iii) Cuts, fills, tunnels, or bridges are not required.

(iv) Such routes are free of sharp curves or steep grades and are not likely to be affected by landslides or rock slides.

(v) Such routes bypass local cities and towns.

(2) Proximity to local highways and railroads that provide access to regional highways and railroads and are adequate to serve the repository without significant upgrading or reconstruction.

(3) Proximity to regional highways, mainline railroads, or inland waterways that provide access to the national transportation system.

(4) Availability of a regional railroad system with a minimum number of interchange points at which train crew and equipment changes would be required.

(5) Total projected life-cycle cost and risk for transportation of all wastes designated for the repository site which are significantly lower than those for comparable siting options, considering locations of present and potential sources of waste, interim storage facilities, and other repositories.

(6) Availability of regional and local carriers—truck, rail, and water—which have the capability and are willing to handle waste shipments to the repository.

(7) Absence of legal impediment with regard to compliance with Federal regulations for the transportation of waste in or through the affected State and adjoining States.

(8) Plans, procedures, and capabilities for response to radioactive waste transportation accidents in the affected State that are completed or being developed.

(9) A regional meteorological history indicating that significant transportation disruptions would not be routine seasonal occurrences.

(c) *Potentially Adverse Conditions.* (1) Access routes to existing local highways and railroads that are expensive to construct relative to comparable siting options.

(2) Terrain between the site and existing local highways and railroads such that steep grades, sharp switchbacks, rivers, lakes, landslides, rock slides, or potential sources of hazard to incoming waste shipments will be encountered along access routes to the site.

(3) Existing local highways and railroads that could require significant reconstruction or upgrading to provide adequate routes to the regional and national transportation system.

(4) Any local condition that could cause the transportation-related costs, environmental impacts, or risk to public health and safety from waste transportation operations to be significantly greater than those projected for other comparable siting options.

Ease and Cost of Siting, Construction, Operation, and Closure

§ 960.5-2-8 Surface characteristics.

(a) *Qualifying Condition.* The site shall be located such that, considering the surface characteristics and conditions of the site and surrounding area, including surface-water systems and the terrain, the requirements specified in § 960.5-1(a)(3) can be met during repository siting, construction, operation, and closure.

(b) *Favorable Conditions.* (1) Generally flat terrain.

(2) Generally well-drained terrain.

(c) *Potentially Adverse Condition.* Surface characteristics that could lead to the flooding of surface or underground facilities by the occupancy and modification of flood plains, the failure of existing or planned man-made surface-water impoundments, or the failure of engineered components of the repository.

§ 960.5-2-9 Rock characteristics.

(a) *Qualifying Condition.* The site shall be located such that (1) the thickness and lateral extent and the characteristics and composition of the host rock will be suitable for accommodation of the underground facility; (2) repository construction, operation, and closure will not cause undue hazard to personnel; and (3) the requirements specified in § 960.5-1(a)(3) can be met.

(b) *Favorable Conditions.* (1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility.

(2) A host rock with characteristics that would require minimal or no artificial support for underground openings to ensure safe repository construction, operation, and closure.

(c) *Potentially Adverse Conditions.* (1) A host rock that is suitable for repository construction, operation, and closure, but is so thin or laterally restricted that little flexibility is available for selecting the depth, configuration, or location of an underground facility.

(2) In situ characteristics and conditions that could require engineering measures beyond reasonably available technology in the construction of the shafts and underground facility.

(3) Geomechanical properties that could necessitate extensive maintenance of the underground openings during repository operation and closure.

(4) Potential for such phenomena as thermally induced fracturing, the hydration and dehydration of mineral components, or other physical, chemical, or radiation-related phenomena that could lead to safety hazards or difficulty in retrieval during repository operation.

(5) Existing faults, shear zones, pressurized brine pockets, dissolution effects, or other stratigraphic or structural features that could compromise the safety of repository personnel because of water inflow or construction problems.

(d) *Disqualifying Condition.* The site shall be *disqualified* if the rock characteristics are such that the activities associated with repository construction, operation, or closure are predicted to cause significant risk to the health and safety of personnel, taking into account mitigating measures that use reasonably available technology.

§ 960.5-2-10 Hydrology.

(a) *Qualifying Condition.* The site shall be located such that the geohydrologic setting of the site will (1) be compatible with the activities required for repository construction, operation, and closure; (2) not compromise the intended functions of the shaft liners and seals; and (3) permit the requirements specified in § 960.5-1(a)(3) to be met.

(b) *Favorable Conditions.* (1) Absence of aquifers between the host rock and the land surface.

(2) Absence of surface-water systems that could potentially cause flooding of the repository.

(3) Availability of the water required for repository construction, operation, and closure.

(c) *Potentially Adverse Condition.* Ground-water conditions that could require complex engineering measures that are beyond reasonably available technology for repository construction, operation, and closure.

(d) *Disqualifying Condition.* A site shall be disqualified if, based on expected ground-water conditions, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure.

§ 960.5-2-11 Tectonics.

(a) *Qualifying Conditions.* The site shall be located in a geologic setting in which any projected effects of expected tectonic phenomena or igneous activity on repository construction, operation, or closure will be such that the requirements specified in § 960.5-1(a)(3) can be met.

(b) *Favorable Condition.* The nature and rates of faulting, if any, within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities.

(c) *Potentially Adverse Conditions.* (1) Evidence of active faulting within the geologic setting.

(2) Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits.

(3) Evidence, based on correlations of earthquakes with tectonic processes and features, (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger then predicted from historical seismicity.

(d) *Disqualifying Condition.* A site shall be disqualified if, based on the expected nature and rates of fault movement or other ground motion, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure.

Appendix I—NRC and EPA Requirements for Postclosure Repository Performance

Under proposed 40 CFR Part 191, Subpart B—*Environmental Standards for Disposal*, § 191.13, "Containment Requirements", specifies that for 10,000 years after disposal (a) releases of radioactive materials to the accessible environment that are estimated to have more than one chance in 100 of occurring over a 10,000 year period ("reasonably foreseeable releases") shall be projected to be less than the quantities permitted by Table 2 of that regulation's Appendix; and (b) for "very unlikely releases" (i.e., those estimated to have between one chance in 100 and one chance in 10,000 of occurring over a 10,000 year period), the limits specified in Table 2 would be multiplied by 10. The basis for Table 2 is an upper limit on long term risks of 1,000 health effects over 10,000 years for a repository containing wastes generated from 100,000 metric tons of heavy metal of reactor fuel. For releases involving more than one radionuclide, the allowed release for each radionuclide is reduced to the fraction of its limit that insures that the overall limit on harm is not exceeded. Additionally, to provide confidence needed for compliance with the containment requirements specified above, § 191.14, "Assurance Requirements", specifies the disposal of radioactive waste in accordance with seven requirements, relating to prompt disposal of waste; selection and design of disposal systems to keep releases to the accessible environment as small as reasonably achievable; engineered and natural barriers; nonreliance on active institutional controls after closure; passive controls after closure; natural resource areas; and design of disposal systems to allow future recovery of wastes.

The guidelines will be revised as necessary after the adoption of final regulations by the EPA.

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The implementation of 40 CFR Part 191, Subpart B is required by 10 CFR 60.112. 10 CFR 60.113 establishes minimum conditions to be met for engineered components and ground-water flow; specifically: (1) Containment of radioactive waste within the waste packages will be substantially complete for a period to be determined by the NRC taking into account the factors specified in 10 CFR 60.113(b) provided that such period shall be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository; (2) the release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the NRC, provided that this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste originally emplaced in the underground facility that remains after 1,000 years of radioactive decay; and (3) the geologic repository shall be located so that pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the NRC.

The guidelines will be revised as necessary to ensure consistency with 10 CFR Part 60.

Appendix II—NRC and EPA Requirements for Preclosure Repository Performance

Under proposed 40 CFR Part 191, Subpart A—*Environmental Standards for Management and Storage*, Section 191.03, "Standards for Normal Operations", specifies: (1) That operations should be conducted so as to reduce exposure to members of the public to the extent reasonably achievable, taking into account technical, social, and economic considerations; and (2) that, except for variances permitted for unusual operations under Section 191.04 as an upper limit, normal operations shall be conducted in such a manner as to provide reasonable assurance that the combined annual dose equivalent to any member of the public due to: (i) operations covered by 40 CFR Part 190, (ii) planned discharges of radioactive material to the general environment from operations covered by this Subpart, and (iii) direct radiation from these operations; shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, or 25 millirems to any other organ.

The guidelines will be revised as necessary after the adoption of final regulations by the EPA.

The implementation of 40 CFR Part 191, Subpart A and 10 CFR Part 20 is required by 10 CFR 60.111. 10 CFR 60.111 also specifies requirements for waste retrieval, if necessary, including considerations of design, backfilling, and schedule. 10 CFR Part 20 establishes (a) exposure limits for operating personnel and (b) permissible concentrations of radionuclides in uncontrolled areas for air and water. The latter are generally less restrictive than 40 CFR 191, Subpart A, but may be limiting under certain conditions (i.e., if used as a maximum for short durations rather than annual averages).

The guidelines will be revised as necessary to ensure consistency with 10 CFR Part 60.

Appendix III—Application of the System and Technical Guidelines During the Siting Process

1. This appendix presents a table that specifies how the guidelines of Subparts C and D are to be applied at the principal decision points of the siting process. The decision points, as referenced in the table, are defined as follows:

"Potentially acceptable" means the decision point at which a site is identified as potentially acceptable.

"Nomination and recommendation" means the decision point at which a site is nominated as suitable for characterization or recommended as a candidate site for characterization.

"Repository site selection" means the decision point at which a site is recommended for the development of a repository.

2. The findings resulting from the application of a disqualifying condition for any particular guideline at a given decision point are denoted in the table by the numeral 1 or 2. The numerals 1 and 2 signify the types of findings that are required and are defined as follows:

"1" means *either* of the following:

(a) The evidence does *not* support a finding that the site is disqualified.

or

(b) The evidence supports a finding that the site is disqualified.

"2" means *either* of the following:

(a) The evidence supports a finding that the site is *not* disqualified on the basis of that evidence and is *not* likely to be disqualified.

or

(b) The evidence supports a finding that the site is disqualified or is likely to be disqualified.

3. The findings resulting from the application of a qualifying condition for any particular guideline at a given decision point are denoted in the table by the numeral 3 or 4. The numerals 3 and 4 signify the types of findings that are required and are defined as follows:

"3" means *either* of the following:

(a) The evidence does *not* support a finding that the site is *not* likely to meet the qualifying condition.

or

(b) The evidence supports a finding that the site is *not* likely to meet the qualifying condition, and therefore the site is disqualified.

"4" means *either* of the following:

(a) The evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition.

or

(b) The evidence supports a finding that the site cannot meet the qualifying condition or is unlikely to be able to meet the qualifying condition, and therefore the site is disqualified.

4. If performance assessments are used to substantiate any of the above findings, those assessments shall include estimates of the effects of uncertainties in data and modeling.

5. For both the disqualifying and qualifying conditions of any guideline, a higher finding (e.g., a "2" finding rather than "1") shall be made if there is sufficient evidence to support such a finding.

FINDINGS RESULTING FROM THE APPLICATION OF THE QUALIFYING AND DISQUALIFYING CONDITIONS OF THE TECHNICAL GUIDELINES AT MAJOR SITING DECISIONS

Section 960	Guideline	Condition	Siting decision: Potentially acceptable	Siting decision: Nomination and recommendation	Siting decision: Repository site selection
4-1(a)	System	Qualifying		3	4
4-2-1(a)	Geohydrology	do		3	4
4-2-1(d)	do	Disqualifying		1	2
4-2-2(a)	Geochemistry	Qualifying		3	4
4-2-3(a)	Rock Characteristics	do		3	4
4-2-4(a)	Climatic Changes	do		3	4
4-2-5(a)	Erosion	do		3	4
4-2-5(d)	do	Disqualifying	1	1	2
4-2-6(a)	Dissolution	Qualifying		3	4
4-2-6(d)	do	Disqualifying	1	1	2
4-2-7(a)	Tectonics	Qualifying		3	4
4-2-7(d)	do	Disqualifying	1	1	2
4-2-8-1(a)	Natural Resources	Qualifying		3	4
4-2-8-1(d)(1)	do	Disqualifying	1	1	2
4-2-8-1(d)(2)	do	do		1	2
4-2-8-2(a)	Site Ownership and Control	Qualifying		3	4
5-1(a)(1)	System	do		3	4
5-1(a)(2)	do	do		3	4
5-1(a)(3)	do	do		3	4
5-2-1(a)	Population Density and Distribution	do		3	4
5-2-1(d)(1)	do	Disqualifying	1	1	2
5-2-1(d)(2)	do	do	1	1	2
5-2-1(d)(3)	do	do		1	2
5-2-2(a)	Site Ownership and Control	Qualifying		3	4
5-2-3(a)	Meteorology	do		3	4
5-2-4(a)	Offsite Installations and Operations	do		3	4

FINDINGS RESULTING FROM THE APPLICATION OF THE QUALIFYING AND DISQUALIFYING CONDITIONS OF THE TECHNICAL GUIDELINES AT MAJOR SITING DECISIONS—Continued

Section 960	Guideline	Condition	Siting decision		
			Potentially acceptable	Nomination and recommendation	Repository site selection
5-2-4(d)	....do	Disqualifying	1	1	2
5-2-5(a)	Environmental Quality	Qualifying		3	4
5-2-5(d)(1)	....do	Disqualifying		1	2
5-2-5(d)(2)	....do	....do	1	1	2
5-2-5(d)(3)	....do	....do	1	1	2
5-2-6(a)	Socioeconomic Impacts	Qualifying		3	4
5-2-6(d)	....do	Disqualifying		1	2
5-2-7(a)	Transportation	Qualifying		3	4
5-2-8(a)	Surface Characteristics	....do		3	4
5-2-9(a)	Rock Characteristics	....do		3	4
5-2-9(d)	....do	Disqualifying		1	2
5-2-10(a)	Hydrology	Qualifying		3	4
5-2-10(d)	....do	Disqualifying		1	2
5-2-11(a)	Tectonics	Qualifying		3	4
5-2-11(d)	....do	Disqualifying	1	1	2

Appendix IV—Types of Information for the Nomination of Sites as Suitable for Characterization

The types of information specified below are those that the DOE expects will be included in the evidence used for evaluations and applications of the guidelines of Subparts C and D at the time of nomination of a site as suitable for characterization. The types of information listed under each guideline are considered to be the most significant for the evaluation of that guideline. However, the types of information listed under any particular guideline will be used, as necessary, for the evaluation of any other guideline. As stated in § 960.3–1–4–2, the DOE will use technically conservative assumptions or extrapolations of regional data, where necessary, to supplement this information. The information specified below will be supplemented with conceptual models, as appropriate, and analyses of uncertainties in the data.

Before site-characterization studies and related nongeologic data gathering activities, the evidence is not expected to provide precise information, but, rather, to provide a reasonable basis for assessing the merits or shortcomings of the site against the guidelines of Subparts C and D. Consequently, the types of information described below should be interpreted so as to accommodate differences among sites and differences in the information acquired before detailed studies.

The specific information required for the guideline applications set forth in Appendix III of this Part is expected to differ from site to site because of site-specific factors, both with regard to favorable and potentially adverse conditions and with regard to the sources and reliability of the information. The types of information specified in this appendix will be used except where the findings set forth in Appendix III of this part can be arrived at by reasonable alternative means or the information is not required for the particular site.

Section 960.4–2–1 Geohydrology.

Description of the geohydrologic setting of the site, in context with its geologic setting, in order to estimate the pre-waste-emplacement ground-water flow conditions. The types of information to support this description should include—

- Location and estimated hydraulic properties of aquifers, confining units, and aquitards.
- Potential areas and modes of recharge and discharge for aquifers.
- Regional potentiometric surfaces of aquifers.
- Likely flow paths from the repository to locations in the expected accessible environment, as based on regional data.
- Preliminary estimates of ground-water travel times along the likely flow paths from the repository to locations in the expected accessible environment.
- Current use of principal aquifers and State or local management plans for such use.

Section 960.4–2–2 Geochemistry.

Description of the geochemical and hydrochemical conditions of the host rock, of the surrounding geohydrologic units, and along likely ground-water paths to locations in the expected accessible environment, in order to estimate the potential for the migration of radionuclides. The types of information to support this description should include—

- Petrology of the rocks.
- Mineralogy of the rocks and general characteristics of fracture fillings.
- Geochemical and mechanical stability of the minerals under expected repository conditions.
- General characteristics of the ground-water chemistry (e.g., reducing/oxidizing conditions and the principal ions that may affect the waste package or radionuclide behavior).
- Geochemical properties of minerals as related to radionuclide transport.

Section 960.4–2–3 Rock characteristics.

Description of the geologic and geomechanical characteristics of the site, in context with the geologic setting, in order to estimate the capability of the host rock and surrounding rock units to accommodate the thermal, mechanical, chemical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground-water, and engineered components of the repository system. The types of information to support this description should include—

- Approximate geology and stratigraphy of the site, including the depth, thickness, and lateral extent of the host rock and surrounding rock units.
- Approximate structural framework of the rock units and any major discontinuities identified from core samples.
- Approximate thermal, mechanical, and thermomechanical properties of the rocks, with consideration of the effects of time, stress, temperature, dimensional scale, and any major identified structural discontinuities.
- Estimates of the magnitude and direction of in situ stress and of temperature in the host rock and surrounding rock units.

Section 960.4–2–4 Climatic changes.

Description of the climatic conditions of the site region, in context with global and regional patterns of climatic changes during the Quaternary Period, in order to project likely future changes in climate such that potential impacts on the repository can be estimated. The types of information to support this description should include—

- Expected climatic conditions and cycles, based on extrapolation of climates during the Quaternary Period.
- Geomorphology of the site region and evidence of changes due to climatic changes.
- Estimated effects of expected climatic cycles on the surface-water and the ground-water systems.

Section 960.4–2–5 Erosion.

Description of the structure, stratigraphy, and geomorphology of the site, in context with the geologic setting, in order to estimate the depth of waste emplacement and the likelihood for erosional processes to uncover the waste in less than one million years. The types of information to support this description should include—

- Depth, thickness, and lateral extent of the host rock and the overlying rock units.
- Lithology of the stratigraphic units above the host rock.
- Nature and rates of geomorphic processes during the Quaternary Period.

Section 960.4–2–6 Dissolution.

Description of the stratigraphy, structure, hydrology, and geochemistry of the site, in context with the geologic setting, to delineate the approximate limits of subsurface rock dissolution, if any. This description should include such information as the following:

- The stratigraphy of the site, including rock units largely comprised of water-soluble minerals.
- The approximate extent and configuration of features indicative of dissolution within the geologic setting.

Section 960.4–2–7 Tectonics.

Description of the tectonic setting of the site, in context with its geologic setting, in order to project the tectonic stability of the site over the next 10,000 years and to identify tectonic features and processes that could be reasonably expected to have a potentially adverse effect on the performance of the repository. The types of information to support this description should include—

• The tectonic history and framework of the geologic setting and the site.

• Quaternary faults in the geologic setting, including their length, displacement, and any information regarding the age of latest movement.

• Active tectonic processes, such as uplift, diapirism, tilting, subsidence, faulting, and volcanism.

• Estimate of the geothermal gradient.

• Estimate of the regional in situ stress field.

• The historical seismicity of the geologic setting.

Section 960.4-2-8 Human interference.

Section 960.4-2-8-1 Natural resources.

Description of the mineral and energy resources of the site, in order to project whether past or future exploration and recovery could have a potentially adverse effect on the performance of the repository. The types of information to support this description should include—

• Known occurrences of energy and mineral resources, including ground water.

• Estimates of the present and projected value of these resources compared with resources contained in other areas of similar size in the geologic setting.

• Past and present drilling and mining operations in the vicinity of the site.

Section 960.4-2-8-2 Site ownership and control.

Description of the ownership of land for the geologic-repository operations area and the controlled area, in order to evaluate whether the DOE can obtain ownership of, and control access to, the site. The types of information to support this description should include—

• Present land ownership.

Section 960.5-2-1 Population density and distribution.

Description of the population density and distribution of the site region, in order to identify highly populated areas and the nearest 1 mile by 1 mile area having a population greater than 1,000 persons. The types of information to support this description should include—

• The most-recent U.S. census, including population composition, distribution, and density.

Section 960.5-2-2 Site ownership and control.

Description of current ownership of land, including surface and subsurface mineral and water rights, in order to evaluate whether the DOE can obtain control of land within the projected restricted area. The types of information to support this description should include—

• Present land ownership.

Section 960.5-2-3 Meteorology.

The meteorological setting, as determined from the closest recording station, in order to project meteorological conditions during repository operation and closure and their potential effects on the transport of airborne emissions. The types of information to support this description should include—

• Wind and atmospheric-dispersion characteristics.

• Precipitation characteristics.

• Extreme weather phenomena.

Section 960.5-2-4 Offsite installations and operations.

Description of offsite installations and operations in the vicinity of the site in order to estimate their projected effects on repository construction, operation, or closure. The types of information to support this description should include—

• Location and nature of nearby industrial, transportation, and military installations and operations, including atomic energy defense activities.

Section 960.5-2-5 Environmental quality.

Description of environmental conditions in order to estimate potential impacts on public health and welfare and on environmental quality. The types of information to support this description should include—

• Applicable Federal, State, and local procedural and substantive environmental requirements.

• Existing air quality and trends.

• Existing surface-water and ground-water quality and quantity.

• Existing land resources and uses.

• Existing terrestrial and aquatic vegetation and wildlife.

• Location of any identified critical habitats for threatened or endangered species.

• Existing aesthetic characteristics.

• Location of components of the National Park System, the National Wildlife Refuge System, the National Wild and Scenic Rivers System, the National Wilderness Preservation System, or National Forest Land.

• Location of significant State or regional protected resource areas, such as State parks, wildlife areas, or historical areas.

• Location of significant Native American resources such as major Indian religious sites, or other sites of unique cultural interest.

Section 960.5-2-6 Socioeconomic impacts.

Description of the socioeconomic conditions of the site, including population density and distribution, economics, community services and facilities, social conditions, and fiscal and government structure, in order to estimate the impacts that might result from site characterization and from the development of a repository at that site. The types of information to support this description should include—

• Population composition, density, and distribution.

• Economic base and economic activity, including major sectors of local economy.

• Employment distribution and trends by economic sector.

• Resource usage.

• Community services and infrastructure, including trends in use and current capacity utilization.

• Housing supply and demand.

• Life style and indicators of the quality of life.

• Existing social problems.

• Sources of, and trends in, local government expenditures and revenues.

Section 960.5-2-7 Transportation.

Description of the transportation facilities in the vicinity of the site in order to evaluate existing or required access routes or improvements. The types of information to support this description should include—

• Estimates of the overall cost and risk of transporting waste to the site.

• Description of the road and rail network between the site and the nearest Interstate highways and major rail lines; also, description of the waterway system, if any.

• Analyses of the adequacy of the existing regional transportation network to handle waste shipments; the movement of supplies for repository construction, operation, and closure; removal of nonradioactive waste from the site; and the transportation of the labor force.

• Improvements anticipated to be required in the transportation network and their feasibility, cost, and environmental impacts.

• Compatibility of the required transportation network improvements with the local and regional transportation and land-use plans.

• Analysis of weather impacts on transportation.

• Analysis of emergency response requirements and capabilities related to transportation.

Section 960.5-2-8 Surface characteristics.

Description of the surface characteristics of the site, in order to evaluate whether repository construction, operation, and closure are feasible on the basis of site characteristics that influence those activities. The types of information to support this description should include—

• Topography of the site.

• Existing and planned surface bodies of water.

• Definition of areas of landslides and other potentially unstable slopes, poorly drained material, or materials of low bearing strength or of high liquefaction potential.

Section 960.5-2-9 Rock characteristics.

Description of the geologic and geomechanical characteristics of the site, in context with the geologic setting, in order to project the capability of the host rock and the surrounding rock units to provide the space required for the underground facility and safe underground openings during repository construction, operation, and closure. The types of information to support this description should include—

• Depth, thickness, and lateral extent of the host rock.

• Stratigraphic and structural features within the host rock and adjacent rock units.

• Thermal, mechanical, and thermomechanical properties and constructibility characteristics of the rocks, with consideration of the effects of time, stress, temperature, dimensional scale, and any major identified structural discontinuities.

• Fluid inclusions and gas content in the host rock.

- Estimates of the magnitude and direction of in situ stress and of temperature in the host rock.

Section 960.5-2-10 Hydrology.

Description of the hydrology of the site, in context with its geologic setting, in order to project compatibility with repository construction, operation, and closure. The types of information to support this description should include—

- Surface-water systems, including recharge and runoff characteristics, and potential for flooding of the repository.
- Nature and location of aquifers, confining units, and aquitards.
- Potentiometric surfaces of aquifers.
- Hydraulic properties of geohydrologic units.

Section 960.5-2-11 Tectonics.

Description of the tectonic setting of the site, in context with the regional setting, in order to estimate any expected effects of tectonic activity on repository construction, operation, or closure. The types of information to support this description should include—

Quaternary faults.

Active tectonic processes.

- Preliminary estimates of expected ground motion caused by the maximum potential earthquake within the geologic setting.

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Appendix C

ORIGIN AND NATURE OF THE HOST ROCKS CONSIDERED FOR THE FIRST REPOSITORY

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Appendix C

ORIGIN AND NATURE OF THE HOST ROCKS CONSIDERED FOR THE FIRST REPOSITORY

C.1 BASALT LAVAS

Lava is molten material (magma) that pours out on the earth's surface from volcanoes or from fissures. Magma originates from the melting of the lower crust and upper mantle, usually at depths of 30 to 125 miles below the surface. This melting is influenced by temperature, pressure, composition, and the amount of water present; it can be initiated by an increase in temperature or a decrease in pressure. At a given temperature and pressure, a rock mass may only be partly melted because each component mineral melts at a different temperature and in a definite sequence. Because of this process of partial melting, the liquid (magma) will have a composition quite different from that of the original rock.

Conversely, as magma cools, the various minerals crystallize in a definite sequence. When partial crystallization occurs, the remaining magma can be separated from the crystals to form a magma quite different from the parent magma. This process is called magmatic differentiation.

Depending on the degree of potential melting and, subsequently, of magmatic differentiation, a broad spectrum of composition of igneous rocks may result. The common "end members" of the compositional spectrum are basalt (whose coarse-grained intrusive equivalent is gabbro) and rhyolite (whose equivalent is granite). Magmas of intermediate composition produce rocks of the andesite (diorite) family.

Basaltic (gabbroic) magma contains about 50 percent silica (SiO_2), has temperatures ranging from about 900 to 1200°C, and generally is of low viscosity. Since dissolved gases readily escape, basaltic lava is typically extruded quietly from fissures to form lava flows that cover large areas. Eruptions of greater violence are volumetrically trivial; they include cinder cones and spatter cones produced by lava fountains. Rhyolitic (granitic) magma contains about 70 percent silica, has temperatures lower than 800°C, and is relatively viscous and rich in gas.

Where basalt lavas flowed over moist ground or shallow lakes and ponds, the lava was quenched and either explosively shattered to rubble or formed bulbous pillow-shaped pods embedded in lava or shattered lava. These basal rubble zones are overlain by a zone of columnar-jointed lava (called the "colonnade") that formed as the lava cooled from the base upward. This, in turn, is overlain by a zone of haphazardly arranged joint blocks (called the "entablature") in which columns may occur, some oriented in fan-shaped arrays. This zone and the overlying flow-top rubble zone resulted from cooling from the top downward. Many variations of this zonation occur.

The lavas at the Hanford Site are part of an areally extensive sequence of sheetlike basalt lavas that were erupted from fissures and interbedded sedimentary deposits. This sequence makes up the Columbia Plateau, which occupies vast areas in Washington, Oregon, and Idaho. At the Hanford Site, the sequence of lavas and interbeds is more than a mile thick. The lower part consists entirely of basalt lava flows. Interbedded sedimentary deposits appear in the middle of the section and increase in abundance upward.

The rubble zones at the base and top of the flows, and most of the sedimentary interbeds, are zones of relatively high permeability and commonly are act as aquifers. The dense colonnade and entablature, although pervasively cut by fractures (cooling joints) are of relatively low permeability. This is especially so in the lower part of the section, where secondary minerals such as opal, clay, and zeolites have sealed much of the fracture space and other voids.

C.2 ROCK SALT

Rock salt is the best-known member of a class of sedimentary rocks called evaporites. Evaporites are rocks that formed from a saline solution as a result of extensive or total evaporation of the solvent (water) under arid or semiarid conditions. Rock salt forms by the precipitation of sodium chloride from saturated evaporating bodies of water in basins such as epicontinental seas, shallow lakes that have no outlets, and restricted coastal-plain marshes.

As sea water evaporates, the remaining brine becomes more saline, and minerals precipitate from it in the order of their solubilities, the most soluble remaining in solution the longest. Aragonite or calcite ($CaCO_3$) precipitates early, followed by gypsum ($CaSO_4$-$2H_2O$) and then by halite (rock salt, NaCl) and other mineral salts of sodium, potassium, and magnesium (including those of importance as potash resources).

The sequence of deposition of evaporite minerals commonly is interrupted by changes in response to such things as periodic replenishing of water from cloudbursts and tidal floods or influx by intermittent streams. Some dissolution or erosion of the last-formed evaporites may occur, layers of mud are deposited on the evaporite layers, and the cycle starts anew. The layers or thin films of mud tend to occur basinwide and serve as reliable stratigraphic marker beds.

If the shallow basins or coastal plains subside slowly as they are being filled, the repeated cycles of beds of salt and other evaporite beds and interbedded sediments become deeply buried by sand, mud, and marl, which eventually become indurated to form sandstone, shale, and limestone. In the areas of bedded salt being studied, the salt was buried by some 10,000 feet of strata. Because of subsequent uplift and erosion, the salt beds now occur in places at depths suitable for repositories (i.e., about 1000 to 3000 feet).

The density of salt (2.0 to 2.2 g/cm^3) is considerably lower than that of the overlying sedimentary strata (2.3 to 2.8 g/cm^3). As a result, where salt beds are overlain by a great thickness of strata such that the salt lies at depths of tens of thousands of feet, the high temperature and pressure at that depth enable the salt to rise buoyantly by plastic flow along zones of weakness into and through the overlying strata. The result is a crosscutting and intrusive salt body called a "salt dome." Such bodies are also referred to as "diapirs", which is the general term for the class of bodies formed by the piercement of overlying rocks by mobile or plastic material (such as salt, shale, or magma) which has been squeezed out of its former position.

Salt domes (see Figure C-1) have various shapes and sizes but, in general, are vertical fingerlike bodies whose height is greater than their width. Generally they are circular or oval in horizontal cross section. Many domes are the coalesced composites of two or more separately intruded salt bodies. The domes rise until there is no longer a sufficient contrast in density with the enclosing deposits to give them buoyancy, and they become stabilized. In places, they rise to the surface, where they erode or dissolve.

When the rising salt dome reaches water-bearing strata, the top and upper flanks of the dome begin to dissolve. The insoluble material in the salt is left as a chaotic assemblage of anhydrite, dolomite, mud, silt, and sand that becomes cemented into a generally impervious or cavernous carapace referred to as the "caprock."

Beds alongside the dome are dragged by the rising salt pillar to form folds and faults. Oil and gas generated in deeply buried deposits rise to higher levels until trapped by such structures or by the caprock, where deposits of sulfur (formed by the reduction of calcium sulfate) also occur.

In salt domes, the original interbedded layers of the sequence of bedded salt have been intensely deformed by the flowage of salt as the mass bulged and flowed upward through thousands of feet of strata. The internal structures of the resulting salt domes are highly complex and essentially vertical.

C.3 TUFF

Tuff is compacted and indurated ash that was erupted from volcanoes. Because of its generally viscous nature and high gas content, magma of the granite-rhyolite family produces the most voluminous eruptions of ash (see the discussion of basalt lavas in Section C.1).

Of particular interest as a potential host rock for a repository at Yucca Mountain in Nevada is a special kind of tuff called "welded tuff." Welded tuff is interpreted as having been emplaced by an avalanche of a highly heated mixture of volcanic gases and ash, traveling down the slopes of a volcano and along the surface of the surrounding lowlands and valleys to form extensive sheetlike deposits. This current is produced by the explosive disintegration of gas-charged ash from a crater or from fissures. The gas provides great buoyancy and mobility to these flows of ash. In many places the heat caused softening of chunks of pumice and glass shards. When the ash flow came to rest, the weight of the deposit caused the soft, hot particles to press together to become welded into compact sheetlike masses, some of which covered vast areas. Temperatures of about 500°C are required for such welding to take place.

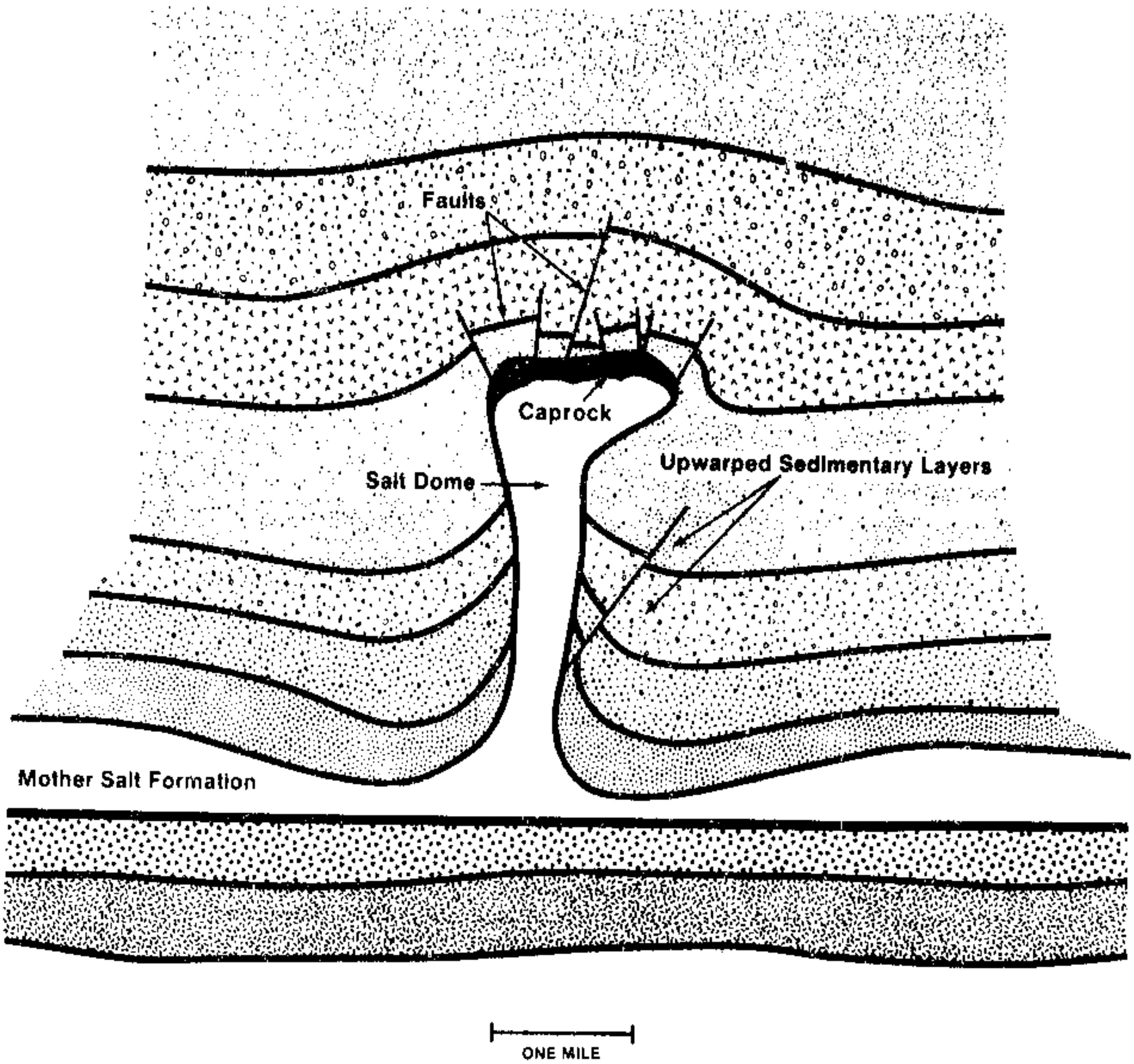

Figure C-1. Diagrammatic cross section of a salt dome.

Because the welding is produced partly by compaction from the weight of the overlying material, there are pronounced vertical changes in the degree and the nature of welding, density, and porosity. Densely welded material tends to be highly jointed and to lie between zones of partial welding that are relatively free of joints, grading upward into nonwelded ash. Lateral variations in welding, density, and porosity are caused by changes in thickness, distance from the source, and irregularities in the surface on which the ash was deposited. These variations tend to be less pronounced than do the vertical variations, as they generally take place over greater distances.

Upon cooling, large parts of the deposit crystallize by devitrification of glass, condensation of vapors, and vapor-phase alteration. Subsequent percolation by ground water causes further alteration, principally to clay, silica, and zeolites. The variations in properties of the zones affect the hydrologic, chemical, and mechanical behavior of the welded tuff.

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