AR TARGET SHEET

The following document was too large to scan as one unit, therefore, it has been broken down into sections.

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APPENDIX R

ASSESSMENT OF LONG-TERM PERFORMANCE OF WASTE DISPOSAL SYSTEMS

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ASSESSMENT OF LONG-TERM PERFORMANCE OF WASTE DISPOSAL SYSTEMS

Impacts on public health and safety in the post-disposal period were assessed in support of Chapter 5 of this EIS. This assessment identified and evaluated plausible natural and human-induced events that could affect the performance of the disposal systems and result in the release of radionuclides. Supporting information for the analyses presented in this appendix is given in Appendix F on dose calculation methods, Appendix M on the performance of the protective barrier and marker system, Appendix N on radiological health effects, Appendix P on release models and radionuclide inventories for subsurface sources, Appendix Q on application of geohydrologic models to the scenarios of this appendix, and Appendix U on analysis of hazardous chemical transport by groundwater.

Key findings of the analyses reported in this appendix are as follows:

- The major pathway for transport of radionuclides and chemicals to the affected environment is via groundwater.
- For wastes disposed of near the surface on the Hanford Site, the consequences to the offsite population would be negligible compared with consequences from naturally occurring radiation sources. This holds true for all scenarios for any of the disposal alternatives and also for no disposal action.
- With a protective barrier in place and with perfect performance, the mechanism reasonably postulated for moving radionuclides to groundwater involves diffusion of the waste to a zone beyond the barrier. Advection would then dominate the transport process. This process would require several thousand years for nuclides to move to the groundwater.
- Scenarios involving contact with or intrusion into waste, developed for the case in which only passive institutional controls exist for the disposal alternatives and no institutional controls for the no disposal action (continued storage) after the year 2150, predict significant adverse or fatal consequences to those ignoring warnings and intruding into the wastes. Probability of intrusion is highest in the no disposal action case.
- Some events, such as catastrophic floods associated with glaciation, would in themselves create such overwhelming environmental impact as to obliterate or obscure any impact from released defense waste.

Although no significant releases of either radionuclides or toxic chemicals are expected from waste disposed of by either the geologic disposal alternative, the in-place stabilization and disposal alternative, or the reference (combination) alternative during planned operation of these disposal systems, it is necessary to examine all reasonably postulated events that might cause releases and possibly affect health and safety. Thus this appendix

describes postdisposal impacts, performance of waste disposal systems, and postulated natural and human-induced events that could potentially disrupt such disposal systems. These events are listed in Table R.1. Scenarios for events where a reasonable risk of release of nuclides to the biosphere exists are discussed in detail.

TABLE R.1. Events Investigated for Potential Impact on Waste Disposal Systems

- Irrigation
  - Onsite
  - Offsite
- Falling Objects
  - Meteorites
  - Airplane Crashes
  - Space Debris
- Drilling
  - Resource Exploration
  - Water Well
- Excavation
  - Major, Large Scale
  - Minor
- Resettlement/Farming/Gardening
  - Residential/Home Garden
  - Post Drilling/Excavation Habitation
  - Contaminated Water Supply Well
  - Biotic Transport/Habitation
- Climate State
  - Current
  - Drier
  - Wetter
- Glacial Flooding
- Other Surface Flooding
  - 100-Year Flood
  - Standard Project Flood
  - Probable Maximum Flood
  - Dam Failure
  - Rise in Sea Level
- Wind Erosion
  - Prevailing Winds
  - Tornados
- Magmatic Activity
  - Basalt Flows
  - Volcanism
  - Igneous Intrustion
- Seismic Activity
- Criticality
- Diffusion
- Terrorism
- Warfare

Of the list of possible events in Table R.1 that might affect the waste, eight were judged to have sufficient probability and/or consequence to warrant further detailed analysis:

Climatic State	Section R.1.1
Irrigation	Section R.1.2
Impact Crater (airplane crash)	Section R.2.2
Drilling Intrusion	Section R.3
Major Excavation	Section R.4
Residential/Home Garden	Section R.5.1
Biotic Transport	Section R.5.2
Postdrilling/Excavation Habitation	Section R.5.3

The consequences of the potential releases were then developed, including calculated doses to individuals and population groups as appropriate according to the methods described in Appendix F.

A summary of the waste classes, disposal alternatives and no disposal action (continued storage) for which each exposure scenario is applicable[a] is provided in the appropriate section. Maximum annual radiation doses to individuals are provided for all evaluated scenarios. For scenarios potentially having an impact on more than a few individuals, population doses are given as well. Because the year in which these scenarios might occur cannot be predicted, impacts are given for 100, 400, 1,000, and 10,000 years after disposal for those cases for which these times could apply.

R.1 WASTE MIGRATION THROUGH GROUNDWATER RECHARGE

If precipitation were to percolate though the overburden and into a waste site, it could cause the radionuclides to move slowly from the waste site, through the vadose zone, into the groundwater, and eventually to the biosphere. The quantity of water available for percolation is dependent on the climate or on the amount of land irrigated in the immediate vicinity.

R.1.1 Climatic Considerations

Predictions of future climate are generally projected from data for past climatic states. The Pasco Basin is believed to have been cooler and wetter 13,000 to 10,000 years ago than it is today and to have changed to a warmer, drier climate about 8,000 years ago (Nickmann and Leopold 1985). (See also Chapter 4.)

Because warm interglacial climates such as the present are typical of only about 10% of the climatic record for the past one million years (Bull 1979), it seems likely that the most probable change will be toward a cooler climate. Because of the uncertainties in predicting what will happen over the next 10,000 years, climate is considered under three different states, including an assumed change toward a cooler and wetter state:

- existing climate remaining
- climate becoming more arid
- climate becoming wetter and leading to additional recharge to the groundwater system.

Existing conditions and change to a more arid climate are discussed briefly because these states are less likely to supply a mechanism for transporting waste than are conditions that increase water available to the land surface.

Estimates of groundwater recharge (i.e., the amount of water trickling through the upper soil to the water table) for the Pasco Basin and the Hanford Site under present conditions vary with location and soil characteristics. In the area of principal interest, 200 West and

(a) "Applicability" means physically possible. The probability of an event may be substantially different between two alternatives, yet the event is applicable for analytical purposes. For example, the drilling scenario is applicable to in-place stabilization and disposal and to the no disposal action (continued storage) alternative, but the estimated probability of occurrence differs by a factor of 100 or more between the two alternatives.

200 East Areas, little groundwater recharge is expected from present levels of precipitation. Under a wetter climate a higher recharge rate would be expected. A range for average annual recharge of 0.5 to 5 cm/yr has been used in this EIS.

A more arid climate rather than wetter is not considered so likely to affect the disposal systems adversely. A drier and windier climate could increase wind erosion over unprotected sites, but with the present low groundwater recharge rates and existing arid climate, a change to more arid conditions would not be expected to disturb waste sites.

R.1.2 Irrigation Considerations

Irrigation is considered a credible event for affecting wastes only at unprotected waste sites in the event of no disposal action (continued storage) if institutional control were absent. It is assumed that sites covered with a protective barrier, designed to preclude the deep-root-crop pathway, and marked and recorded, would, together with continued federal ownership, make large-scale irrigation over waste sites extremely unlikely. Potential effects on the water table from offsite irrigation are discussed in Appendix Q.

R.1.3 Migration Analysis

For analysis of migration, three scenarios are considered:

- no infiltration[(a)]
- a recharge of 0.5 cm/yr (assumed to be representative of current climatic conditions)
- a recharge of 5 cm/yr.

Water infiltration associated with these scenarios is postulated to cause portions of the radionuclide inventory in the waste to gradually dissolve and move downward to the water table, where it might be intercepted by wells or would eventually reach the Columbia River. These scenarios are intended to provide a basis for estimating radiological impacts associated with non-zero infiltration rates.

The time required for the recharge water to travel from the location of the wastes to the water table depends on the amount of water available, the depth to groundwater, and the soil types. Six samples have been taken from the major soil horizons visible in the 15-m-deep 241-AP Hanford tank farm excavation. Laboratory analyses of these samples were performed for particle size, saturated hydraulic conductivity, and water retention characteristics. The soil layers deeper than those sampled appear to be similar to the soils evaluated. By modeling the unsaturated flow through the layered soils, travel times to the water table for recharge rates of 0.5 cm/yr and 5 cm/yr were obtained (Appendix O). The travel time for 0.5-cm/yr recharge ranges from 800 to 1,100 years. For 5-cm/yr recharge, the travel times are estimated to be between 100 and 150 years.

A protective barrier system can effectively prevent water migration directly through the waste (see Appendix M), but water will still percolate through soil beyond the edges of the barrier. Since a residual quantity of water will remain in the soil beneath the barrier, there is still the potential for slow diffusion of the waste components. These components

(a) Where the recharge to groundwater is zero there is no driving force for nuclide movement and radiological impacts from scenarios presented in this section would be zero.

may, over long periods, move to the edge of the barrier and be intercepted by the downward flowing moisture and carried to the groundwater. A discussion of this mechanism is provided in Appendix P. Doses resulting from this mechanism are addressed in this appendix, R, where applicable.

Detail on the models and flow rates used in this analysis can be found in Appendices O and P. Results of modeling individual cases are summarized in Appendix Q.

R.1.4 Dosimetric Analysis

People do not receive immediate radiation doses once the radionuclides have begun to migrate through the soil. There is a delay while the nuclides are transported through the unsaturated zone and the groundwater before they finally arrive at a point where people can be exposed. The location of the point of exposure is also dependent on future actions. It may be that a domestic well penetrates to contaminated plume, or the contaminated groundwater may eventually reach the Columbia River. For this analysis, wells have been assumed at a distance of 5 km down-gradient from the 200 Areas. The nuclides are also assumed to reach the Columbia River, where they may affect the downstream population. Radiation doses to individuals drinking water and irrigating from the 5-km well have been calculated. (The 5-km distance is a calculational convenience--the calculated water concentrations change relatively little from the point of contaminant entry to downstream locations. The value at 5 km is representative of distances 0 to 10 km or more from the waste.) The total integrated population dose to all people living along the Columbia River for the next 10,000 years has also been calculated. These doses are addressed in the following sections.

R.1.4.1 Drinking Well Water

A measure of the level of contamination of groundwater is the radiation dose caused only by drinking the water. Annual and lifetime doses to individuals drinking water from a well located 5 km downstream of each waste site for each disposal alternative and for no disposal action are given in Tables R.2 through R.21.

The source of the time-dependent radionuclide inventories in groundwater used in the dose calculations is the analysis summarized in Appendix Q. The cross-reference indicators in Tables R.2 through R.21, (labeled as references to the "Transport Assessment Table") and the following tables, are to the summaries provided in Appendix Q Tables Q.2 through Q.16. Because both the doses and the groundwater results are time functions including multiple radionuclides, peak times reported in Appendix Q may not exactly correspond to the peak dose rates in this appendix. Total-body doses and critical-organ doses (the dose to the organ receiving the highest dose) are summarized in the tables, along with the time the dose occurs and the radionuclide that contributes most to the dose (the "Dominant Nuclide"). Internal organs generally receive doses that exceed the average total-body dose. The ratio of critical-organ dose to total-body dose is given in Table R.22 for those nuclides from the wastes found to result in the highest doses.

TABLE R.2. Geologic Disposal Alternative--Individual Maximum Potential 1-Year Radiation Doses from Drinking Well Water (barriers remain effective)

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.2	3×10^{-6}	Thyroid	1×10^{-4}	5,100	^{129}I	Q.6	1×10^{-7}	Thyroid	1×10^{-5}	5,000	^{129}I
Grouted Process Residuals	Q.2	6×10^{-5}	Thyroid	7×10^{-3}	5,500	^{129}I	Q.6	1×10^{-5}	Thyroid	1×10^{-3}	5,200	^{129}I
Existing Double-Shell Tanks												
Tank Residuals	Q.2	1×10^{-7}	GI-LLI	1×10^{-5}	5,000	^{99}Tc	Q.6	3×10^{-9}	GI-LLI	9×10^{-8}	5,700	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks												
Tank Residuals	Q.2	3×10^{-9}	Thyroid	4×10^{-7}	5,900	^{129}I	Q.6	4×10^{-10}	Thyroid	7×10^{-8}	5,100	^{129}I
Grouted Process Residuals	Q.2	1×10^{-5}	Thyroid	4×10^{-3}	5,000	^{129}I	Q.6	3×10^{-6}	Thyroid	1×10^{-3}	5,200	^{129}I
Sr/Cs Capsules[b]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
RS/NG[c] TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.2	6×10^{-6}	Thyroid	6×10^{-4}	5,200	^{129}I	Q.6	3×10^{-6}	Thyroid	3×10^{-4}	5,000	^{129}I
Existing Double-Shell Tanks												
Tank Residuals	Q.2	4×10^{-7}	Thyroid	4×10^{-5}	5,100	^{129}I	Q.6	1×10^{-7}	Thyroid	1×10^{-5}	5,000	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
RS/NG TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
600 Area Wastes												
300 Area Burial Sites[b,e]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site[b]	--	--	--	--	--	--	--	--	--	--	--	--

(a) Existing DST grout is included in the SST grout calculation.
(b) This waste form does not apply to the geologic disposal alternative.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.3. Geologic Disposal Alternative--Individual Maximum Potential 70-Year Radiation Doses from Drinking Well Water (barriers remain effective)

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.2	2×10^{-4}	Thyroid	1×10^{-2}	5,100	^{129}I	Q.6	1×10^{-5}	Thyroid	1×10^{-3}	5,000	^{129}I
Grouted Process Residuals	Q.2	4×10^{-3}	Thyroid	5×10^{-1}	5,500	^{129}I	Q.6	1×10^{-3}	Thyroid	1×10^{-1}	5,200	^{129}I
Existing Double-Shell Tanks												
Tank Residuals	Q.2	1×10^{-5}	GI-LLI	9×10^{-4}	5,000	^{99}Tc	Q.6	2×10^{-7}	GI-LLI	6×10^{-6}	5,700	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks												
Tank Residuals	Q.2	2×10^{-7}	Thyroid	3×10^{-5}	5,900	^{129}I	Q.6	3×10^{-8}	Thyroid	5×10^{-6}	5,100	^{129}I
Grouted Process Residuals	Q.2	7×10^{-4}	Thyroid	3×10^{-1}	5,000	^{129}I	Q.6	2×10^{-4}	Thyroid	7×10^{-2}	5,000	^{129}I
Sr/Cs Capsules[b]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
RS/NG[c] TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.2	4×10^{-4}	Thyroid	4×10^{-2}	5,200	^{129}I	Q.6	2×10^{-4}	Thyroid	2×10^{-2}	5,000	^{129}I
Existing Double-Shell Tanks												
Tank Residuals	Q.2	3×10^{-5}	Thyroid	3×10^{-3}	5,100	^{129}I	Q.6	7×10^{-6}	Thyroid	7×10^{-4}	5,000	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
RS/NG TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
600 Area Wastes												
300 Area Burial Sites[b,e]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site[b]	--	--	--	--	--	--	--	--	--	--	--	--

(a) Existing DST grout is included in the SST grout calculation.
(b) This waste form does not apply to the geologic disposal alternative.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.4. Geologic Disposal Alternative--Individual Maximum Potential 1-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Disruptive Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.7	1×10^{-3}	Bone	3×10^{-2}	9,800	^{239}Pu
Grouted Process Residuals	Q.7	1×10^{-3}	Thyroid	1×10^{-1}	1,000	^{129}I
Existing Double-Shell Tanks						
Tank Residuals	Q.7	4×10^{-5}	Thyroid	3×10^{-3}	200	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Future Double-Shell Tanks						
Tank Residuals	Q.7	4×10^{-6}	Bone	9×10^{-5}	9,800	^{239}Pu
Grouted Process Residuals	Q.7	1×10^{-5}	Thyroid	3×10^{-3}	1,800	^{129}I
Sr/Cs Capsules[b]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG[c] TRU[b]	--	--	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.7	1×10^{-3}	Thyroid	4×10^{-2}	200	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	1×10^{-4}	Thyroid	7×10^{-3}	200	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG TRU[b]	--	--	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[b,e]	--	--	--	--	--	--
300 Wye Site[b]	--	--	--	--	--	--

(a) Existing DST grout is included in the SST grout calculation.
(b) This waste form does not apply to the geologic disposal alternative.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.5. Geologic Disposal Alternative--Individual Maximum Potential 70-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Disruptive Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
		200 East Area Wastes				
Single-Shell Tanks						
Tank Residuals	Q.7	8×10^{-2}	Bone	2	9,800	^{239}Pu
Grouted Process Residuals	Q.7	8×10^{-2}	Thyroid	8	1,000	^{129}I
Existing Double-Shell Tanks						
Tank Residuals	Q.7	3×10^{-3}	Thyroid	2×10^{-1}	200	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Future Double-Shell Tanks						
Tank Residuals	Q.7	3×10^{-4}	Bone	6×10^{-3}	9,800	^{239}Pu
Grouted Process Residuals	Q.7	7×10^{-4}	Thyroid	2×10^{-1}	1,800	^{129}I
Sr/Cs Capsules[b]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG[c] TRU[b]	--	--	--	--	--	--
		200 West Area Wastes				
Single-Shell Tanks						
Tank Residuals	Q.7	1×10^{-1}	Thyroid	3	200	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	8×10^{-3}	Thyroid	5×10^{-1}	200	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG TRU[b]	--	--	--	--	--	--
		600 Area Wastes				
300 Area Burial Sites[b,e]	--	--	--	--	--	--
300 Wye Site[b]	--	--	--	--	--	--

(a) Existing DST grout is included in the SST grout calculation.
(b) This waste form does not apply to the geologic disposal alternative.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.6. Geologic Disposal Alternative--Individual Maximum Potential 1-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Functional Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.8	6×10^{-5}	Thyroid	7×10^{-3}	4,300	^{129}I
Grouted Process Residuals	Q.8	3×10^{-4}	Thyroid	4×10^{-2}	4,500	^{129}I
Existing Double-Shell Tanks						
Tank Residuals	Q.8	1×10^{-6}	Thyroid	1×10^{-4}	4,400	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Future Double-Shell Tanks						
Tank Residuals	Q.8	3×10^{-7}	Thyroid	4×10^{-5}	4,500	^{129}I
Grouted Process Residuals	Q.8	1×10^{-5}	Thyroid	1×10^{-3}	4,500	^{129}I
Sr/Cs Capsules[b]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG[c] TRU[b]	--	--	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.8	9×10^{-4}	Thyroid	1×10^{-2}	4,300	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	7×10^{-5}	Thyroid	9×10^{-3}	4,400	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG TRU[b]	--	--	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[b,e]	--	--	--	--	--	--
300 Wye Site[b]	--	--	--	--	--	--

(a) Existing DST grout is included in the SST grout calculation.
(b) This waste form does not apply to the geologic disposal alternative.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.7. Geologic Disposal Alternative--Individual Maximum Potential 70-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Functional Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.8	4×10^{-3}	Thyroid	5×10^{-1}	4,300	^{129}I
Grouted Process Residuals	Q.8	2×10^{-2}	Thyroid	3	4,500	^{129}I
Existing Double-Shell Tanks						
Tank Residuals	Q.8	1×10^{-4}	Thyroid	1×10^{-2}	4,400	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Future Double-Shell Tanks						
Tank Residuals	Q.8	2×10^{-5}	Thyroid	3×10^{-3}	4,500	^{129}I
Grouted Process Residuals	Q.8	1×10^{-3}	Thyroid	8×10^{-2}	4,500	^{129}I
Sr/Cs Capsules[b]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG[c] TRU[b]	--	--	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.8	6×10^{-2}	Thyroid	8	4,300	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	5×10^{-3}	Thyroid	6×10^{-1}	4,400	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG TRU[b]	--	--	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[b,e]	--	--	--	--	--	--
300 Wye Site[b]	--	--	--	--	--	--

(a) Existing DST grout is included in the SST grout calculation.
(b) This waste form does not apply to the geologic disposal alternative.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.8. In-Place Stabilization and Disposal Alternative--Individual Maximum Potential 1-Year Radiation Dose from Drinking Well Water (barriers remain effective)

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	9×10^{-6}	GI-LLI	7×10^{-4}	6,800	^{99}Tc	Q.9	1×10^{-6}	GI-LLI	9×10^{-5}	5,000	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks												
Tank Residuals	Q.2	1×10^{-7}	GI-LLI	1×10^{-5}	5,000	^{99}Tc	Q.6	3×10^{-9}	GI-LLI	9×10^{-8}	5,700	^{99}Tc
Grouted Process Residuals	Q.3	1×10^{-4}	Thyroid	1×10^{-2}	5,000	^{129}I	Q.9	3×10^{-5}	Thyroid	3×10^{-3}	5,000	^{129}I
Future Double-Shell Tanks												
Tank Residuals	Q.2	3×10^{-9}	Thyroid	4×10^{-7}	5,900	^{129}I	Q.6	4×10^{-10}	Thyroid	7×10^{-8}	5,100	^{129}I
Grouted Process Residuals	Q.3	1×10^{-5}	Thyroid	3×10^{-3}	5,500	^{129}I	Q.9	6×10^{-6}	Thyroid	1×10^{-3}	5,200	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--	--	--
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	3×10^{-5}	GI-LLI	3×10^{-3}	8,300	^{99}Tc	Q.9	3×10^{-5}	GI-LLI	3×10^{-3}	6,300	^{99}Tc
Existing Double-Shell Tanks												
Tank Residuals	Q.2	4×10^{-7}	Thyroid	4×10^{-5}	5,100	^{129}I	Q.6	1×10^{-7}	Thyroid	1×10^{-5}	5,000	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--	--	--
600 Area Wastes												
300 Area Burial Sites[e,f]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site	Q.16	NR	--	--	--	--	Q.16	NR	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) Sites are so close to the Columbia River that no well is postulated.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.9. In-Place Stabilization and Disposal Alternative--Individual Maximum Potential 70-Year Radiation Dose from Drinking Well Water (barriers remain effective)

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	6×10^{-4}	GI-LLI	5×10^{-2}	6,800	^{99}Tc	Q.9	8×10^{-5}	GI-LLI	6×10^{-3}	5,000	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks												
Tank Residuals	Q.2	1×10^{-5}	GI-LLI	9×10^{-4}	5,000	^{99}Tc	Q.6	2×10^{-7}	GI-LLI	6×10^{-6}	5,700	^{99}Tc
Grouted Process Residuals	Q.3	9×10^{-3}	Thyroid	8×10^{-1}	5,000	^{129}I	Q.9	2×10^{-3}	Thyroid	2×10^{-1}	5,000	^{129}I
Future Double-Shell Tanks												
Tank Residuals	Q.2	2×10^{-7}	Thyroid	3×10^{-5}	5,900	^{129}I	Q.6	3×10^{-8}	Thyroid	5×10^{-6}	5,100	^{129}I
Grouted Process Residuals	Q.3	9×10^{-4}	Thyroid	2×10^{-1}	5,500	^{129}I	Q.9	4×10^{-4}	Thyroid	7×10^{-2}	5,200	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	NR	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	2×10^{-3}	GI-LLI	2×10^{-1}	8,300	^{99}Tc	Q.9	2×10^{-3}	GI-LLI	2×10^{-1}	6,300	^{99}Tc
Existing Double-Shell Tanks												
Tank Residuals	Q.2	3×10^{-5}	Thyroid	3×10^{-3}	5,100	^{129}I	Q.6	7×10^{-6}	Thyroid	7×10^{-4}	5,000	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
600 Area Wastes												
300 Area Burial Sites[e,f]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site	Q.16	NR	--	--	--	--	Q.16	NR	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) Sites are so close to the Columbia River that no well is postulated.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.10. In-Place Stabilization and Disposal Alternative--Individual Maximum Potential 1-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Disruptive Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	4×10^{-3}	Bone	9×10^{-2}	10,000	^{239}Pu
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	4×10^{-5}	Thyroid	3×10^{-3}	200	^{129}I
Grouted Process Residuals	Q.10	1×10^{-3}	Thyroid	9×10^{-2}	4,300	^{129}I
Future Double-Shell Tanks						
Tank Residuals	Q.7	4×10^{-6}	Bone	9×10^{-5}	9,800	^{239}Pu
Grouted Process Residuals	Q.10	1×10^{-2}	Bone	4×10^{-1}	2,800	^{241}Am
Sr/Cs Capsules	--	NR[b]	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	3×10^{-2}	Thyroid	1	200	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	1×10^{-4}	Thyroid	7×10^{-3}	200	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[e,f]	--	--	--	--	--	--
300 Wye Site	--	NR	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) Sites are so close to the Columbia River that no well is postulated.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.11. In-Place Stabilization and Disposal Alternative--Individual Maximum Potential 70-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Disruptive Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	3×10^{-1}	Bone	6	10,000	^{239}Pu
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	3×10^{-3}	Thyroid	2×10^{-1}	200	^{129}I
Grouted Process Residuals	Q.10	1×10^{-1}	Thyroid	6	4,300	^{129}I
Future Double-Shell Tanks						
Tank Residuals	Q.7	3×10^{-4}	Bone	6×10^{-3}	9,800	^{239}Pu
Grouted Process Residuals	Q.10	1	Bone	3×10^{1}	2,800	^{241}Am
Sr/Cs Capsules	--	NR[b]	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	2	Thyroid	1×10^{2}	200	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	8×10^{-3}	Thyroid	5×10^{-1}	200	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[e,f]	--	--	--	--	--	--
300 Wye Site	--	NR	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) Sites are so close to the Columbia River that no well is postulated.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.12. In-Place Stabilization and Disposal Alternative--Individual Maximum Potential 1-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Functional Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	1×10^{-4}	Thyroid	1×10^{-2}	4,600	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	1×10^{-6}	Thyroid	1×10^{-4}	4,400	^{129}I
Grouted Process Residuals	Q.11	4×10^{-4}	Thyroid	4×10^{-2}	4,500	^{129}I
Future Double-Shell Tanks						
Tank Residuals	Q.8	3×10^{-7}	Thyroid	4×10^{-5}	4,500	^{129}I
Grouted Process Residuals	Q.11	6×10^{-5}	Thyroid	1×10^{-2}	4,500	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	3×10^{-3}	GI-LLI	3×10^{-1}	5,400	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	7×10^{-5}	Thyroid	9×10^{-3}	4,400	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[e,f]	--	--	--	--	--	--
300 Wye Site	--	NR	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) Sites are so close to the Columbia River that no wells are postulated.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.13. In-Place Stabilization and Disposal Alternative--Individual Maximum Potential 70-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Functional Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	1×10^{-2}	Thyroid	9×10^{-1}	4,600	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	1×10^{-4}	Thyroid	1×10^{-2}	4,400	^{129}I
Grouted Process Residuals	Q.11	3×10^{-2}	Thyroid	3	4,500	^{129}I
Future Double-Shell Tanks						
Tank Residuals	Q.8	2×10^{-5}	Thyroid	3×10^{-3}	4,500	^{129}I
Grouted Process Residuals	Q.11	4×10^{-3}	Thyroid	8×10^{-1}	4,500	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	2×10^{-1}	GI-LLI	2×10^{1}	5,400	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	5×10^{-3}	Thyroid	6×10^{-1}	4,400	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[e,f]	--	--	--	--	--	--
300 Wye Site	--	NR	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) Sites are so close to the Columbia River that no wells are postulated.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.14. Reference Alternative--Individual Maximum Potential 1-Year Radiation Dose from Drinking Well Water (barriers remain effective)

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	9×10^{-6}	GI-LLI	7×10^{-4}	6,800	^{99}Tc	Q.9	1×10^{-6}	GI-LLI	9×10^{-5}	5,000	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks												
Tank Residuals	Q.2	1×10^{-7}	GI-LLI	1×10^{-5}	5,000	^{99}Tc	Q.6	3×10^{-9}	GI-LLI	9×10^{-8}	5,700	^{99}Tc
Grouted Process Residuals	Q.4	1×10^{-4}	Thyroid	1×10^{-2}	5,000	^{129}I	Q.12	3×10^{-5}	Thyroid	3×10^{-3}	5,100	^{129}I
Future Double-Shell Tanks												
Tank Residuals	Q.2	3×10^{-9}	Thyroid	4×10^{-7}	5,900	^{129}I	Q.6	4×10^{-10}	Thyroid	7×10^{-8}	5,100	^{129}I
Grouted Process Residuals	Q.4	2×10^{-5}	Thyroid	4×10^{-3}	5,500	^{129}I	Q.12	6×10^{-6}	Thyroid	1×10^{-3}	5,200	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	5,000	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--	--	--
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	3×10^{-5}	GI-LLI	3×10^{-3}	8,300	^{99}Tc	Q.9	3×10^{-5}	GI-LLI	3×10^{-3}	6,300	^{99}Tc
Existing Double-Shell Tanks												
Tank Residuals	Q.2	4×10^{-7}	Thyroid	4×10^{-5}	5,100	^{129}I	Q.6	1×10^{-7}	Thyroid	1×10^{-5}	5,000	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--	--	--
600 Area Wastes												
300 Area Burial Sites[a,e]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.15. Reference Alternative--Individual Maximum Potential 70-Year Radiation Dose from Drinking Well Water (barriers remain effective)

Waste Form	0.5 cm/yr Recharge: Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	5 cm/yr Recharge: Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	6×10^{-4}	GI-LLI	5×10^{-2}	6,800	^{99}Tc	Q.9	8×10^{-5}	GI-LLI	6×10^{-3}	5,000	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks												
Tank Residuals	Q.2	1×10^{-5}	GI-LLI	9×10^{-4}	5,000	^{99}Tc	Q.6	2×10^{-7}	GI-LLI	6×10^{-6}	5,700	^{99}Tc
Grouted Process Residuals	Q.4	8×10^{-3}	Thyroid	8×10^{-1}	5,000	^{129}I	Q.12	2×10^{-3}	Thyroid	2×10^{-1}	5,100	^{129}I
Future Double-Shell Tanks												
Tank Residuals	Q.2	2×10^{-7}	Thyroid	3×10^{-5}	5,900	^{129}I	Q.6	3×10^{-8}	Thyroid	5×10^{-6}	5,100	^{129}I
Grouted Process Residuals	Q.4	2×10^{-3}	Thyroid	3×10^{-1}	5,500	^{129}I	Q.12	4×10^{-4}	Thyroid	7×10^{-2}	5,200	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	NR	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	2×10^{-3}	GI-LLI	2×10^{-1}	8,300	^{99}Tc	Q.9	2×10^{-3}	GI-LLI	2×10^{-1}	6,300	^{99}Tc
Existing Double-Shell Tanks												
Tank Residuals	Q.2	3×10^{-5}	Thyroid	3×10^{-3}	5,100	^{129}I	Q.6	7×10^{-6}	Thyroid	7×10^{-4}	5,000	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--	--	--
600 Area Wastes												
300 Area Burial Sites[a,e]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.16. Reference Alternative--Individual Maximum Potential 1-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Disruptive Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	4×10^{-3}	Bone	9×10^{-2}	10,000	^{239}Pu
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals[b]	Q.7	4×10^{-5}	Thyroid	3×10^{-3}	200	^{129}I
Grouted Process Residuals	Q.13	1×10^{-4}	Thyroid	9×10^{-3}	500	^{129}I
Future Double-Shell Tanks						
Tank Residuals[b]	Q.7	4×10^{-6}	Bone	9×10^{-5}	9,800	^{239}Pu
Grouted Process Residuals	Q.13	1×10^{-5}	Thyroid	3×10^{-3}	1,800	^{129}I
Sr/Cs Capsules	--	NR[c]	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[d] TRU	--	NR	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	3×10^{-2}	Thyroid	1	200	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals[b]	Q.7	1×10^{-4}	Thyroid	7×10^{-3}	200	^{129}I
Grouted Process Residuals[e]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[a,f]	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) Only sites with barriers installed are considered.
(c) NR = no release calculated for at least 10,000 years.
(d) RS/NG = retrievably stored and newly generated.
(e) All grouts are assumed to be in the 200 East Area.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.17. **Reference Alternative--Individual Maximum Potential 70-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Disruptive Barrier Failure** (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	3×10^{-1}	Bone	6	10,000	^{239}Pu
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	3×10^{-3}	Thyroid	2×10^{-1}	200	^{129}I
Grouted Process Residuals	Q.13	8×10^{-3}	Thyroid	6×10^{-1}	500	^{129}I
Future Double-Shell Tanks						
Tank Residuals	Q.7	3×10^{-4}	Bone	6×10^{-3}	9,800	^{239}Pu
Grouted Process Residuals	Q.13	1×10^{-3}	Thyroid	2×10^{-1}	1,800	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	2	Thyroid	1×10^{2}	200	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	8×10^{-3}	Thyroid	5×10^{-1}	200	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[a,e]	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.18. Reference Alternative--Individual Maximum Potential 1-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Functional Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	1×10^{-4}	Thyroid	1×10^{-2}	4,600	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	1×10^{-6}	Thyroid	1×10^{-4}	4,400	^{129}I
Grouted Process Residuals	Q.14	4×10^{-4}	Thyroid	4×10^{-2}	4,500	^{129}I
Future Double-Shell Tanks						
Tank Residuals	Q.8	3×10^{-7}	Thyroid	4×10^{-5}	4,500	^{129}I
Grouted Process Residuals	Q.14	6×10^{-5}	Thyroid	1×10^{-2}	4,500	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	3×10^{-3}	GI-LLI	3×10^{-1}	5,400	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	7×10^{-5}	Thyroid	9×10^{-3}	4,400	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[a,e]	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.19. Reference Alternative--Individual Maximum Potential 70-Year Radiation Dose from Drinking Well Water--5-cm/yr Recharge with Functional Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	1×10^{-2}	Thyroid	9×10^{-1}	4,600	^{129}I
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	1×10^{-4}	Thyroid	1×10^{-2}	4,400	^{129}I
Grouted Process Residuals	Q.14	3×10^{-2}	Thyroid	3	4,500	^{129}I
Future Double-Shell Tanks						
Tank Residuals	Q.8	2×10^{-5}	Thyroid	3×10^{-3}	4,500	^{129}I
Grouted Process Residuals	Q.14	4×10^{-3}	Thyroid	8×10^{-1}	4,500	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	2×10^{-1}	GI-LLI	2×10^{1}	5,400	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	5×10^{-3}	Thyroid	6×10^{-1}	4,400	^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[a,e]	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.20. No Disposal Action (Continued Storage) Alternative--Individual Maximum Potential 1-Year Radiation Dose from Drinking Well Water

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.5	2×10^{-2}	GI-LLI	1	1,300	^{99}Tc	Q.15	4×10^{1}	Bone	1×10^{2}	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks												
Tank Residuals	Q.5	4×10^{-1}	Thyroid	3×10^{1}	400	^{129}I	Q.15	6×10^{1}	Bone	1×10^{2}	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks												
Tank Residuals	Q.5	3×10^{-1}	Bone	7	3,600	^{239}Pu	Q.15	1×10^{2}	Bone	6×10^{2}	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	Q.15	9×10^{-8}	Bone	3×10^{-7}	600	^{90}Sr
Pre-1970 TRU	--	NR	--	--	--	--	Q.15	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	Q.15	1×10^{-9}	Bone	7×10^{-9}	600	^{90}Sr
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.5	6×10^{-2}	GI-LLI	6	1,400	^{99}Tc	Q.15	3×10^{2}	Bone	9×10^{2}	400	^{90}Sr
Existing Double-Shell Tanks												
Tank Residuals	Q.5	4×10^{-1}	Thyroid	3×10^{1}	400	^{129}I	Q.15	1×10^{3}	Bone	4×10^{3}	400	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	Q.5	NR	--	--	--	--	Q.15	3×10^{-8}	Bone	1×10^{-7}	900	^{90}Sr
Pre-1970 TRU	Q.5	3×10^{-4}	Bone	1×10^{-3}	1,300	^{14}C	Q.15	3×10^{-4}	Bone	1×10^{-3}	700	^{90}Sr
RS/NG TRU	Q.5	4×10^{-4}	Bone	3×10^{-3}	1,300	^{14}C	Q.15	1×10^{-5}	Bone	8×10^{-5}	300	^{90}Sr
600 Area Wastes												
300 Area Burial Sites[d,e]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site	Q.16	1×10^{-8}	Bone	7×10^{-8}	1,000	^{90}Sr	Q.16	3×10^{-2}	Bone	1×10^{-1}	400	^{90}Sr

(a) This waste form does not apply to the no disposal action alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) Sites are so close to the Columbia River that no well is postulated.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.21. No Disposal Action (Continued Storage) **Alternative--Individual Maximum Potential 70-Year Radiation Dose from Drinking Well Water**

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.5	1	GI-LLI	1×10^{2}	1,300	^{99}Tc	Q.15	3×10^{3}	Bone	1×10^{4}	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks												
Tank Residuals	Q.5	3×10^{1}	Thyroid	2×10^{3}	400	^{129}I	Q.15	4×10^{3}	Bone	1×10^{4}	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks												
Tank Residuals	Q.5	2×10^{1}	Bone	5×10^{2}	3,600	^{239}Pu	Q.15	1×10^{4}	Bone	4×10^{4}	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	NR	--	--	--	--
TRU-Contaminated Soil	Q.5	NR	--	--	--	--	Q.15	6×10^{-6}	Bone	2×10^{-5}	600	^{90}Sr
Pre-1970 TRU	Q.5	NR	--	--	--	--	Q.15	NR	--	--	--	--
RS/NG[c] TRU	Q.5	NR	--	--	--	--	Q.15	1×10^{-7}	Bone	5×10^{-7}	600	^{90}Sr
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.5	4	GI-LLI	4×10^{2}	1,400	^{99}Tc	Q.15	2×10^{4}	Bone	6×10^{4}	400	^{90}Sr
Existing Double-Shell Tanks												
Tank Residuals	Q.5	3×10^{1}	Thyroid	2×10^{3}	400	^{129}I	Q.15	7×10^{4}	Bone	3×10^{5}	400	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	Q.15	2×10^{-6}	Bone	9×10^{-6}	900	^{90}Sr
Pre-1970 TRU	Q.5	2×10^{-2}	Bone	8×10^{-2}	1,300	^{14}C	Q.15	2×10^{-2}	Bone	8×10^{-2}	700	^{14}C
RS/NG TRU	Q.5	3×10^{-2}	Bone	2×10^{-1}	1,300	^{14}C	Q.15	1×10^{-3}	Bone	6×10^{-3}	300	^{90}Sr
600 Area Wastes												
300 Area Burial Sites[d,e]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site	Q.16	1×10^{-6}	Bone	5×10^{-6}	1,000	^{90}Sr	Q.16	2	Bone	7	400	^{90}Sr

(a) This waste form does not apply to the no disposal action alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) Sites are so close to the Columbia River that no well is postulated.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.22. Ratio of Critical-Organ Dose to Total-Body Dose for Selected Radionuclides

Radionuclide	Critical Organ	Ratio[a]
^{14}C	Bone	4.9
^{79}Se	Kidney	10.3
^{90}Sr	Bone	3.8
^{99}Tc	GI Tract	140
^{129}I	Thyroid	790
^{237}Np	Bone	22
^{239}Pu	Bone	21
^{241}Am	Bone	25

(a) Based on 70-year lifetime accumulated dose, ingestion rate assumed to be essentially constant.

Tables R.2 through R.21 report doses anticipated if the disposal systems function as designed. Also included are doses that could be expected if the barriers over the wastes were to fail. As described in Appendix M, Section M.6, doses are projected for both a serious disruptive failure scenario and for a lesser, functional failure scenario. For the disruptive failure scenario, it is assumed that 15 cm/yr of precipitation infiltrates 10% of the wastes, starting 500 years after waste disposal, caused by a major disruption of the barrier. For the functional failure scenario, caused by substandard barrier performance under conditions of 30-cm/yr precipitation, the precipitation infiltrates 50% of the wastes, starting at the time of disposal.

The results reported in Tables R.2 through R.22 are given in terms of the dose rate to total-body and maximum organ at the time of highest dose in the next 10,000 years. The dose rate as a function of time depends on the release and transport rates of radionuclides from the wastes. Wastes disposed of as planned in the alternatives described in this EIS would tend to be released slowly to the environment. This is illustrated in Figure R.1, which shows the calculated water concentrations in a 5-km well from a representative barriered waste form (200 West Area single-shell tanks). The initial delay provided by the barrier is evident in Figure R.1, as well as the controlled, long-term nature of the potential release. For all of the disposal alternatives there are no instances of groundwater contamination within the first 4,500 years. Nonsorbed radionuclides, such as ^{99}Tc and ^{129}I, arrive at the same time as would a water front moving from the waste. Nuclides whose transport is retarded, such as ^{239}Pu, arrive later in time and reduced in concentration. The small hump in the curves for the nonsorbed nuclides is caused by the diffusion of the wastes beneath the barrier; the wastes diffusing straight down, and not transported by the recharge outside the barrier, arrive at the groundwater in about 25,000 years.

Contrasted to Figure R.1 is Figure R.2, which gives the 5-km well water concentrations for the same waste form, but without a barrier installed (i.e., for no disposal action

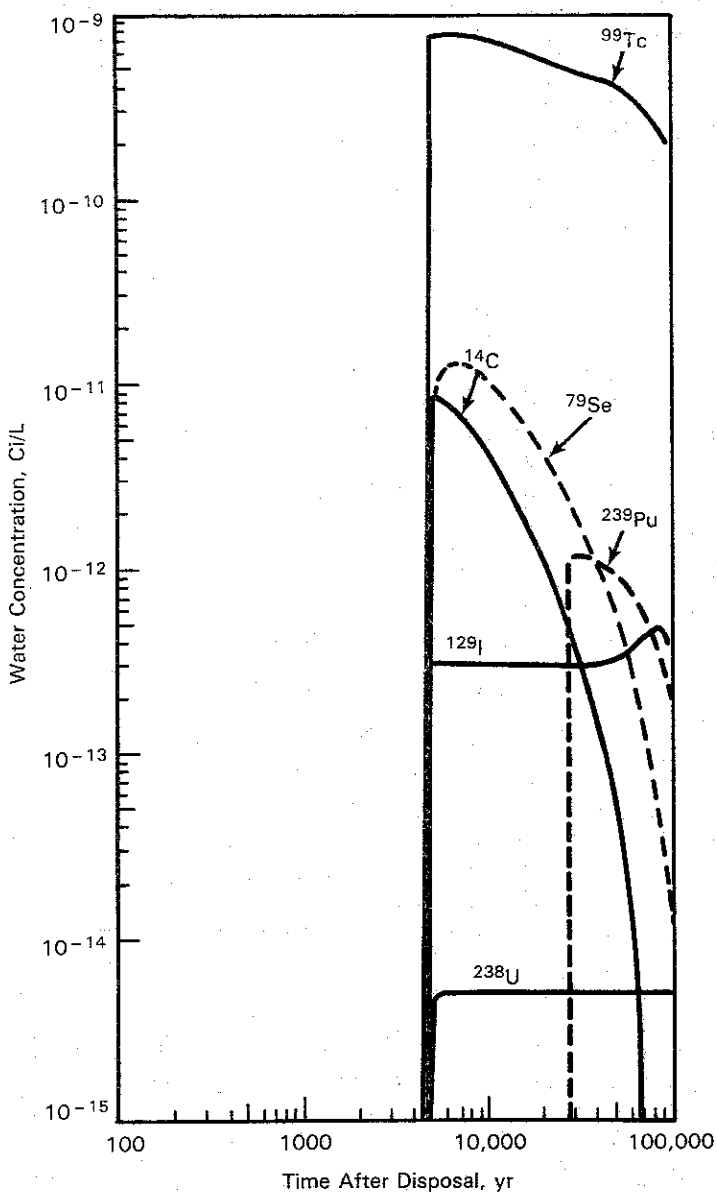

FIGURE R.1. Concentration of Selected Radionuclides in Groundwater at a 5-km Well from 200 West Area Single-Shell Tanks, In-Place Stabilization and Disposal or Reference Alternatives, 5-cm/yr Recharge

followed by loss of institutional control). The percolating recharge water is assumed to interact directly with the wastes, moving the nonsorbed nuclides directly to the water table. This results in a sudden pulse release at very high concentrations. These high concentrations are of relatively short duration, lasting about as long as it takes the salt-cake waste form to dissolve. The contaminated groundwater then washes the wastes further down gradient. Sorbed nuclides again arrive later, and more spread out in time, but they too are eventually washed past the location of the well.

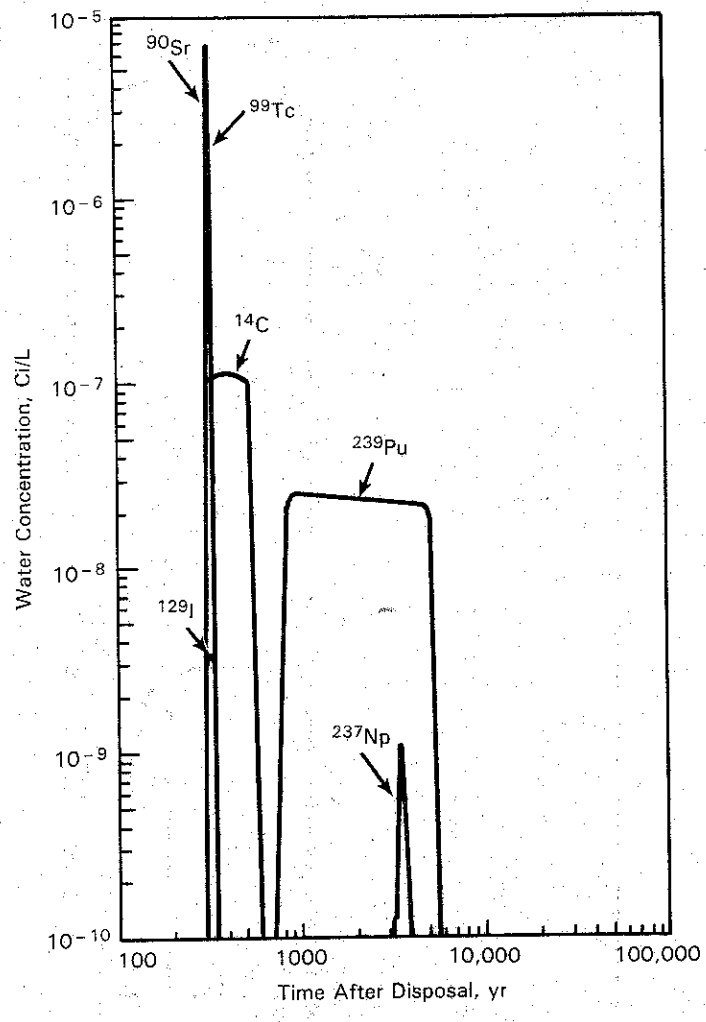

FIGURE R.2. Concentration of Selected Radionuclides in Groundwater at a 5-km Well from 200 West Area Single-Shell Tanks, No Disposal Action (continued storage), **5-cm/yr Recharge**

Figure R.1 gives the groundwater concentration with fully functional barriers. The two scenarios of barrier failure described above would lead to intermediate cases. These are illustrated in Figure R.3 for the disruptive failure and in Figure R.4 for the functional failure. These two figures can be superimposed on Figure R.1 to obtain the total release for either case.

The pattern of the groundwater concentration of radionuclides is reflected in the potential radiation dose rate to individuals using water from the well. Dose rates to individuals drinking water from the well of Figure R.1 are shown in Figure R.5. Doses to the thyroid and GI tract (lower large intestine) can be seen to shadow the curves of ^{129}I and ^{99}Tc, respectively. The bone dose rate reflects contributions from the ^{14}C, ^{99}Tc, and ^{129}I initially, with a larger contribution from ^{239}Pu when it finally arrives. The dose to the thyroid is largest in this case, and it is essentially constant once the water is contaminated.

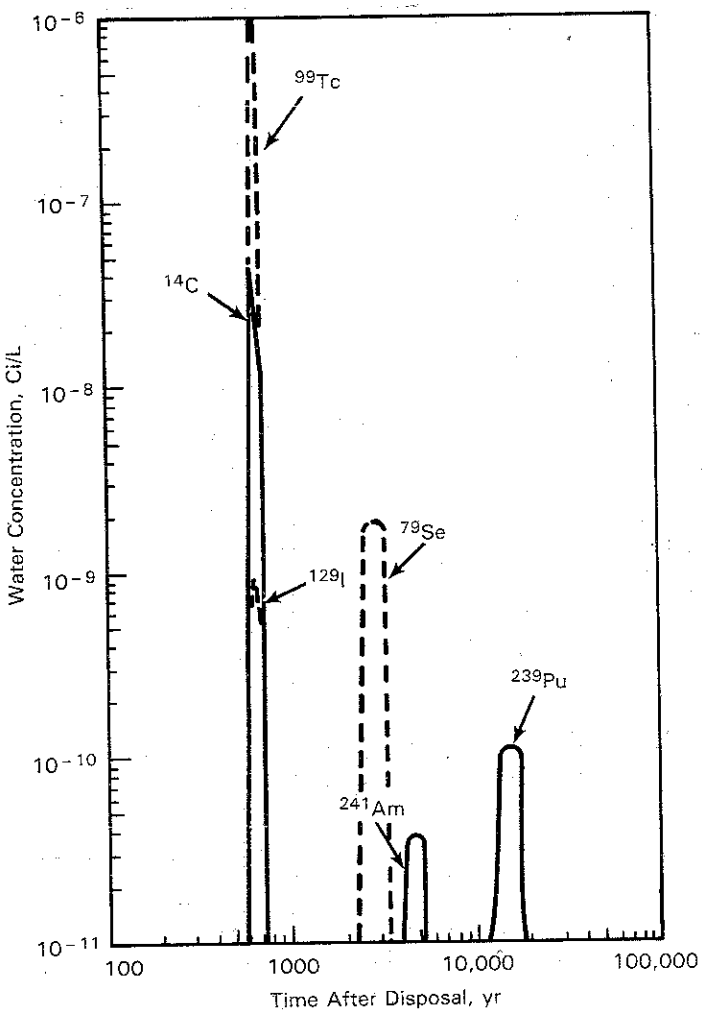

FIGURE R.3. Concentration of Selected Radionuclides in Groundwater at a 5-km Well from 200 West Area Single-Shell Tanks, In-Place Stabilization and Disposal or Reference Alternative, Disruptive Barrier Failure at 500 Years

Dose rates from the unbarriered waste site contaminating the water as illustrated in Figure R.2 are shown in Figure R.6. The water contamination is not continuous, and so neither is the potential radiation dose rate. There are early peaks corresponding to the passage of the nonsorbed nuclides, and later peaks corresponding to sorbed nuclides.

Dose rates from drinking water from sites with failed barriers are illustrated in Figures R.7 and R.8. Figure R.7 corresponds to the water concentrations of Figure R.3 resulting from disruptive barrier failure. Figure R.8 corresponds to the water concentrations of Figure R.4 resulting from functional barrier failure.

The dose rates reported in Tables R.2 through R.21 are summaries of calculations that tracked dose versus time in a manner similar to that presented in Figures R.3 and R.4. The peak dose reported is the highest dose in the 10,000-year period following waste disposal. Both total body, with contributing nuclide, and critical organ are given. For waste sites

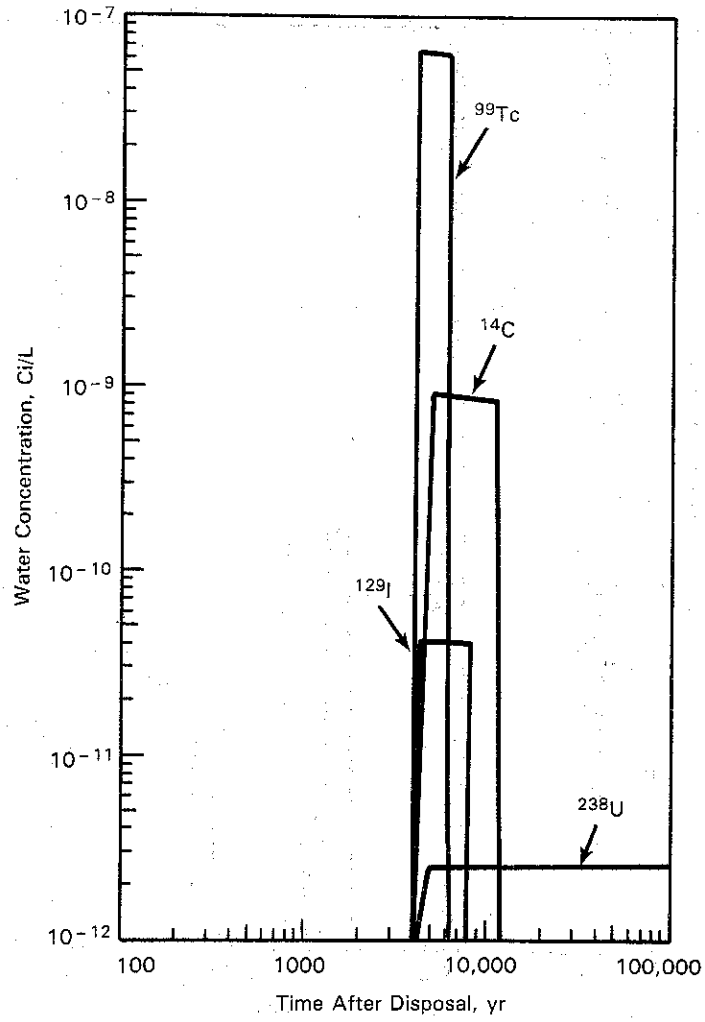

FIGURE R.4. Concentration of Selected Radionuclides in Groundwater at a 5-km Well from the 200 West Area Single-Shell Tanks, In-Place Stabilization and Disposal or Reference Alternatives, Functional Barrier Failure

with barriers, the time given generally corresponds to the initial arrival of the contamination at the well. For these barriered cases, the dose rate continues at about the same level for a long period after initiation. In a few instances, the peak corresponds to the arrival of a sorbed nuclide in addition to the nonsorbed ones, following which the dose rate is still approximately constant. However, for unbarriered wastes, such as those in the no disposal action, the dose peaks reported are the largest single one in the 10,000-year period. These may or may not correspond to the highest-activity calculations for radionuclides reported in Appendix Q; the controlling factor is the product of the radionuclide "dose factor" (rem/curies ingested) and the water concentration. As a rule, the peaks in the 10,000-year window are the largest over all time; the dose rate is not greater than that reported, even through times over 100,000 years.

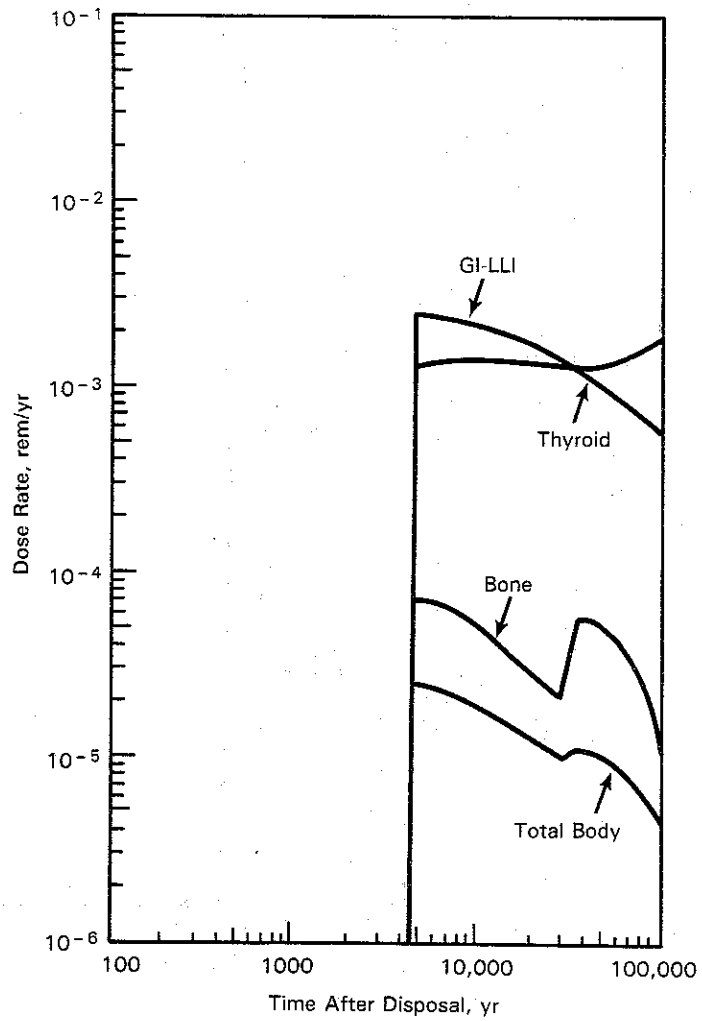

FIGURE R.5. Individual Dose Rates from Drinking Water from the 5-km Well Down Gradient of the 200 West Area Single-Shell Tanks, In-Place Stabilization and Disposal or Reference Alternatives, 5-cm/yr Recharge

In some instances, the dose rates are higher to the individual from the 0.5-cm/yr recharge rate than from the 5-cm/yr infiltration. While this appears counter to what might be expected, since with the lower infiltration less waste is entering the groundwater per year, it is a result of the shifting water table. With lower recharge, there is also decreased groundwater movement, resulting in less dilution of the transported wastes. In several instances, the direction of groundwater flow is changed. Thus the postulated 5-km well for the 0.5-cm/yr recharge can be in a very different location from the 5-km well for

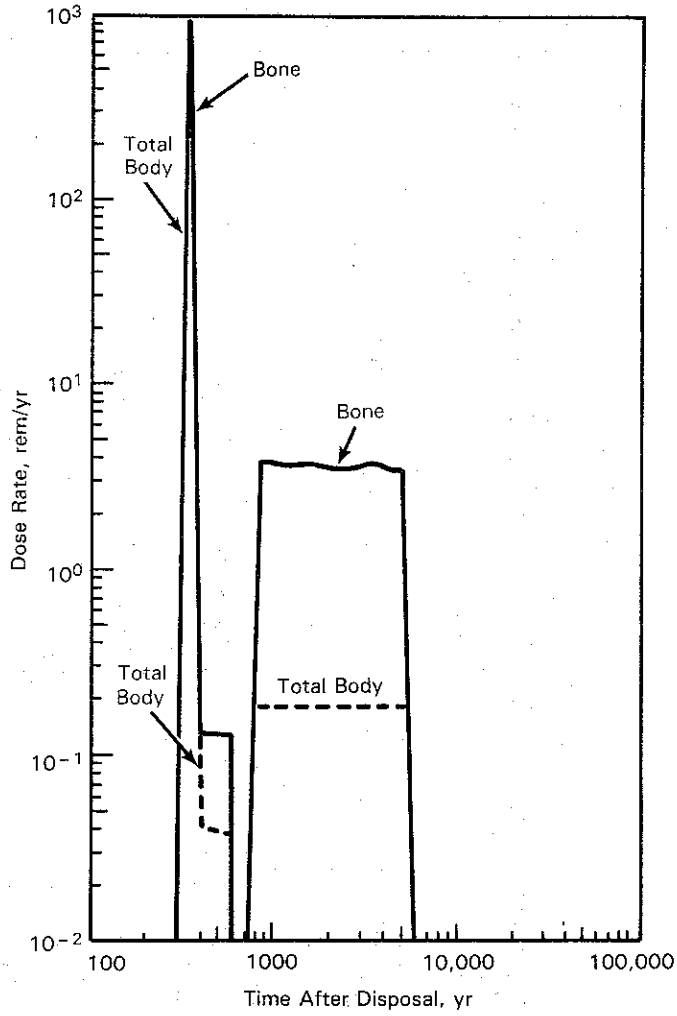

FIGURE R.6. **Individual Dose Rates from Drinking Water from the 5-km Well Down Gradient of the 200 West Area Single-Shell Tanks No Disposal Action** (continued storage), **5-cm/yr Recharge**

the 5-cm/yr recharge for the same waste forms.[a] Thus it is important to recognize that the two cases are not directly comparable because the well would be located so as to intercept the plume.

The doses presented in Tables R.2 through R.21 are not strictly additive. The mechanics of groundwater flow essentially preserve independent contaminated plumes in the groundwater for each waste site. Only if one plume passed beneath another waste site would the two plumes mix. As can be seen from the figures of groundwater flow in Appendix Q, this situation is not likely for waste sites in the 200 West Area, because the flow paths are generally

(a) In the 5-cm recharge case, contaminated groundwater moves to the north, west of Gable Mountain, and on to the Columbia River. In the 0.5-cm recharge case, contaminated water flows southeast from the 200 Areas and enters the river to the east and southeast. This is illustrated in Appendix Q.

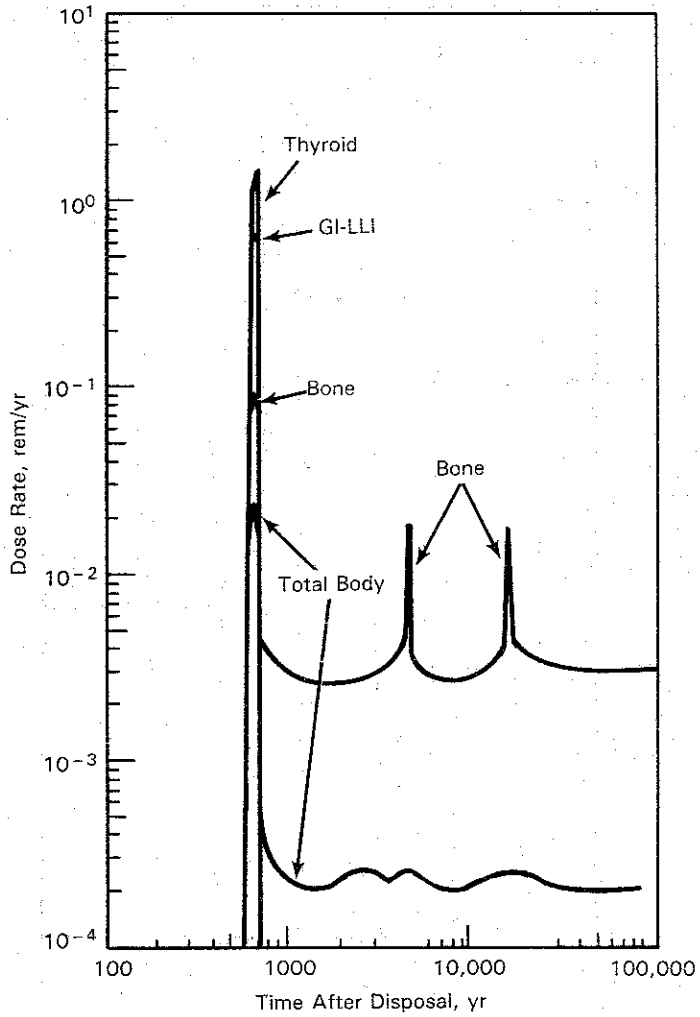

FIGURE R.7. Individual Dose Rates from Drinking Water for the 5-km Well Down Gradient of the 200 West Area Single-Shell Tanks, In-Place Stabilization and Disposal Alternatives, Disruptive Barrier Failure

from west to east and the waste sites line up north to south. There is more possibility for multiple-site contamination in the 200 East Area, but it is difficult to predict because the flow patterns change radically with different assumptions on recharge. Because the radionuclide inventories of the existing tank wastes are uncertain, the doses have been conservatively estimated by assuming that all the inventory is in both the single-shell and the double-shell tanks. Therefore, a reasonable estimate of maximum dose from groundwater for the 200 East Area wastes, even assuming some plume mixing, is the largest value reported in the tables.

The radiation dose rates from drinking water are quite low for the disposal alternatives with the protective barriers operating according to design specifications. At these dose rates, no health effects would be observed.

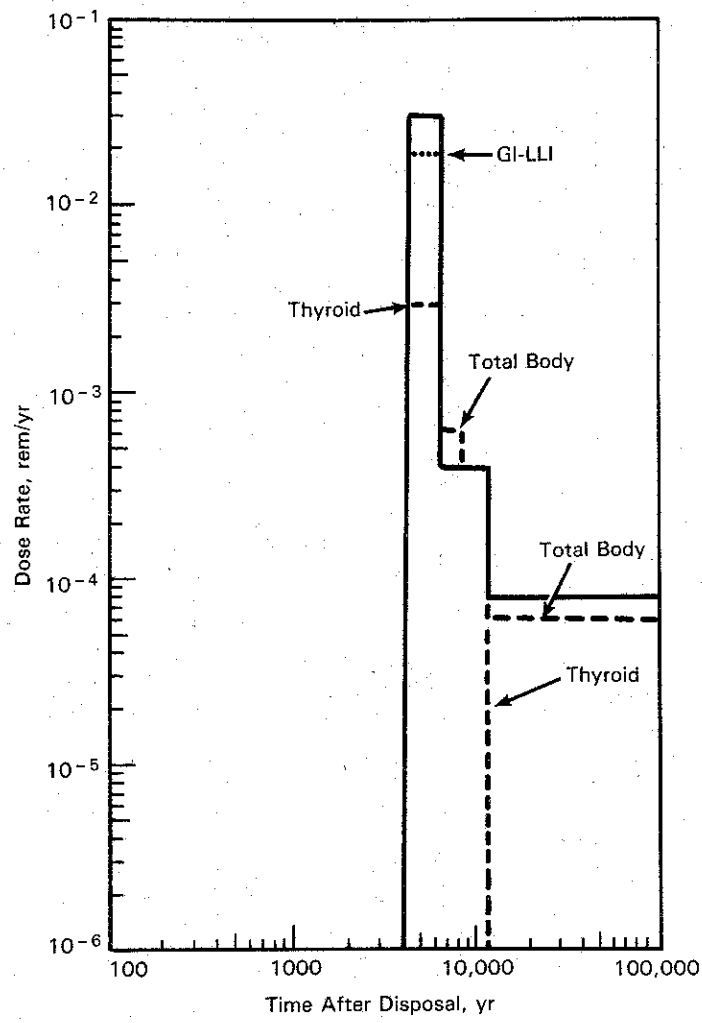

FIGURE R.8. Individual Dose Rates from Drinking Water from the 5-km Well Down Gradient of the 200 West Area Single-Shell Tanks, In-Place Stabilization and Disposal or Reference Alternatives, Functional Barrier Failure

R.1.4.2 Full-Garden Scenario for Well Water

Contaminated well water might be used for irrigation and livestock water, as well as for human drinking water. Radiation doses are estimated for the same well-water concentrations as in Tables R.2 through R.21 but for a scenario in which an individual grows a large percentage of his food[(a)] using the well for irrigation, as might occur on a small, 2-ha (5-acre) family farm. In addition to drinking water, the individual is exposed to radionuclides deposited on the soil and accumulated in crops and animal products. Doses to individuals are given in Tables R.23 through R.32; these are given for each waste form for no disposal action and for each disposal alternative, both with barriers that function as

(a) Scenario assumes Hanford Maximum Individual, see Table F.6.

TABLE R.23. Geologic Disposal Alternative--Individual Maximum Potential 70-Year Radiation Doses from the Full-Garden Scenario (barriers remain effective)

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.2	4×10^{-3}	GI-LLI	8×10^{-2}	5,100	^{129}I	Q.6	5×10^{-4}	Thyroid	8×10^{-3}	5,100	^{129}I
Grouted Process Residual	Q.2	2×10^{-1}	Thyroid	4	5,500	^{129}I	Q.6	6×10^{-2}	Thyroid	1	5,200	^{129}I
Existing Double-Shell Tanks												
Tank Residuals	Q.2	2×10^{-4}	GI-LLI	1×10^{-2}	6,000	^{99}Tc	Q.6	4×10^{-6}	GI-LLI	1×10^{-4}	9,700	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks												
Tank Residuals	Q.2	1×10^{-5}	Thyroid	2×10^{-4}	6,000	^{129}I	Q.6	2×10^{-6}	Thyroid	3×10^{-5}	5,100	^{129}I
Grouted Process Residuals	Q.2	6×10^{-3}	Thyroid	2	5,000	^{129}I	Q.6	3×10^{-2}	Thyroid	5×10^{-1}	5,000	^{129}I
Sr/Cs Capsules[b]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
RS/NG[c] TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.2	2×10^{-2}	Thyroid	3×10^{-1}	5,200	^{129}I	Q.6	9×10^{-3}	GI-LLI	2×10^{-1}	5,100	^{99}Tc
Existing Double-Shell Tanks												
Tank Residuals	Q.2	5×10^{-4}	GI-LLI	3×10^{-2}	7,400	^{99}Tc	Q.6	1×10^{-4}	GI-LLI	9×10^{-3}	6,100	^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
RS/NG TRU[b]	--	--	--	--	--	--	--	--	--	--	--	--
600 Area Wastes												
300 Area Burial Sites[b,e]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site[b]	--	--	--	--	--	--	--	--	--	--	--	--

(a) Existing DST grout is included in the SST grout calculation.
(b) This waste form does not apply to the geologic disposal alternative.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.24. Geologic Disposal Alternative--Individual Maximum Potential 70-Year Radiation Doses from the Full-Garden Scenario--5-cm/yr Recharge with Disruptive Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.7	3×10^{-1}	Bone	6	9,800	^{239}Pu
Grouted Process Residuals	Q.7	4	Thyroid	6×10^{1}	1,800	^{129}I
Existing Double-Shell Tanks						
Tank Residuals	Q.7	3×10^{-2}	GI-LLI	2	200	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Future Double-Shell Tanks						
Tank Residuals	Q.7	1×10^{-3}	Bone	2×10^{-2}	9,400	^{239}Pu
Grouted Process Residuals	Q.7	9×10^{-2}	Thyroid	1	1,900	^{129}I
Sr/Cs Capsules[b]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG[c] TRU[b]	--	--	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.7	0.8	Kidney	8	2,500	^{79}Se
Grouted Process Residuals[d]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	8×10^{-2}	GI-LLI	5	200	^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG TRU[b]	--	--	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[b,e]	--	--	--	--	--	--
300 Wye Site[b]	--	--	--	--	--	--

(a) Existing DST grout is included in the SST grout calculation.
(b) This waste form does not apply to the geologic disposal alternative.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.25. Geologic Disposal Alternative--Individual Maximum Potential 70-Year Radiation Dose from Full-Garden Scenario--5-cm/yr Recharge with Functional Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.8	5×10^{-2}	GI-LLI	5	3,800	^{99}Tc
Grouted Process Residuals	Q.8	2×10^{-1}	Thyroid	3×10^{1}	4,000	^{129}I
Existing Double-Shell Tanks						
Tank Residuals	Q.8	2×10^{-3}	GI-LLI	1×10^{-1}	3,900	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Future Double-Shell Tanks						
Tank Residuals	Q.8	2×10^{-4}	Thyroid	3×10^{-2}	4,000	^{129}I
Grouted Process Residuals	Q.8	1×10^{-2}	Thyroid	7×10^{-1}	4,000	^{129}I
Sr/Cs Capsules[b]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG[c] TRU[b]	--	--	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.8	1×10^{-2}	GI-LLI	1	3,800	^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	7×10^{-2}	GI-LLI	7	3,900	^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil[b]	--	--	--	--	--	--
Pre-1970 TRU[b]	--	--	--	--	--	--
RS/NG TRU[b]	--	--	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[b,e]	--	--	--	--	--	--
300 Wye Site[b]	--	--	--	--	--	--

(a) Existing DST grout is included in the SST grout calculation.
(b) This waste form does not apply to the geologic disposal alternative.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.26 **In-Place Stabilization and Disposal Alternative--Individual Maximum Potential 70-Year Radiation Doses from the Full-Garden Scenario** (barriers remain effective)

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	4×10^{-2}	GI-LLI	9×10^{-1}	7,100	^{99}Tc	Q.9	6×10^{-3}	GI-LLI	1×10^{-1}	5,100	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks												
Tank Residuals	Q.2	2×10^{-4}	GI-LLI	1×10^{-2}	6,000	^{99}Tc	Q.6	4×10^{-6}	GI-LLI	1×10^{-4}	9,700	^{99}Tc
Grouted Process Residuals	Q.3	1×10^{-1}	GI-LLI	8	5,100	^{99}Tc	Q.9	3×10^{-2}	GI-LLI	2	5,100	^{99}Tc
Future Double-Shell Tanks												
Tank Residuals	Q.2	1×10^{-5}	Thyroid	2×10^{-4}	6,000	^{129}I	Q.6	2×10^{-6}	Thyroid	3×10^{-5}	5,100	^{129}I
Grouted Process Residuals	Q.3	8×10^{-2}	Thyroid	1	5,500	^{129}I	Q.9	3×10^{-2}	Thyroid	5×10^{-1}	5,200	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	NR	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	1×10^{-1}	GI-LLI	3	8,300	^{99}Tc	Q.9	1×10^{-1}	GI-LLI	3	6,300	^{99}Tc
Existing Double-Shell Tanks												
Tank Residuals	Q.2	5×10^{-4}	GI-LLI	3×10^{-2}	7,400	^{99}Tc	Q.6	1×10^{-4}	GI-LLI	9×10^{-3}	6,100	^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
600 Area Wastes												
300 Area Burial Sites[e,f]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site	Q.16	NR	--	--	--	--	Q.16	NR	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) Sites are so close to the Columbia River that no well is postulated.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.27. In-Place Stabilization and Disposal Alternative--Individual Maximum Potential 70-Year Radiation Doses from the Full-Garden Scenario--5-cm/yr Recharge with Disruptive Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	3	Kidney	3×10^{1}	1,500	^{79}Se
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	3×10^{-2}	GI-LLI	2	200	^{99}Tc
Grouted Process Residuals	Q.10	2	GI-LLI	6×10^{1}	4,500	^{99}Tc
Future Double-Shell Tanks						
Tank Residuals	Q.7	1×10^{-3}	Bone	2×10^{-2}	9,400	^{239}Pu
Grouted Process Residuals	Q.10	1×10^{1}	Bone	8×10^{1}	3,200	^{241}Am
Sr/Cs Capsules	--	NR[b]	--	--	--	--
TRU-Contaminated So	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	2×10^{1}	Thyroid	8×10^{2}	700	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	8×10^{-2}	GI-LLI	5	200	^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[e,f]	--	--	--	--	--	--
300 Wye Site	--	NR	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) Sites are so close to the Columbia River that no well is postulated.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.28. In-Place Stabilization and Disposal Alternative--Individual Maximum Potential 70-Year Radiation Dose from Full-Garden Scenario--5-cm/yr Recharge with Functional Barrier Failures (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	2×10^{-1}	GI-LLI	2×10^{1}	4,100	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	2×10^{-3}	GI-LLI	1×10^{-1}	3,900	^{99}Tc
Grouted Process Residuals	Q.11	4×10^{-1}	GI-LLI	3×10^{1}	4,000	^{99}Tc
Future Double-Shell Tanks						
Tank Residuals	Q.8	2×10^{-4}	Thyroid	3×10^{-2}	4,000	^{129}I
Grouted Process Residuals	Q.11	6×10^{-2}	Thyroid	7	4,000	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	2	GI-LLI	1×10^{2}	4,900	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	7×10^{-2}	GI-LLI	7	3,900	^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[e,f]	--	--	--	--	--	--
300 Wye Site	--	NR	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) Sites are so close to the Columbia River that no well is postulated.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.29. Reference Alternative--Individual Maximum Potential 70-Year Radiation Doses from the Full-Garden Scenario (barriers remain effective)

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	4×10^{-2}	GI-LLI	9×10^{-1}	7,100	^{99}Tc	Q.9	6×10^{-3}	GI-LLI	1×10^{-1}	5,100	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks												
Tank Residuals	Q.2	2×10^{-4}	GI-LLI	1×10^{-2}	6,000	^{99}Tc	Q.6	4×10^{-6}	GI-LLI	1×10^{-4}	9,700	^{99}Tc
Grouted Process Residuals	Q.4	1×10^{-1}	GI-LLI	8	6,200	^{99}Tc	Q.12	4×10^{-2}	GI-LLI	2	5,200	^{99}Tc
Future Double-Shell Tanks												
Tank Residuals	Q.2	1×10^{-5}	Thyroid	2×10^{-4}	6,000	^{129}I	Q.6	2×10^{-6}	Thyroid	3×10^{-5}	5,100	^{129}I
Grouted Process Residuals	Q.4	2×10^{-2}	Thyroid	2	5,000	^{129}I	Q.12	3×10^{-2}	Thyroid	5×10^{-1}	5,200	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	NR	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.3	1×10^{-1}	GI-LLI	3	8,300	^{99}Tc	Q.9	1×10^{-1}	GI-LLI	3	6,300	^{99}Tc
Existing Double-Shell Tanks												
Tank Residuals	Q.2	5×10^{-4}	GI-LLI	3×10^{-2}	7,400	^{99}Tc	Q.6	1×10^{-4}	GI-LLI	9×10^{-3}	6,100	^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	NR	--	--	--	--
600 Area Wastes												
300 Area Burial Sites[a,e]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.30. Reference Alternative--Individual Maximum Potential 70-Year Radiation Dose from Full-Garden Scenario--5-cm/yr Recharge with Disruptive Barrier Failure (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	3	Kidney	3×10^{1}	1,500	^{79}Se
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	3×10^{-2}	GI-LLI	2	200	^{99}Tc
Grouted Process Residuals	Q.13	1×10^{-1}	GI-LLI	6	1,800	^{99}Tc
Future Double-Shell Tanks						
Tank Residuals	Q.7	1×10^{-3}	Bone	2×10^{-2}	9,400	^{239}Pu
Grouted Process Residuals	Q.13	9×10^{-2}	Thyroid	1	1,900	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.10	2×10^{1}	Thyroid	8×10^{2}	700	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.7	8×10^{-2}	GI-LLI	5	200	^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[a,e]	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.31. **Reference Alternative--Individual Maximum Potential 70-Year Radiation Dose from Full-Garden Scenario--5-cm/yr Recharge with Functional Barrier Failure** (considered as increments above normal performance)

Waste Form	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Barrier Failure	Dominant Nuclide
200 East Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	2×10^{-1}	GI-LLI	2×10^{1}	4,100	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	2×10^{-3}	GI-LLI	1×10^{-1}	3,900	^{99}Tc
Grouted Process Residuals	Q.14	4×10^{-1}	GI-LLI	3×10^{1}	4,000	^{99}Tc
Future Double-Shell Tanks						
Tank Residuals	Q.8	2×10^{-4}	Thyroid	3×10^{-2}	4,000	^{129}I
Grouted Process Residuals	Q.14	6×10^{-2}	Thyroid	7	4,000	^{129}I
Sr/Cs Capsules	--	NR[b]	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--
200 West Area Wastes						
Single-Shell Tanks						
Tank Residuals	Q.11	2	GI-LLI	1×10^{2}	4,900	^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--
Existing Double-Shell Tanks						
Tank Residuals	Q.8	7×10^{-2}	GI-LLI	7	3,900	^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--
600 Area Wastes						
300 Area Burial Sites[a,e]	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.32. **No Disposal Action** (continued storage) **Alternative--Individual Maximum Potential 70-Year Radiation Dose from the Full-Garden Scenario**

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.5	2×10^{1}	GI-LLI	2×10^{3}	1,300	^{99}Tc	Q.15	4×10^{5}	Bone	2×10^{6}	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks												
Tank Residuals	Q.5	3×10^{2}	GI-LLI	2×10^{4}	400	^{99}Tc	Q.15	5×10^{5}	Bone	2×10^{6}	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks												
Tank Residuals	Q.5	1×10^{2}	Bone	2×10^{3}	4,200	^{239}Pu	Q.15	1×10^{6}	Bone	5×10^{6}	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	Q.5	NR	--	--	--	--	Q.15	8×10^{-4}	Bone	3×10^{-3}	600	^{90}Sr
Pre-1970 TRU	Q.5	NR	--	--	--	--	Q.15	NR	--	--	--	--
RS/NG[c] TRU[a]	Q.5	NR	--	--	--	--	Q.15	2×10^{-5}	Bone	6×10^{-5}	600	^{90}Sr
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.5	6×10^{1}	GI-LLI	7×10^{3}	1,400	^{99}Tc	Q.15	2×10^{6}	Bone	8×10^{6}	400	^{90}Sr
Existing Double-Shell Tanks												
Tank Residuals	Q.5	3×10^{2}	GI-LLI	2×10^{4}	400	^{99}Tc	Q.15	9×10^{6}	Bone	3×10^{7}	400	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	Q.15	3×10^{-4}	Bone	1×10^{-3}	900	^{90}Sr
Pre-1970 TRU	Q.5	1×10^{-1}	Bone	7×10^{-1}	1,300	^{14}C	Q.15	1×10^{-1}	Bone	7×10^{-1}	700	^{90}Sr
RS/NG TRU	Q.5	3×10^{-1}	Bone	1	1,300	^{14}C	Q.15	3×10^{-1}	Bone	1	600	^{90}Sr
600 Area Wastes												
300 Area Burial Sites[d,e]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site	--	--	--	--	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the no disposal action.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) Sites are so close to the Columbia River that no well is postulated.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

designed or, for the higher recharge case, with barriers experiencing either the disruptive or functional failure as described in Section R.1.4.1. Only lifetime doses are presented in this set of tables.

The radiation doses the individual might receive from the full-garden scenario are increased from those he could receive by water alone. For nuclides that are not readily taken up by plants, the increase in dose is generally less than a factor of 10, as can be seen in comparing the results for ^{239}Pu or ^{14}C in Tables R.2 through R.21 with the corresponding entries in Tables R.23 through R.32. For nuclides readily taken up by plants, such as ^{90}Sr, the increase in dose can be as much as a factor of 100.

In general, the radiation dose rate to individuals, as a function of time after waste disposal, will follow the same pattern as the groundwater concentrations described for drinking water in Section R.1.4.1. There is some additional contribution from radionuclides being redistributed in the soil by irrigation, but over many years it is not as significant as the contribution from the water directly. The caveats pertaining to the drinking water pathway (Section R.1.4.1) apply also to the garden scenario.

R.1.4.3 Radionuclide Migration to the Columbia River

Radionuclides and other contaminants leached into the groundwater would likely reach the Columbia River eventually. The rate at which nuclides enter the river depends on the rate at which they enter the groundwater, their radioactive decay, their chemical characteristics, and the flow of the aquifer and distance to the river. The highly mobile radionuclides (^{14}C, ^{99}Tc) could reach the Columbia within a few hundred years after the initiation of waste leaching if no barriers to migration intervene. The less mobile nuclides (^{137}Cs, ^{241}Am) may entirely decay before ever reaching the water table. The relative rates and proportions of radionuclides eventually reaching the river are functions of the initial inventories (given in Appendix Q and Chapter 3) and the flow rate of the transporting water, if any.

The Columbia River is now used for drinking, irrigation, and recreation by many people living downstream of Hanford. These uses can only be assumed to increase in the future. Presently, only a small fraction of the river's flow below Hanford is used for irrigation or drinking. (Water for the large irrigation projects in the area is primarily derived from the Columbia River upstream of Hanford.) Within 80 km of Hanford, only 2000 people are estimated to eat only food grown with irrigation water from the Columbia, 70,000 people drink water from the river, and about 125,000 people swim or boat in the river (McCormack et al. 1984). To conservatively account for all people living downstream along the Columbia between Hanford and the river's mouth, a population growing to nearly 5,000,000 affected individuals is assumed over the next 10,000 years. For this many people to be affected, a very large increase in the amount of irrigated land in both Washington and Oregon would be required, concurrent with a large increase in overall population. The total number of people thus assumed to live along the Columbia River over the 10,000-year period is about 410 million. The total dose a group this size would receive from naturally occurring background sources is

nearly 3 billion man-rem. As a subset of this population the 70,000 people currently using the Columbia for drinking water, if held constant over the next 10,000 years, would receive a natural background dose of about 70 million man-rem.

Persons living along the Columbia River downstream from the waste entering by postulated groundwater recharge would be subject to time-dependent radiation doses. The gradual release of contaminants to the river would cause a slow increase in dose rate to a peak, followed by a gradual decline. There could be more than one peak, separated in time from the others, caused by different radionuclides. The total dose to all people living over the next 10,000 years depends mostly on the total activity of each nuclide (curies) released, but the rate of release controls the dose rate to any one individual. This is analogous to the considerations described in Section R.1.4.1 for the groundwater well. The population dose to all residents downstream is illustrated in Figure R.9 for the waste form used as an example in Section R.1.4.1 (SST wastes in the 200 West Area, with and without barriers). The population dose shown for the case without barriers indicates that most impact is due to the early arrival of the nonsorbed nuclides. The nuclides would reach the river in pulses, much like those shown in Figure R.2. The later arrivals of the sorbed nuclides are at much lower rates than the arrivals of early nonsorbed nuclides, and add only incrementally to the total dose. For the wastes with barriers, the slow release results in greatly reduced population doses. Because the models used assume that all nondecayed nuclides would eventually be released, the total population dose predicted would asymptotically approach the one calculated for the no-barrier example, but it would take several million years to get there.

The maximum lifetime dose to an average individual living downstream of Hanford along the Columbia River is given in Tables R.33 through R.46 for each disposal alternative and for the no disposal action, for each postulated rate of groundwater recharge, with and without functional barriers. As described in Appendix M and Section R.1.4.1, doses are also projected both for a serious disruptive barrier failure scenario and for a lesser, functional barrier failure scenario. The percentage contribution to the total dose provided by drinking water only is provided, as analogous to the drinking water well of Section R.1.4.1.

The lifetime doses to average individuals from any of the disposal alternatives are very small; the largest is equivalent to the dose received in 3 or 4 hr from natural background. The total 10,000-year integrated population doses are likewise small. There is very little difference between the dose estimates; for the 0.5-cm and 5-cm recharge rates the total population doses are directly dependent only on the total quantity of each radionuclide ultimately released to the river, which is nearly the same in each case. This is caused by the slow release from the waste provided by the protective barrier, which is in turn independent of the recharge rate assumed (the release being driven by diffusion, not leaching).

Also, while the initial inventories of most fission products and transuranics disposed of near surface differ for the in-place disposal and reference alternatives, the nonsorbed nuclides ^{14}C, ^{99}Tc, and ^{129}I are the same for these two alternatives, and therefore so are the final doses. (This generalization, of course, is not true for the cases in which the barriers are assumed to fail.) The total number of health effects that might result in the

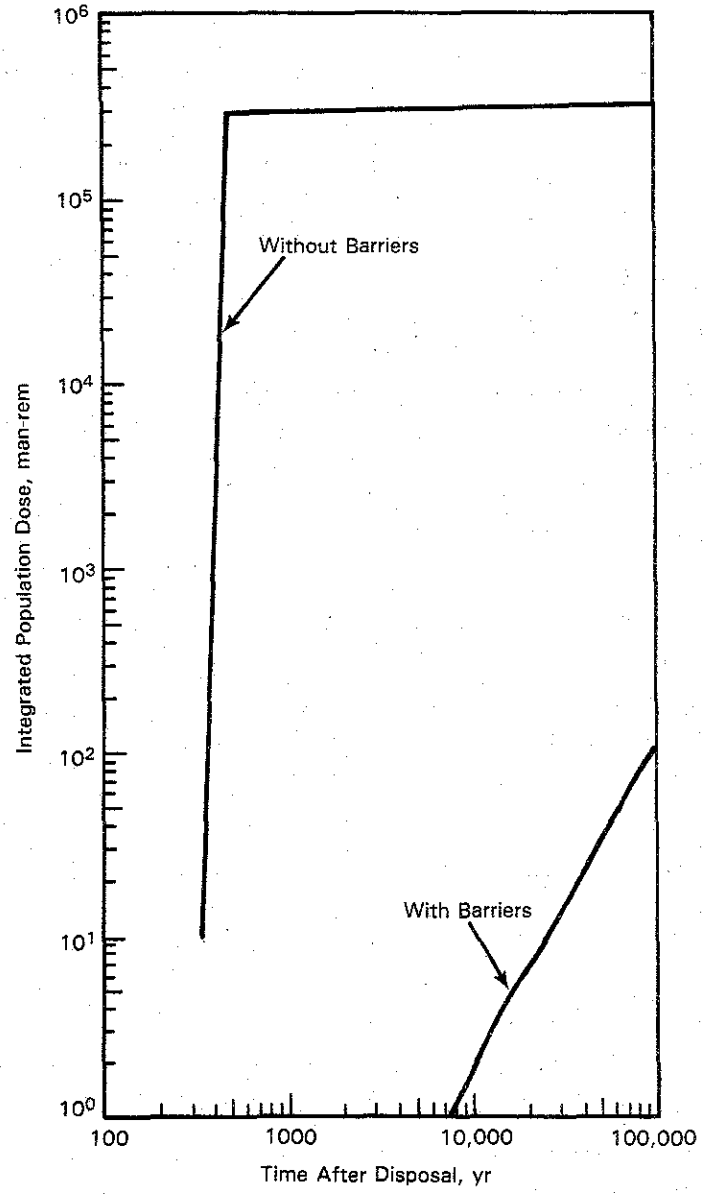

FIGURE R.9. **Integrated Population Dose from Releases of Radionuclides from 200 West Area Single-Shell Tanks, With and Without Barriers**

downriver population (of about 410 million people) can be estimated from the total population dose from all waste forms. As described in Section R.1.4.2, the doses for the existing tank wastes have been based on the assumption that most of the radionuclide inventory is both in single- and in double-shell tanks. Thus, to get a realistic maximum, the largest reported doses from these waste forms should be considered representative.

Previous studies have investigated the potential for population dose resulting from releases from wastes in the Hanford 200 Areas. The most applicable is that by Murthy et al.

TABLE R.33. Geologic Disposal Alternative--Public Doses from Contaminant Migration to the Columbia River for 0.5-cm/yr Recharge (barriers remain effective)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide: Total-Body	Dominant Nuclide: Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.2	6×10^{-10}	9	Thyroid	5×10^{-8}	9,700	62% ^{99}Tc	99% ^{129}I	2×10^{-1}	57% ^{99}Tc
Grouted Process Residuals	Q.2	4×10^{-9}	14	Thyroid	1×10^{-6}	9,600	67% ^{14}C	99% ^{129}I	1	72% ^{14}C
Existing Double-Shell Tanks										
Tank Residuals	Q.2	4×10^{-12}	7	GI-LLI	4×10^{-10}	9,900	84% ^{99}Tc	99% ^{99}Tc	1×10^{-3}	81% ^{99}Tc
Grouted Process Residuals[b]	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks										
Tank Residuals	Q.2	2×10^{-12}	7	Thyroid	3×10^{-10}	9,700	67% ^{99}Tc	99% ^{129}I	4×10^{-4}	64% ^{99}Tc
Grouted Process Residuals	Q.2	1×10^{-9}	9	Thyroid	5×10^{-7}	9,400	71% ^{129}I	60% ^{129}I	4×10^{-1}	50% ^{129}I
Sr/Cs Capsules[c]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[c]	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[c]	--	--	--	--	--	--	--	--	--	--
RS/NG[d] TRU[c]	--	--	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.2	9×10^{-10}	9	GI-LLI	7×10^{-8}	9,900	63% ^{99}Tc	99% ^{99}Tc	3×10^{-1}	58% ^{99}Tc
Existing Double-Shell Tanks										
Tank Residuals	Q.2	1×10^{-12}	7	GI-LLI	1×10^{-10}	9,400	78% ^{99}Tc	99% ^{99}Tc	3×10^{-4}	75% ^{14}C
Grouted Process Residuals[e]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[c]	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[c]	--	--	--	--	--	--	--	--	--	--
RS/NG TRU[c]	--	--	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[c,f]	--	--	--	--	--	--	--	--	--	--
300 Wye Site[c]	--	--	--	--	--	--	--	--	--	--

(a) Doses from drinking water contamination are based on the maximum water concentration, which usually occurs somewhat earlier than the maximum dose from all sources (irrigation, etc.).
(b) Existing DST grout is included in SST grout calculations.
(c) This waste form does not apply to the geologic disposal alternative.
(d) RS/NG = retrievably stored and newly generated.
(e) All grouts are assumed to be in the 200 East Area.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.34. Geologic Disposal Alternative--Public Doses from Contaminant Migration to the Columbia River for 5-cm/yr Recharge (barriers remain effective)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide: Total-Body	Dominant Nuclide: Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.6	3×10^{-9}	9	Thyroid	5×10^{-8}	9,900	78% ^{79}Se	99% ^{129}I	8×10^{-1}	78% ^{79}Se
Grouted Process Residuals	Q.6	5×10^{-8}	15	Thyroid	1×10^{-6}	10,000	91% ^{79}Se	99% ^{129}I	2×10^{1}	90% ^{79}Se
Existing Double-Shell Tanks										
Tank Residuals	Q.6	8×10^{-12}	7	GI-LLI	5×10^{-10}	10,000	49% ^{99}Tc	99% ^{99}Tc	2×10^{-3}	46% ^{99}Tc
Grouted Process Residuals[b]	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks										
Tank Residuals	Q.6	1×10^{-11}	7	Thyroid	2×10^{-10}	9,700	88% ^{79}Se	99% ^{129}I	4×10^{-3}	88% ^{79}Se
Grouted Process Residuals	Q.6	3×10^{-8}	10	Thyroid	5×10^{-7}	9,700	96% ^{79}Se	99% ^{129}I	8	99% ^{79}Se
Sr/Cs Capsules[c]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[c]	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[c]	--	--	--	--	--	--	--	--	--	--
RS/NG[d] TRU[c]	--	--	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.6	5×10^{-9}	9	GI-LLI	8×10^{-8}	9,600	81% ^{79}Se	94% ^{99}Tc	1	77% ^{79}Se
Existing Double-Shell Tanks										
Tank Residuals	Q.6	2×10^{-12}	7	GI-LLI	1×10^{-10}	9,700	47% ^{99}Tc	99% ^{99}Tc	6×10^{-4}	47% ^{99}Tc
Grouted Process Residuals[e]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[c]	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[c]	--	--	--	--	--	--	--	--	--	--
RS/NG TRU[c]	--	--	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[c,f]	--	--	--	--	--	--	--	--	--	--
300 Wye Site[c]	--	--	--	--	--	--	--	--	--	--

(a) Doses from drinking water contamination are based on the maximum water concentration, which usually occurs somewhat earlier than the maximum dose from all sources (irrigation, etc.).
(b) Existing DST grout is included in SST grout calculations.
(c) This waste form does not apply to the geologic disposal alternative.
(d) RS/NG = retrievably stored and newly generated.
(e) All grouts are assumed to be in the 200 East Area.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.35. Geologic Disposal Alternative--Public Doses from Contaminant Migration to the Columbia River for 5-cm/yr Recharge with Disruptive Barrier Failure (considered as increments above normal performance)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide: Total-Body	Dominant Nuclide: Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.7	6×10^{-7}	15	Kidney	8×10^{-6}	2,300	97% ^{79}Se	99% ^{79}Se	1×10^{1}	49% ^{238}U
Grouted Process Residuals	Q.7	3×10^{-7}	21	Thyroid	5×10^{-6}	9,900	91% ^{79}Se	99% ^{129}I	1×10^{2}	89% ^{79}Se
Existing Double-Shell Tanks										
Tank Residuals	Q.7	7×10^{-9}	9	GI-LLI	4×10^{-7}	600	44% ^{99}Tc	99% ^{99}Tc	4×10^{-2}	71% ^{241}Am
Grouted Process Residuals[b]	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks										
Tank Residuals	Q.7	6×10^{-9}	7	Kidney	6×10^{-8}	2,400	99% ^{79}Se	99% ^{79}Se	2×10^{-2}	95% ^{79}Se
Grouted Process Residuals	Q.7	6×10^{-8}	13	Kidney	6×10^{-7}	9,900	96% ^{79}Se	99% ^{79}Se	3×10^{1}	95% ^{79}Se
Sr/Cs Capsules[c]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[c]	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[c]	--	--	--	--	--	--	--	--	--	--
RS/NG[d] TRU[c]	--	--	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.7	7×10^{-7}	36	Kidney	8×10^{-6}	3,300	99% ^{79}Se	99% ^{79}Se	4	59% ^{79}Se
Existing Double-Shell Tanks										
Tank Residuals	Q.7	7×10^{-9}	7	GI-LLI	8×10^{-7}	700	86% ^{99}Tc	99% ^{99}Tc	7×10^{-3}	79% ^{99}Tc
Grouted Process Residuals[e]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[c]	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[c]	--	--	--	--	--	--	--	--	--	--
RS/NG TRU[c]	--	--	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[c,f]	--	--	--	--	--	--	--	--	--	--
300 Wye Site[c]	--	--	--	--	--	--	--	--	--	--

(a) Doses from drinking water contamination are based on the maximum water concentration, which usually occurs somewhat earlier than the maximum dose from all sources (irrigation, etc.).
(b) Existing DST grout is included in SST grout calculations.
(c) Only wastes with barriers are considered.
(d) RS/NG = retrievably stored and newly generated.
(e) All grouts are assumed to be in the 200 East Area.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.36. Geologic Disposal Alternative--Public Doses from Contaminant Migration to the Columbia River for 5-cm/yr Recharge with Functional Barrier Failure (considered as increments above normal performance)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide Total-Body	Dominant Nuclide Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.8	5×10^{-7}	6	GI-LLI	6×10^{-5}	4,300	82% ^{99}Tc	99% ^{99}Tc	3	50% ^{99}Tc
Grouted Process Residuals	Q.8	1×10^{-7}	15	Thyroid	3×10^{-5}	10,000	66% ^{14}C	99% ^{129}I	4×10^{1}	72% ^{14}C
Existing Double-Shell Tanks										
Tank Residuals	Q.8	2×10^{-8}	8	GI-LLI	2×10^{-6}	4,300	55% ^{99}Tc	99% ^{99}Tc	8×10^{-2}	55% ^{99}Tc
Grouted Process Residuals[b]	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks										
Tank Residuals	Q.8	2×10^{-9}	7	Thyroid	3×10^{-7}	4,500	64% ^{99}Tc	99% ^{129}I	1×10^{-2}	64% ^{99}Tc
Grouted Process Residuals	Q.8	6×10^{-9}	16	Thyroid	6×10^{-7}	9,500	71% ^{14}C	99% ^{129}I	2	76% ^{14}C
Sr/Cs Capsules[c]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[c]	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[c]	--	--	--	--	--	--	--	--	--	--
RS/NG[d] TRU[c]	--	--	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.8	9×10^{-7}	6	GI-LLI	1×10^{-4}	4,300	83% ^{99}Tc	99% ^{99}Tc	6	48% ^{99}Tc
Existing Double-Shell Tanks										
Tank Residuals	Q.8	2×10^{-9}	7	GI-LLI	2×10^{-7}	4,400	80% ^{99}Tc	99% ^{99}Tc	3×10^{-2}	51% ^{129}I
Grouted Process Residuals[e]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil[c]	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU[c]	--	--	--	--	--	--	--	--	--	--
RS/NG TRU[c]	--	--	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[c,f]	--	--	--	--	--	--	--	--	--	--
300 Wye Site[c]	--	--	--	--	--	--	--	--	--	--

(a) Doses from drinking water contamination are based on the maximum water concentration, which usually occurs somewhat earlier than the maximum dose from all sources (irrigation, etc.).
(b) Existing DST grout is included in SST grout calculations.
(c) This waste form does not apply to the geologic disposal alternative.
(d) RS/NG = retrievably stored and newly generated.
(e) All grouts are assumed to be in the 200 East Area.
(f) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.37. In-Place Stabilization and Disposal Alternative--Public Doses from Contaminant Migration to the Columbia River for 0.5-cm/yr Recharge (barriers remain effective)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide: Total-Body	Dominant Nuclide: Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.3	5×10^{-9}	7	GI-LLI	5×10^{-7}	9,800	84% ^{99}Tc	99% ^{99}Tc	1	81% ^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks										
Tank Residuals	Q.2	4×10^{-12}	7	GI-LLI	4×10^{-10}	9,900	84% ^{99}Tc	99% ^{99}Tc	1×10^{-3}	81% ^{99}Tc
Grouted Process Residuals	Q.3	2×10^{-8}	9	GI-LLI	2×10^{-6}	9,400	66% ^{99}Tc	99% ^{99}Tc	6	61% ^{99}Tc
Future Double-Shell Tanks										
Tank Residuals	Q.2	2×10^{-12}	7	Thyroid	3×10^{-10}	9,700	67% ^{99}Tc	99% ^{129}I	5×10^{-4}	56% ^{99}Tc
Grouted Process Residuals	Q.3	4×10^{-9}	7	Thyroid	5×10^{-7}	9,400	69% ^{99}Tc	99% ^{129}I	1	66% ^{99}Tc
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.3	6×10^{-9}	7	GI-LLI	7×10^{-7}	9,500	84% ^{99}Tc	99% ^{99}Tc	2	81% ^{99}Tc
Existing Double-Shell Tanks										
Tank Residuals	Q.2	1×10^{-12}	7	GI-LLI	1×10^{-10}	9,400	78% ^{99}Tc	99% ^{99}Tc	3×10^{-4}	75% ^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[e]	Q.16	NR	--	--	--	--	--	--	--	--
300 Wye Site	Q.16	NR	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.38. In-Place Stabilization and Disposal Alternative--Public Doses from Contaminant Migration to the Columbia River for 5-cm/yr Recharge (barriers remain effective)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide: Total-Body	Dominant Nuclide: Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.9	3×10^{-8}	7	GI-LLI	6×10^{-7}	10,000	81% ^{79}Se	96% ^{99}Tc	9	81% ^{79}Se
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks										
Tank Residuals	Q.6	8×10^{-12}	7	GI-LLI	5×10^{-10}	10,000	49% ^{99}Tc	99% ^{99}Tc	2×10^{-3}	46% ^{99}Tc
Grouted Process Residuals	Q.9	3×10^{-8}	9	GI-LLI	2×10^{-6}	9,900	45% ^{99}Tc	99% ^{99}Tc	9	42% ^{99}Tc
Future Double-Shell Tanks										
Tank Residuals	Q.6	1×10^{-11}	7	Thyroid	2×10^{-10}	9,700	88% ^{79}Se	99% ^{129}I	4×10^{-3}	85% ^{79}Se
Grouted Process Residuals	Q.9	3×15^{-8}	7	Thyroid	5×10^{-7}	9,700	88% ^{79}Se	99% ^{129}I	9	87% ^{79}Se
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.9	4×10^{-8}	7	GI-LLI	8×10^{-7}	9,600	82% ^{79}Se	99% ^{99}Tc	1×10^{1}	80% ^{79}Se
Existing Double-Shell Tanks										
Tank Residuals	Q.6	2×10^{-12}	7	GI-LLI	1×10^{-10}	9,700	47% ^{99}Tc	99% ^{99}Tc	6×10^{-4}	47% ^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[e]	Q.16	NR	--	--	--	--	--	--	-	-
300 Wye Site	Q.16	NR	--	--	--	--	--	--	-	-

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.39. In-Place Stabilization and Disposal Alternative--Public Doses from Contaminant Migration to the Columbia River for 5-cm/yr Recharge with Disruptive Barrier Failure (considered as increments above normal performance)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide: Total-Body	Dominant Nuclide: Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.10	1×10^{-5}	18	Kidney	1×10^{-4}	5,200	99% ^{79}Se	99% ^{79}Se	1×10^{2}	38% ^{241}Am
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks										
Tank Residuals	Q.7	7×10^{-9}	9	GI-LLI	4×10^{-7}	600	44% ^{99}Tc	99% ^{99}Tc	4×10^{-2}	71% ^{241}Am
Grouted Process Residuals	Q.10	2×10^{-7}	6	GI-LLI	5×10^{-6}	9,900	53% ^{237}Np	97% ^{99}Tc	6×10^{1}	39% ^{237}Np
Future Double-Shell Tanks										
Tank Residuals	Q.7	6×10^{-9}	7	Kidney	6×10^{-8}	2,400	99% ^{79}Se	99% ^{79}Se	2×10^{-2}	95% ^{79}Se
Grouted Process Residuals	Q.10	5×10^{-7}	9	Bone	3×10^{-6}	4,200	98% ^{241}Am	99% ^{241}Am	4×10^{1}	84% ^{241}Am
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.10	1×10^{-5}	30	Kidney	1×10^{-4}	3,300	99% ^{79}Se	99% ^{79}Se	1×10^{2}	67% ^{79}Se
Existing Double-Shell Tanks										
Tank Residuals	Q.7	7×10^{-9}	7	GI-LLI	8×10^{-7}	700	86% ^{99}Tc	99% ^{99}Tc	7×10^{-3}	79% ^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[e]	--	NR	--	--	--	--	--	--	--	--
300 Wye Site	--	NR	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.40. **In-Place Stabilization and Disposal Alternative--Public Doses from Contaminant Migration to the Columbia River for 5-cm/yr Recharge with Functional Barrier Failure** (considered as increments above normal performance)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide Total-Body	Dominant Nuclide Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.11	9×10^{-7}	6	GI-LLI	1×10^{-4}	5,200	85% ^{99}Tc	99% ^{99}Tc	7×10^{1}	51% ^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks										
Tank Residuals	Q.8	2×10^{-8}	8	GI-LLI	2×10^{-6}	4,300	55% ^{99}Tc	99% ^{99}Tc	8×10^{-2}	55% ^{99}Tc
Grouted Process Residuals	Q.11	3×10^{-7}	9	GI-LLI	2×10^{-5}	10,000	66% ^{99}Tc	99% ^{99}Tc	9×10^{1}	61% ^{99}Tc
Future Double-Shell Tanks										
Tank Residuals	Q.8	2×10^{-9}	7	Thyroid	7×10^{-7}	4,500	64% ^{99}Tc	99% ^{129}I	1×10^{-2}	64% ^{99}Tc
Grouted Process Residuals	Q.11	4×10^{-8}	7	Thyroid	6×10^{-6}	10,000	70% ^{99}Tc	99% ^{99}Tc	2×10^{1}	59% ^{99}Tc
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.11	1×10^{-6}	7	GI-LLI	1×10^{-4}	5,800	82% ^{99}Tc	99% ^{99}Tc	1×10^{2}	55% ^{99}Tc
Existing Double-Shell Tanks										
Tank Residuals	Q.8	2×10^{-9}	7	GI-LLI	2×10^{-7}	4,400	80% ^{99}Tc	99% ^{99}Tc	3×10^{-2}	51% ^{129}I
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[e]	--	NR	--	--	--	--	--	--	--	--
300 Wye Site	--	NR	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.41. Reference Alternative--Public Doses from Contaminant Migration to the Columbia River for 0.5-cm/yr Recharge (barriers remain effective)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide: Total-Body	Dominant Nuclide: Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.3	5×10^{-9}	7	GI-LLI	5×10^{-7}	9,800	84% ^{99}Tc	99% ^{99}Tc	1	81% ^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks										
Tank Residuals	Q.2	4×10^{-12}	7	GI-LLI	4×10^{-10}	9,900	84% ^{99}Tc	99% ^{99}Tc	1×10^{-3}	81% ^{99}Tc
Grouted Process Residuals	Q.4	2×10^{-8}	9	GI-LLI	2×10^{-6}	9,400	66% ^{99}Tc	99% ^{99}Tc	6	61% ^{99}Tc
Future Double-Shell Tanks										
Tank Residuals	Q.2	2×10^{-12}	7	Thyroid	3×10^{-10}	9,700	59% ^{99}Tc	99% ^{129}I	5×10^{-4}	56% ^{99}Tc
Grouted Process Residuals	Q.4	4×10^{-9}	7	Thyroid	5×10^{-7}	9,400	70% ^{99}Tc	99% ^{129}I	1	66% ^{99}Tc
Sr/Cs Capsules[a]	--	NR[b]	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.3	6×10^{-9}	7	GI-LLI	7×10^{-7}	9,500	84% ^{99}Tc	99% ^{99}Tc	2	81% ^{99}Tc
Existing Double-Shell Tanks										
Tank Residuals	Q.2	1×10^{-12}	7	GI-LLI	1×10^{-10}	9,400	78% ^{99}Tc	99% ^{99}Tc	3×10^{-4}	75% ^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[a,e]	--	NR	--	--	--	--	--	--	--	--
300 Wye Site[a]	--	NR	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.42. Reference Alternative--Public Doses from Contaminant Migration to the Columbia River for 5-cm/yr Recharge (barriers remain effective)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide Total-Body	Dominant Nuclide Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.9	3×10^{-8}	7	GI-LLI	6×10^{-7}	10,000	81% ^{79}Se	96% ^{99}Tc	9	81% ^{79}Se
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks										
Tank Residuals	Q.6	8×10^{-12}	7	GI-LLI	5×10^{-10}	10,000	49% ^{99}Tc	99% ^{99}Tc	2×10^{-3}	46% ^{99}Tc
Grouted Process Residuals	Q.12	3×10^{-8}	9	GI-LLI	2×10^{-6}	9,900	45% ^{99}Tc	99% ^{99}Tc	9	42% ^{99}Tc
Future Double-Shell Tanks										
Tank Residuals	Q.6	1×10^{-11}	7	Thyroid	2×10^{-10}	9,700	59% ^{99}Tc	99% ^{129}I	5×10^{-4}	56% ^{99}Tc
Grouted Process Residuals	Q.12	3×10^{-8}	7	Thyroid	5×10^{-7}	9,700	88% ^{79}Se	99% ^{129}I	9	87% ^{79}Se
Sr/Cs Capsules[a]	--	NR[b]	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.9	4×10^{-8}	7	GI-LLI	8×10^{-7}	9,600	82% ^{79}Se	99% ^{99}Tc	1×10^{1}	80% ^{79}Se
Existing Double-Shell Tanks										
Tank Residuals	Q.6	2×10^{-12}	7	GI-LLI	1×10^{-10}	9,700	47% ^{99}Tc	99% ^{99}Tc	6×10^{-4}	47% ^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[a,e]	--	--	--	--	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.43. Reference Alternative--Public Doses from Contaminant Migration to the Columbia River for 5-cm/yr Recharge with Disruptive Barrier Failure (considered as increments above normal performance)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide: Total-Body	Dominant Nuclide: Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.10	1×10^{-5}	18	Kidney	1×10^{-4}	5,200	99% ^{79}Se	99% ^{79}Se	1×10^{2}	38% ^{241}Am
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks										
Tank Residuals	Q.7	7×10^{-9}	9	GI-LLI	4×10^{-7}	600	44% ^{99}Tc	99% ^{99}Tc	4×10^{-2}	71% ^{241}Am
Grouted Process Residuals	Q.8	8×10^{-8}	12	GI-LLI	5×10^{-6}	9,900	45% ^{99}Tc	99% ^{99}Tc	4×10^{1}	40% ^{99}Tc
Future Double-Shell Tanks										
Tank Residuals	Q.7	6×10^{-9}	7	Kidney	6×10^{-8}	2,400	99% ^{79}Se	99% ^{79}Se	2×10^{-2}	95% ^{79}Se
Grouted Process Residuals	Q.8	7×10^{-8}	8	Thyroid	1×10^{-6}	9,900	88% ^{79}Se	99% ^{129}I	3×10^{1}	88% ^{79}Se
Sr/Cs Capsules[a]	--	NR[b]	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.10	1×10^{-5}	30	Kidney	1×10^{-4}	3,300	99% ^{79}Se	99% ^{79}Se	1×10^{2}	67% ^{79}Se
Existing Double-Shell Tanks										
Tank Residuals	Q.7	7×10^{-9}	7	GI-LLI	8×10^{-7}	700	86% ^{99}Tc	99% ^{99}Tc	7×10^{-3}	79% ^{99}Tc
Grouted Process Residuals[d]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[a,e]	--	--	--	--	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the reference alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.44. Reference Alternative--Public Doses from Contaminant Migration to the Columbia River for 5-cm/yr Recharge with Functional Barrier Failure (considered as increments above normal performance)

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide Total-Body	Dominant Nuclide Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.11	9×10^{-7}	6	GI-LLI	1×10^{-4}	5,200	85% ^{99}Tc	99% ^{99}Tc	7×10^{1}	51% ^{99}Tc
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks										
Tank Residuals	Q.8	2×10^{-8}	8	GI-LLI	2×10^{-6}	4,300	55% ^{99}Tc	99% ^{99}Tc	8×10^{-2}	55% ^{99}Tc
Grouted Process Residuals	Q.13	3×10^{-7}	9	GI-LLI	2×10^{-5}	10,000	67% ^{99}Tc	99% ^{99}Tc	9×10^{1}	62% ^{99}Tc
Future Double-Shell Tanks										
Tank Residuals	Q.8	2×10^{-9}	7	Thyroid	7×10^{-7}	4,500	64% ^{99}Tc	99% ^{129}I	1×10^{-2}	64% ^{99}Tc
Grouted Process Residuals	Q.13	4×10^{-8}	7	Thyroid	6×10^{-6}	10,000	70% ^{99}Tc	99% ^{129}I	1×10^{1}	67% ^{99}Tc
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.11	1×10^{-6}	7	GI-LLI	1×10^{-4}	5,800	82% ^{99}Tc	99% ^{99}Tc	1×10^{2}	55% ^{99}Tc
Existing Double-Shell Tanks										
Tank Residuals	Q.8	2×10^{-9}	7	GI-LLI	2×10^{-7}	4,400	80% ^{99}Tc	99% ^{99}Tc	3×10^{-2}	51% ^{129}I
Grouted Process Residuals[d]	--	NR	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--
600 Area Wastes										
300 Area Burial Sites[a,e]	--	--	--	--	--	--	--	--	--	--
300 Wye Site[a]	--	--	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the in-place stabilization and disposal alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) All grouts are assumed to be in the 200 East Area.
(e) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.45. No Disposal Action (continued storage) **Alternative--Public Doses from Contaminant Migration to the Columbia River for 0.5-cm/yr Recharge**

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide Total-Body	Dominant Nuclide Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.5	1×10^{-5}	73	Bone	2×10^{-4}	9,700	99% ^{239}Pu	99% ^{239}Pu	2×10^{3}	95% ^{239}Pu
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks										
Tank Residuals	Q.5	4×10^{-6}	9	Kidney	3×10^{-5}	6,700	75% ^{79}Se	99% ^{79}Se	8×10^{2}	52% ^{79}Se
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks										
Tank Residuals	Q.5	7×10^{-5}	76	Bone	1×10^{-3}	6,300	100% ^{239}Pu	100% ^{239}Pu	2×10^{4}	99% ^{239}Pu
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.5	1×10^{-5}	73	Bone	2×10^{-4}	9,700	99% ^{239}Pu	99% ^{239}Pu	2×10^{3}	91% ^{239}Pu
Existing Double-Shell Tanks										
Tank Residuals	Q.5	2×10^{-6}	9	GI-LLI	1×10^{-4}	700	43% ^{99}Tc	99% ^{99}Tc	1×10^{2}	40% ^{239}Pu
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG TRU	Q.15	2×10^{-8}	12	Bone	1×10^{-7}	600	100% ^{14}C	100% ^{14}C	7×10^{-2}	100% ^{14}C
600 Area Wastes										
300 Area Burial Sites[d]	Q.16	7×10^{-11}	10	Bone	3×10^{-10}	700	100% ^{90}Sr	100% ^{90}Sr	1×10^{-4}	100% ^{90}Sr
300 Wye Site	Q.16	2×10^{-16}	1	Bone	8×10^{-16}	1,300	100% ^{90}Sr	100% ^{90}Sr	7×10^{-10}	100% ^{90}Sr

(a) This waste form does not apply to the no disposal action alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

TABLE R.46. **No Disposal Action** (continued storage) **Alternative--Public Doses from Contaminant Migration to the Columbia River for 5-cm/yr Recharge**

Waste Form	Average Downriver Individual, Lifetime Dose, During Peak Release Period								10,000-Yr Integrated Population Dose	
	Transport Assessment Table	Total-Body Dose, rem	Drinking-Water Contamination %[a]	Critical Organ	Critical-Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide: Total-Body	Dominant Nuclide: Critical-Organ	Total-Body Dose, man-rem	Dominant Nuclide
200 East Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.15	1	1	Bone	5	400	99% ^{90}Sr	99% ^{90}Sr	8×10^{5}	93% ^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks										
Tank Residuals	Q.15	1	1	Bone	4	300	99% ^{90}Sr	99% ^{90}Sr	7×10^{5}	99% ^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks										
Tank Residuals	Q.15	3	1	Bone	1×10^{1}	300	99% ^{90}Sr	99% ^{90}Sr	2×10^{6}	98% ^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	Q.15	4×10^{-10}	1	Bone	2×10^{-9}	700	100% ^{90}Sr	100% ^{90}Sr	7×10^{-4}	100% ^{90}Sr
Pre-1970 TRU	Q.15	7×10^{-10}	1	Bone	3×10^{-9}	700	100% ^{90}Sr	100% ^{90}Sr	8×10^{-4}	100% ^{90}Sr
RS/NG[c] TRU	Q.15	2×10^{-11}	1	Bone	6×10^{-11}	700	100% ^{90}Sr	100% ^{90}Sr	2×10^{-5}	100% ^{90}Sr
200 West Area Wastes										
Single-Shell Tanks										
Tank Residuals	Q.15	4×10^{-1}	1	Bone	1	400	99% ^{90}Sr	99% ^{90}Sr	3×10^{5}	91% ^{90}Sr
Existing Double-Shell Tanks										
Tank Residuals	Q.15	8×10^{-2}	1	Bone	3×10^{-1}	400	99% ^{90}Sr	99% ^{90}Sr	5×10^{4}	99% ^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	Q.15	1×10^{-10}	1	Bone	5×10^{-10}	800	100% ^{90}Sr	100% ^{90}Sr	3×10^{-4}	100% ^{90}Sr
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--
RS/NG TRU	Q.15	8×10^{-8}	3	Bone	3×10^{-7}	700	100% ^{90}Sr	100% ^{90}Sr	2×10^{-1}	78% ^{90}Sr
600 Area Wastes										
300 Area Burial Sites[d]	Q.16	6×10^{-6}	47	Bone	1×10^{-4}	6,800	99% ^{239}Pu	99% ^{239}Pu	3×10^{2}	99% ^{239}Pu
300 Wye Site	Q.16	1×10^{-6}	1	Bone	4×10^{-6}	500	100% ^{90}Sr	100% ^{90}Sr	4	100% ^{90}Sr

(a) This waste form does not apply to the no disposal action alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

(1983). This study investigated the impacts of leaks of liquids from single-shell tanks, which corresponds to the no disposal action alternative described in this EIS. Murthy et al. concluded that, for offsite population doses:

> The controlling radionuclides that contribute to these doses are technetium-99 and iodine-129 both of which are available only in small quantities. Other radionuclides of potential concern (cesium-137, strontium-90, neptunium-237) were also analyzed. Hydrological modeling indicated that although cesium-137 and strontium-90 are available in greater quantities, they will never reach the accessible environment before decay due to their relatively short half-lives and soil sorption. The trace amounts of neptunium-237 available have a very long half-life, but are not expected to reach the ground water due primarily to the lack of sufficient driving liquids and soil sorption (Murthy et al. 1983, p.1.11).

The analyses performed for this EIS support the above conclusion.

Health effects based on the doses reported in this section are given in Table R.47. The projection of health effects, based on the range given in Appendix N, is from zero to 4000 effects over the 10,000-year period in the entire population.

TABLE R.47. Incremental Radiation Dose to the Maximum Average Individual in the Down-River Population, as a Fraction of Natural Background, and the Total Number of Postulated Health Effects Resulting from Each Waste Disposal Alternative for Assumed 5-cm/yr Groundwater Recharge

Alternative	Average Individual (% of Background)	Total Postulated Health Effects
Geologic	0.000001	0-1
In-Place Stabilization and Disposal	0.000001	0-1
Reference	0.0000005	0-1
No Disposal Action (Continued Storage)	70	400-4000(a)

(a) Based on a range of 100-1000 health effects per 10^6 man-rem. Other factors are sometimes used that do not exclude zero as a possibility. See Appendix N for details.

The doses presented in this section incorporate a factor of dilution of the radionuclides released from groundwater into the Columbia River. This factor is based on the approximately 100 km^3/yr (120,000 ft^3/sec) flow of water past Hanford. Additional dilution caused by influx of water from downstream tributaries is not considered. The flow of the Columbia below the confluences of the Yakima, Snake, and Walla Walla rivers is about 215 km^3/yr (260,000 ft^3/sec); below the Willamette River, about 242 km^3/yr (290,000 ft^3/sec). This additional dilution would tend to lower the reported doses.

Another measure of the impact of the disposal alternatives on the Columbia River is the total quantity of each radionuclide released to the river over the 10,000-year period. This quantity, calculated as a sum of the deterministic evaluations presented in Appendix Q,

Tables Q.2 through Q.10, is given in Table R.48. The effects of double-counting of certain inventories for dose calculations, described above and in Appendix P, Section P.3, have been eliminated from this table. It is not necessary to double count inventories when calculating inputs at the Columbia River, for these are not sensitive to specific source locations. Thus, the predictions of total quantities released to the river presented in Table R.48 are the best estimate of the total source term for each alternative.

TABLE R.48. Cumulative Radionuclide Releases to the Columbia River from All Waste Forms, curies (barriers remain effective)

Radionuclide	Disposal Alternative: Geologic Disposal	In-Place Stabilization and Disposal	Reference Alternative	No Disposal Action
		0.5 cm/yr Recharge		
^{14}C	10	17	17	3,900
^{63}Ni	--	--	--	--
^{90}Sr	--	--	--	--
^{99}Tc	19	350	350	36,000
^{129}I	0.42	0.43	0.43	56
^{151}Sm	--	--	--	--
^{238}U	<0.1	<0.1	<0.1	5.6
^{237}Np	--	--	--	--
$^{239,240}Pu$	--	--	--	7,200
^{241}Am	--	--	--	--
		5 cm/yr Recharge		
^{14}C	13	20	20	4,900
^{63}Ni	--	--	--	--
^{79}Se	6	8	8	900
^{90}Sr	--	--	--	84,000
^{99}Tc	22	520	520	37,000
^{129}I	0.52	0.75	0.75	56
^{151}Sm	--	--	--	--
^{238}U	<0.1	<0.1	<0.1	39
^{237}Np	--	--	--	110
$^{239,240}Pu$	--	--	--	30,000
^{241}Am	--	--	--	980

R.2 FALLING OBJECTS

R.2.1 Meteorites

Based on data on terrestrial cratering rates (Grieve and Robertson 1979) and various configurations of waste sites, the annual probability of a meteorite excavating a Hanford waste site or group of waste sites has been estimated to be on the order of 10^{-9} to 10^{-10} yr^{-1}. Hence, over 10,000 years, the probability of a meteorite event is on the order of 10^{-5} to 10^{-6}.

The impact of a small meteorite (a few meters in diameter) could release waste from near-surface sites, but not affect waste disposed of in a deep geologic repository. On the other hand, a meteorite capable of excavating to a deep geologic repository would easily exhume all waste disposed of near the surface. Wallace et al. (1980) determined that the frequency of major disruptive events is not significantly different from that of minor events; i.e., the chance of a large group of tanks being enveloped by a large meteorite crater is nearly the same as the chance of one or more tanks being disrupted by a small cratering event. Because of the low probability of the event in either case and the fact that waste would be a small factor in the devastation from a giant meteorite, meteorite impacts are not considered an important discriminator in the selection of a waste disposal system. Meteorite impacts are, therefore, dismissed as plausible release events for the 10,000-year time frame.

R.2.2 Airplanes

It is assumed that impacts of large aircraft (over 5000 kg) can cause enough damage to release radioactivity. The closest airport to the Hanford Site that can accommodate large aircraft is in Pasco, 29 km away. However, present flight paths do allow aircraft to pass over Hanford waste sites.

Consequences of an aircraft impact can be increased by fire after the accident. A large aircraft has a maximum fuel capacity of between 11,000 and 190,000 L, with a mean value of 38,000 L. It is possible that 38,000 L of fuel could affect an area of 2,300 m^2. It has been estimated that about 50% of large aircraft accidents result in fire (NSC 1978).

Previous studies (Unruh 1968; NSC 1978; Wallace et al. 1980) have investigated the effects of various types of violent impact on stored or disposed of waste, including crashes of large jet airplanes into single-shell tanks containing salt cake and sludge, and through double-shell tanks containing residual liquids. This type of impact could also affect the other waste classes if they were not protected by barriers. All of the six waste classes would be susceptible to airplane crashes in the event that the no disposal action (continued storage) alternative were implemented; however, any type of disposal action further reduces the consequences of this scenario.

Calculated potential radiation doses for this scenario to a maximum individual and to the population in an 80-km area around Hanford are given in Table R.49. For this scenario the crash is assumed to be followed by a fire, which was taken into account in developing the

TABLE R.49. Potential Total-Body Radiation Doses Resulting from Impact Crater (airplane crash) Scenario[a] (NSC 1978)

Waste Class	Maximum Individual 70-yr Dose Commitment, rem	Population 70-yr Dose Commitment, man-rem
Single-Shell Tanks		
Total Body	2×10^{-3}	0.3
Bone	8×10^{-3}	1
Lung	3×10^{-3}	0.6
Double-Shell Tanks		
Total Body	2×10^{-3}	0.3
Bone	7×10^{-3}	1
Lung	3×10^{-3}	0.5

(a) Radiation doses are given for impact on tanks only. Doses for other waste classes would be significantly lower because of their smaller inventories.

release source terms. The doses reported are taken from NSC 1978, and include contributions from submersion in contaminated air as well as inhalation of resuspended particulate material.

R.3 DRILLING

Drilling into a waste storage or disposal site means penetration of the waste site from the land surface with actual removal of waste and soil material to the land surface. Drilling on the Hanford Site is considered in the case of loss of active institutional control 100 years after disposal. Monuments, barriers, and markers may reduce the likelihood of drilling, but they cannot preclude it.

Two distinct types of drilling scenarios are postulated. Because each has different drilling objectives and different size drill holes, different volumes of waste and soil material are brought to the surface:

1. A resource exploration well of large diameter, intended to be a deep (300 m or more) exploration test
2. A water well drilled for domestic water supply, which is comparatively shallow (100 m or less).

Drilling, either for water wells or for mineral exploration, is a potential mechanism for moving buried waste directly to the earth's surface with little indication that the waste has been encountered. Any disposal alternative that results in the waste's remaining near the surface creates the potential for the waste to be struck during drilling, even for relatively shallow wells (as for domestic water supplies). Only in instances where the waste is totally removed to a repository is intrusion by drilling a shallow well impossible.

In the drilling scenario, a well 30 cm in diameter is bored through waste of each category. Doses from larger or smaller drill holes scale in proportion to the cross-sectional area (except for doses from strontium/cesium capsules).

Drilling through the waste form itself is assumed to take 1 hr. During this time, the driller breathes suspended material with a mass loading of 1×10^{-4} g/m^3 of air. For the calculation of external exposure, the exhumed waste is assumed to be spread over a 100-m^2 area.

To estimate the maximum activity that might reasonably be transported to the surface, maximum concentration sites are assumed. The waste sites used as a basis for the inventories assumed for the calculation are listed in Table R.50. Inventories from these sites are taken from Rockwell (1985).

TABLE R.50. Source of Inventory for Drilling Scenario

	Example Waste Site Source of Inventory (Rockwell 1985)	Method of Calculating Release
Existing Tank Waste	105-C	Area ratio[a] (412 m^2)
DST Liquids	1 of 14 future DST	Area ratio (412 m^2)
Grouts		
Geologic SST/DST (blend of existing and future)	Projected grout concentration	3-m thickness[b]
Future DST In-Place	Projected grout concentration	3-m thickness
Future DST Reference	Projected grout concentration	3-m thickness
Existing SST/DST In-Place	Projected grout concentration	3-m thickness
Existing SST/DST Reference	Projected grout concentration	3-m thickness
Sr Capsules	1 canister	N/A[c]
Cs Capsules	1 canister	N/A[c]
TRU Soil Sites	216-Z-1A with a peak to average of 10	Area ratio (1,200 m^2)
Pre-1970 TRU	218-W-4B caissons	Area ratio (4.5 m^2)
RS/NG[d] TRU	218-W-4C with a peak to average of 10	Area ratio (4,900 m^2)

(a) Ratio of drill hole area to contaminated area used as a fraction of total site inventory.
(b) Thickness of grout through which drill penetrates.
(c) Entire inventory of a strontium or cesium canister in the drywell field.
(d) RS/NG = retrievably stored and newly generated.

The drillers are assumed to spend 40 hr working in the immediate vicinity of the exhumed waste. (The maximum annual dose includes that from external radiation received during drilling, plus the longer-term dose that would result from inhalation of nuclides in resuspended contaminated drilling muds.)

Maximum annual total-body radiation doses to members of a drill crew as a result of drilling through the waste are presented in Tables R.51 through R.54 for the various waste disposal alternatives. The doses are dominated by the external exposure contribution, generally from ^{137}Cs at early times and ^{241}Am in the longer time periods. Only for drilling through a capsule of ^{137}Cs within the first two centuries after disposal would fatalities to drillers be expected. This is because of the concentrated nature of the waste in the capsules and the decay of ^{137}Cs over two centuries to less hazardous levels. For the geologic disposal and the reference alternatives, the high-activity (and high-hazard) capsules are removed to a geologic repository, reducing the potential for radiation effects to drillers.

Persons living beyond the immediate vicinity of the contaminated area would be exposed to much lower concentrations of radionuclides. Atmospheric dispersion and dilution of resuspended contaminants would greatly reduce the individual doses. Radiation doses to individuals outside the immediate area of the drilling would be caused by long-term resuspension of the drilling muds spread about on the soil surface. Because these would be the same for drilling and for the postdrilling habitation scenario (Section R.5.3), which results in the disturbance of the drilling scenario inventory, doses to the population surrounding the drill hole will be listed in Tables R.63 through R.66 later in this appendix.

R.4 MAJOR EXCAVATION

Several plausible excavation events can be postulated that represent major ground disturbance. These include construction projects required for highway or canal building, or, on a smaller scale, for basements in buildings. In these cases, workers operating heavy machinery can be assumed to be in a "hole in the ground," essentially surrounded by contaminated soil. The hole could range from relatively small (for a basement) to quite large (for a canal), but the direct exposure source and the resuspended air concentration would be about the same in either case. The workers in the hole would be exposed to direct radiation from radionuclides in the soil and to resuspended dust from the construction activity. Minor excavation or digging is considered similar to a drilling intrusion event (Section R.3) because of the amount of material removed and the similar processes of exposure.

Records and federal ownership would reduce the likelihood of major excavation (see Appendix M), but if records and controls have been lost or ignored, it cannot be prevented. Such a systematic intrusion is considered to be credible only in the no disposal action alternative. The barrier and marker system is assumed to preclude excavation; the excavator is assumed to be alerted to the danger by the markers internal to the barrier. Waste in tanks or capsules may be in a recognizable form that would alert the intruder to the hazard, but for the purposes of this analysis, such recognition is not assumed.

TABLE R.51. Potential Doses Resulting from the Well-Drilling Scenario for the Geologic Disposal Alternative

Time, yr	Organ	Waste Form: Single-Shell Tanks, Tank Residuals	Single-Shell Tanks, Grouted Process Residuals	Existing Double-Shell Tanks, Tank Residuals	Existing Double-Shell Tanks, Grouted Process Residuals	Future Double-Shell Tanks, Tank Residuals	Future Double-Shell Tanks, Grouted Process Residuals	Sr/Cs Capsules	TRU-Contaminated Soil	600 Area[a] Sites and Pre-1970 TRU	RS/NG[b] TRU
		Individual Maximum Annual Doses, rem/yr									
100	Total Body	2×10^{-2}	4×10^{-4}	5×10^{-4}	(c)	3×10^{-3}	3×10^{-3}	(d)	(d)	(d)	(d)
	Bone	2×10^{-2}	4×10^{-4}	5×10^{-4}	--	3×10^{-3}	3×10^{-3}	--	--	--	--
	Lung	2×10^{-2}	4×10^{-4}	5×10^{-4}	--	3×10^{-3}	3×10^{-3}	--	--	--	--
	Thyroid	2×10^{-2}	4×10^{-4}	5×10^{-4}	--	3×10^{-3}	3×10^{-3}	--	--	--	--
	LLI	2×10^{-2}	4×10^{-4}	5×10^{-4}	--	3×10^{-3}	3×10^{-3}	--	--	--	--
400	Total Body	1×10^{-4}	5×10^{-7}	5×10^{-7}	--	4×10^{-6}	4×10^{-6}	--	--	--	--
	Bone	1×10^{-4}	5×10^{-7}	5×10^{-7}	--	4×10^{-6}	4×10^{-6}	--	--	--	--
	Lung	1×10^{-4}	6×10^{-7}	5×10^{-7}	--	4×10^{-6}	4×10^{-6}	--	--	--	--
	Thyroid	1×10^{-4}	5×10^{-7}	5×10^{-7}	--	4×10^{-6}	4×10^{-6}	--	--	--	--
	LLI	1×10^{-4}	5×10^{-7}	5×10^{-7}	--	4×10^{-6}	4×10^{-6}	--	--	--	--
1,000	Total Body	3×10^{-5}	7×10^{-8}	5×10^{-8}	--	5×10^{-7}	2×10^{-7}	--	--	--	--
	Bone	3×10^{-5}	7×10^{-8}	5×10^{-8}	--	5×10^{-7}	2×10^{-7}	--	--	--	--
	Lung	4×10^{-5}	8×10^{-8}	5×10^{-8}	--	5×10^{-7}	3×10^{-7}	--	--	--	--
	Thyroid	3×10^{-5}	7×10^{-8}	5×10^{-8}	--	5×10^{-7}	2×10^{-7}	--	--	--	--
	LLI	3×10^{-5}	7×10^{-8}	5×10^{-8}	--	5×10^{-7}	2×10^{-7}	--	--	--	--
10,000	Total Body	3×10^{-6}	5×10^{-8}	3×10^{-8}	--	3×10^{-10}	1×10^{-8}	--	--	--	--
	Bone	3×10^{-6}	5×10^{-8}	3×10^{-8}	--	2×10^{-9}	1×10^{-8}	--	--	--	--
	Lung	6×10^{-6}	5×10^{-8}	3×10^{-8}	--	5×10^{-9}	2×10^{-8}	--	--	--	--
	Thyroid	3×10^{-6}	5×10^{-8}	3×10^{-8}	--	3×10^{-10}	1×10^{-8}	--	--	--	--
	LLI	3×10^{-6}	5×10^{-8}	3×10^{-8}	--	3×10^{-10}	1×10^{-8}	--	--	--	--

(a) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 Sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).
(b) RS/NG = retrievably stored and newly generated.
(c) Existing DST grout is included in SST grout calculation.
(d) This waste form does not apply to the geologic disposal alternative.

TABLE R.52. Potential Doses Resulting from the Well-Drilling Scenario for the In-Place Stabilization and Disposal Alternative

Time, yr	Organ	Waste Form: Single-Shell Tanks, Tank Residuals	Single-Shell Tanks, Grouted Process Residuals	Existing Double-Shell Tanks, Tank Residuals	Existing Double-Shell Tanks, Grouted Process Residuals	Future Double-Shell Tanks, Tank Residuals	Future Double-Shell Tanks, Grouted Process Residuals	Sr/Cs Capsules, Sr	Sr/Cs Capsules, Cs	TRU-Contaminated Soil	600 Area[a] Sites and Pre-1970 TRU	RS/NG[b] TRU
		Individual Maximum Annual Doses, rem/yr										
100	Total Body	3×10^{-1}	(c)	5×10^{-4}	1×10^{-1}	3×10^{-3}	7×10^{-2}	6	1×10^{3}	9×10^{-4}	2×10^{-1}	4×10^{-4}
	Bone	3×10^{-1}	--	5×10^{-4}	1×10^{-1}	3×10^{-3}	7×10^{-2}	6	1×10^{3}	1×10^{-3}	2×10^{-1}	4×10^{-4}
	Lung	3×10^{-1}	--	5×10^{-4}	1×10^{-1}	3×10^{-3}	7×10^{-2}	6	1×10^{3}	2×10^{-3}	2×10^{-1}	4×10^{-4}
	Thyroid	3×10^{-1}	--	5×10^{-4}	1×10^{-1}	3×10^{-3}	7×10^{-2}	6	1×10^{3}	9×10^{-4}	2×10^{-1}	4×10^{-4}
	LLI	3×10^{-1}	--	5×10^{-4}	1×10^{-1}	3×10^{-3}	7×10^{-2}	6	1×10^{3}	9×10^{-4}	2×10^{-1}	4×10^{-4}
400	Total Body	2×10^{-3}	--	5×10^{-7}	2×10^{-4}	4×10^{-6}	6×10^{-4}	4×10^{-3}	1	6×10^{-4}	6×10^{-4}	5×10^{-7}
	Bone	2×10^{-3}	--	5×10^{-7}	2×10^{-4}	4×10^{-6}	6×10^{-4}	4×10^{-3}	1	7×10^{-4}	7×10^{-4}	5×10^{-7}
	Lung	2×10^{-3}	--	5×10^{-7}	2×10^{-4}	4×10^{-6}	6×10^{-4}	4×10^{-3}	1	1×10^{-3}	1×10^{-3}	6×10^{-7}
	Thyroid	2×10^{-3}	--	5×10^{-7}	2×10^{-4}	4×10^{-6}	6×10^{-4}	4×10^{-3}	1	6×10^{-4}	6×10^{-6}	5×10^{-7}
	LLI	2×10^{-3}	--	5×10^{-7}	2×10^{-4}	4×10^{-6}	6×10^{-4}	4×10^{-3}	1	6×10^{-4}	6×10^{-4}	5×10^{-7}
1,000	Total Body	6×10^{-4}	--	5×10^{-8}	2×10^{-5}	5×10^{-7}	2×10^{-4}	2×10^{-9}	2×10^{-6}	2×10^{-4}	2×10^{-4}	7×10^{-8}
	Bone	6×10^{-4}	--	5×10^{-8}	2×10^{-5}	5×10^{-7}	2×10^{-4}	2×10^{-9}	2×10^{-6}	3×10^{-4}	2×10^{-4}	7×10^{-8}
	Lung	7×10^{-4}	--	5×10^{-8}	2×10^{-5}	5×10^{-7}	2×10^{-4}	2×10^{-9}	2×10^{-6}	7×10^{-4}	5×10^{-4}	8×10^{-8}
	Thyroid	6×10^{-4}	--	5×10^{-8}	2×10^{-5}	5×10^{-7}	2×10^{-4}	2×10^{-9}	2×10^{-6}	2×10^{-4}	2×10^{-4}	7×10^{-8}
	LLI	6×10^{-4}	--	5×10^{-8}	2×10^{-5}	5×10^{-7}	2×10^{-4}	2×10^{-9}	2×10^{-6}	2×10^{-4}	2×10^{-4}	7×10^{-8}
10,000	Total Body	5×10^{-5}	--	3×10^{-8}	7×10^{-6}	3×10^{-10}	2×10^{-7}	0	0	9×10^{-6}	3×10^{-5}	5×10^{-8}
	Bone	6×10^{-5}	--	3×10^{-8}	7×10^{-6}	2×10^{-9}	6×10^{-7}	0	0	1×10^{-4}	8×10^{-5}	5×10^{-8}
	Lung	1×10^{-4}	--	3×10^{-8}	7×10^{-6}	5×10^{-9}	2×10^{-7}	0	0	4×10^{-4}	3×10^{-4}	5×10^{-8}
	Thyroid	5×10^{-5}	--	3×10^{-8}	7×10^{-6}	3×10^{-10}	1×10^{-7}	0	0	7×10^{-6}	3×10^{-5}	5×10^{-8}
	LLI	5×10^{-5}	--	3×10^{-8}	7×10^{-6}	3×10^{-10}	1×10^{-7}	0	0	7×10^{-6}	3×10^{-5}	5×10^{-8}

(a) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).
(b) RS/NG = retrievably stored and newly generated.
(c) This waste form does not apply to the in-place stabilization and disposal alternative.

TABLE R.53. Potential Doses Resulting from the Well-Drilling Scenario for the Reference Alternative

Time, yr	Organ	Waste Form: Single-Shell Tanks — Tank Residuals	Single-Shell Tanks — Grouted Process Residuals	Existing Double-Shell Tanks — Tank Residuals	Existing Double-Shell Tanks — Grouted Process Residuals	Future Double-Shell Tanks — Tank Residuals	Future Double-Shell Tanks — Grouted Process Residuals	Sr/Cs Capsules	TRU-Contaminated Soil	600 Area[a] Sites and Pre-1970 TRU	RS/NG[b] TRU
		Individual Maximum Annual Doses, rem/yr									
100	Total Body	3×10^{-1}	(c)	5×10^{-4}	1×10^{-1}	3×10^{-3}	7×10^{-2}	(c)	9×10^{-4}	2×10^{-1}	(c)
	Bone	3×10^{-1}	--	5×10^{-4}	1×10^{-1}	3×10^{-3}	7×10^{-2}	--	1×10^{-3}	2×10^{-1}	--
	Lung	3×10^{-1}	--	5×10^{-4}	1×10^{-1}	3×10^{-3}	7×10^{-2}	--	2×10^{-3}	2×10^{-1}	--
	Thyroid	3×10^{-1}	--	5×10^{-4}	1×10^{-1}	3×10^{-3}	7×10^{-2}	--	9×10^{-4}	2×10^{-1}	--
	LLI	3×10^{-1}	--	5×10^{-4}	1×10^{-1}	3×10^{-3}	7×10^{-2}	--	9×10^{-4}	2×10^{-1}	--
400	Total Body	2×10^{-3}	--	5×10^{-7}	2×10^{-4}	4×10^{-6}	9×10^{-5}	--	6×10^{-4}	6×10^{-4}	--
	Bone	2×10^{-3}	--	5×10^{-7}	2×10^{-4}	4×10^{-6}	9×10^{-5}	--	7×10^{-4}	7×10^{-4}	--
	Lung	2×10^{-3}	--	5×10^{-7}	2×10^{-4}	4×10^{-6}	9×10^{-5}	--	1×10^{-3}	1×10^{-3}	--
	Thyroid	2×10^{-3}	--	5×10^{-7}	2×10^{-4}	4×10^{-6}	9×10^{-5}	--	6×10^{-4}	6×10^{-6}	--
	LLI	2×10^{-3}	--	5×10^{-7}	2×10^{-4}	4×10^{-6}	9×10^{-5}	--	6×10^{-4}	6×10^{-4}	--
1,000	Total Body	6×10^{-4}	--	5×10^{-8}	2×10^{-6}	5×10^{-7}	8×10^{-6}	--	2×10^{-4}	2×10^{-4}	--
	Bone	6×10^{-4}	--	5×10^{-8}	2×10^{-6}	5×10^{-7}	8×10^{-6}	--	3×10^{-4}	2×10^{-4}	--
	Lung	7×10^{-4}	--	5×10^{-8}	2×10^{-6}	5×10^{-7}	8×10^{-6}	--	7×10^{-4}	5×10^{-4}	--
	Thyroid	6×10^{-4}	--	5×10^{-8}	2×10^{-6}	5×10^{-7}	9×10^{-6}	--	2×10^{-4}	2×10^{-4}	--
	LLI	6×10^{-4}	--	5×10^{-8}	2×10^{-6}	5×10^{-7}	8×10^{-6}	--	2×10^{-4}	2×10^{-4}	--
10,000	Total Body	5×10^{-5}	--	3×10^{-8}	9×10^{-7}	3×10^{-10}	7×10^{-8}	--	9×10^{-6}	3×10^{-5}	--
	Bone	6×10^{-5}	--	3×10^{-8}	9×10^{-7}	2×10^{-9}	1×10^{-7}	--	1×10^{-4}	8×10^{-5}	--
	Lung	1×10^{-4}	--	3×10^{-8}	9×10^{-7}	5×10^{-9}	2×10^{-7}	--	4×10^{-4}	3×10^{-4}	--
	Thyroid	5×10^{-5}	--	3×10^{-8}	9×10^{-7}	3×10^{-10}	8×10^{-8}	--	7×10^{-6}	3×10^{-5}	--
	LLI	5×10^{-5}	--	3×10^{-8}	9×10^{-7}	3×10^{-10}	8×10^{-8}	--	7×10^{-6}	3×10^{-5}	--

(a) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

(b) RS/NG = retrievably stored and newly generated.

(c) This waste form does not apply to the reference alternative.

TABLE R.54. Potential Doses Resulting from the Well-Drilling Scenario for the No Disposal Action (continued storage)

Time, yr	Organ	Waste Form: Single-Shell Tanks, Tank Residuals	Single-Shell Tanks, Grouted Process Residuals	Existing Double-Shell Tanks, Tank Residuals	Existing Double-Shell Tanks, Grouted Process Residuals	Future Double-Shell Tanks, Tank Residuals	Future Double-Shell Tanks, Grouted Process Residuals	Sr/Cs Capsules, Sr	Sr/Cs Capsules, Cs	TRU-Contaminated Soil	600 Area[a] Sites and Pre-1970 TRU	RS/NG[b] TRU
		Individual Maximum Annual Doses, rem/yr										
100	Total Body	3×10^{-1}	(c)	1	(c)	5	(c)	6	1×10^{3}	9×10^{-4}	2×10^{-1}	4×10^{-4}
	Bone	3×10^{-1}	--	1	--	5	--	6	1×10^{3}	1×10^{-3}	2×10^{-1}	4×10^{-4}
	Lung	3×10^{-1}	--	1	--	5	--	6	1×10^{3}	2×10^{-3}	2×10^{-1}	4×10^{-4}
	Thyroid	3×10^{-1}	--	1	--	5	--	6	1×10^{3}	9×10^{-4}	2×10^{-1}	4×10^{-4}
	LLI	3×10^{-1}	--	1	--	5	--	6	1×10^{3}	9×10^{-4}	2×10^{-1}	4×10^{-4}
400	Total Body	2×10^{-3}	--	1×10^{-3}	--	8×10^{-3}	--	4×10^{-3}	1	6×10^{-4}	6×10^{-4}	5×10^{-7}
	Bone	2×10^{-3}	--	1×10^{-3}	--	8×10^{-3}	--	4×10^{-3}	1	7×10^{-4}	7×10^{-4}	5×10^{-7}
	Lung	2×10^{-3}	--	1×10^{-3}	--	8×10^{-3}	--	4×10^{-3}	1	1×10^{-3}	1×10^{-3}	6×10^{-7}
	Thyroid	2×10^{-3}	--	1×10^{-3}	--	8×10^{-3}	--	4×10^{-3}	1	6×10^{-4}	6×10^{-6}	5×10^{-7}
	LLI	2×10^{-3}	--	1×10^{-3}	--	8×10^{-3}	--	4×10^{-3}	1	6×10^{-4}	6×10^{-4}	5×10^{-7}
1,000	Total Body	6×10^{-4}	--	1×10^{-4}	--	1×10^{-3}	--	2×10^{-9}	2×10^{-6}	2×10^{-4}	2×10^{-4}	7×10^{-8}
	Bone	6×10^{-4}	--	1×10^{-4}	--	1×10^{-3}	--	2×10^{-9}	2×10^{-6}	3×10^{-4}	2×10^{-4}	7×10^{-8}
	Lung	7×10^{-4}	--	1×10^{-4}	--	1×10^{-3}	--	2×10^{-9}	2×10^{-6}	7×10^{-4}	5×10^{-4}	8×10^{-8}
	Thyroid	6×10^{-4}	--	1×10^{-4}	--	1×10^{-3}	--	2×10^{-9}	2×10^{-6}	2×10^{-4}	2×10^{-4}	7×10^{-8}
	LLI	6×10^{-4}	--	1×10^{-4}	--	1×10^{-3}	--	2×10^{-9}	2×10^{-6}	2×10^{-4}	2×10^{-4}	7×10^{-8}
10,000	Total Body	5×10^{-5}	--	5×10^{-5}	--	6×10^{-7}	--	0	0	9×10^{-6}	3×10^{-5}	5×10^{-8}
	Bone	6×10^{-5}	--	5×10^{-5}	--	3×10^{-6}	--	0	0	1×10^{-4}	8×10^{-5}	5×10^{-8}
	Lung	1×10^{-4}	--	5×10^{-5}	--	1×10^{-5}	--	0	0	4×10^{-4}	3×10^{-4}	5×10^{-8}
	Thyroid	5×10^{-5}	--	5×10^{-5}	--	6×10^{-7}	--	0	0	7×10^{-6}	3×10^{-5}	5×10^{-8}
	LLI	5×10^{-5}	--	5×10^{-5}	--	6×10^{-7}	--	0	0	7×10^{-6}	3×10^{-5}	5×10^{-8}

(a) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).
(b) RS/NG = retrievably stored and newly generated.
(c) This waste form does not apply to the no disposal action alternative.

An individual operating heavy equipment is assumed to work in a contaminated area for 80 hr. A mass loading of 1×10^{-2} g/m^3 of air is assumed. Density of the material is 1.7 g/cm^3. Waste is assumed to be uniformly mixed with soil. Source of inventory and the assumed total volume for determining concentration are listed in Table R.55.

TABLE R.55. Source of Inventory Used for Excavation Scenario

Waste Type	Example Waste Site Source of Inventory (Rockwell 1985)	Volume of Waste Containing Inventory, m^3
Existing Tank Waste	105-C	2,000
DST Liquids	Projected Inventory	N/A(a)
Sr/Cs Capsules	Canister Drywell Field	N/A(b)
TRU-Contaminated Soil	216-Z-1A	8,300
Pre-1970 Buried TRU	218-W-2	23,000
Retrievably Stored & Newly Generated TRU	218-W-4C	4,900

(a) Because of the difficulty of excavating a liquid, the excavator is assumed to simply expose the wastes by breaking through the tank dome.
(b) The contents of both Sr and Cs canisters are assumed to be evenly distributed over the area of the drywell storage facility by the excavation equipment.

Calculated maximum annual total-body radiation doses to workers as a result of excavating the waste at various future times are presented in Table R.56 for only the no disposal action alternative. People excavating buried capsules any time during the first century after disposal would probably receive fatal doses. After about the first century, doses to excavators would probably not significantly affect their health.

Persons living beyond the immediate vicinity of the contaminated area would be exposed to much lower concentrations of radionuclides than the excavators would. Atmospheric dispersion and dilution of resuspended contaminants would reduce the doses.

Because it is assumed that the excavation is caused by people who have moved onto the Hanford Site and who are working in the vicinity of abandoned waste sites, a uniform population density is assumed for the Site (see Section R.5). A population of 250 people/km^2 (640/mile^2), compatible with the residential home-garden scenario, is used. Materials distributed on the surface would be available for resuspension by wind. A resuspension rate of 10^{-10} sec^{-1} (3×10^{-3} yr^{-1}) is assumed (compatible with the air loading of 10^{-4} g/m^3 used in the residential scenario). The radioactive materials are assumed to be distributed by 200 Area annual average meteorology. Assuming the materials from the excavation are not covered, the wastes would remain a source of release for many years. Lifetime doses to the

TABLE R.56. Potential Doses Resulting from the Excavation Scenario for the No Disposal Action (continued storage) Alternative

Time, yr	Organ	Waste Form: Single-Shell Tanks, Tank Residuals	Single-Shell Tanks, Grouted Process Residuals	Existing Double-Shell Tanks, Tank Residuals	Existing Double-Shell Tanks, Grouted Process Residuals	Future Double-Shell Tanks, Tank Residuals	Future Double-Shell Tanks, Grouted Process Residuals	Sr/Cs Capsules	TRU-Contaminated Soil	600 Area[a] Sites and Pre-1970 TRU	RS/NG[b] TRU
Onsite Individual Maximum Annual Doses, rem/yr											
100	Total Body	5×10^{1}	(c)	1×10^{-1}	(c)	5×10^{-1}	(c)	2×10^{4}	4×10^{-1}	3×10^{-1}	4
	Bone	1×10^{2}	--	1×10^{-1}	--	5×10^{-1}	--	2×10^{4}	1×10^{1}	7	8×10^{1}
	Lung	3×10^{2}	--	1×10^{-1}	--	5×10^{-1}	--	2×10^{4}	4×10^{1}	3×10^{1}	3×10^{2}
	Thyroid	5×10^{1}	--	1×10^{-1}	--	5×10^{-1}	--	2×10^{4}	1×10^{-2}	8×10^{-3}	9×10^{-1}
	LLI	5×10^{1}	--	1×10^{-1}	--	5×10^{-1}	--	2×10^{4}	2×10^{-2}	1×10^{-2}	1
400	Total Body	2	--	6×10^{-5}	--	9×10^{-4}	--	2×10^{1}	4×10^{-1}	3×10^{-1}	3
	Bone	5×10^{1}	--	6×10^{-5}	--	9×10^{-4}	--	2×10^{1}	9	6	6×10^{1}
	Lung	2×10^{2}	--	6×10^{-5}	--	9×10^{-4}	--	2×10^{1}	4×10^{1}	3×10^{1}	2×10^{2}
	Thyroid	3×10^{-1}	--	6×10^{-5}	--	9×10^{-4}	--	2×10^{1}	7×10^{-3}	5	2×10^{-2}
	LLI	3×10^{-1}	--	6×10^{-5}	--	9×10^{-4}	--	2×10^{1}	2×10^{-2}	1×10^{-2}	7×10^{-2}
1,000	Total Body	1	--	1×10^{-5}	--	1×10^{-4}	--	2×10^{-5}	4×10^{-1}	2×10^{-1}	2
	Bone	3×10^{1}	--	1×10^{-5}	--	1×10^{-4}	--	2×10^{-5}	8	6	5×10^{1}
	Lung	1×10^{2}	--	1×10^{-5}	--	1×10^{-4}	--	2×10^{-5}	3×10^{1}	2×10^{1}	2×10^{2}
	Thyroid	1×10^{-1}	--	1×10^{-5}	--	1×10^{-4}	--	2×10^{-5}	3×10^{-3}	2×10^{-3}	7×10^{-3}
	LLI	1×10^{-1}	--	1×10^{-5}	--	1×10^{-4}	--	2×10^{-5}	1×10^{-2}	7×10^{-3}	6×10^{-2}
10,000	Total Body	5×10^{-1}	--	6×10^{-6}	--	6×10^{-8}	--	0	2×10^{-1}	2×10^{-1}	2
	Bone	1×10^{1}	--	6×10^{-6}	--	6×10^{-8}	--	0	5	4	4×10^{1}
	Lung	5×10^{1}	--	6×10^{-6}	--	6×10^{-8}	--	0	2×10^{1}	2×10^{1}	1×10^{2}
	Thyroid	1×10^{-2}	--	6×10^{-6}	--	6×10^{-8}	--	0	9×10^{-5}	8×10^{-5}	7×10^{-4}
	LLI	2×10^{-2}	--	6×10^{-6}	--	6×10^{-8}	--	0	5×10^{-3}	4×10^{-3}	4×10^{-2}
Offsite Individual Lifetime Doses, rem											
100	Total Body	9×10^{1}	(c)	(d)	(c)	(d)	(c)	6×10^{2}	3	2	2×10^{1}
400	Total Body	1×10^{1}	--	--	--	--	--	4×10^{-1}	2	2	2×10^{1}
1,000	Total Body	1×10^{1}	--	--	--	--	--	3×10^{-7}	2	2	2×10^{1}
10,000	Total Body	3	--	--	--	--	--	--	2	9×10^{-1}	1×10^{1}
Cumulative Population Lifetime Doses, man-rem											
100	Total Body	1×10^{4}	(c)	(d)	(c)	(d)	(c)	9×10^{4}	5×10^{2}	4×10^{2}	4×10^{3}
400	Total Body	2×10^{3}	--	--	--	--	--	7×10^{1}	4×10^{2}	4×10^{2}	4×10^{3}
1,000	Total Body	2×10^{3}	--	--	--	--	--	5×10^{-5}	4×10^{2}	4×10^{2}	4×10^{3}
10,000	Total Body	5×10^{2}	--	--	--	--	--	--	4×10^{2}	1×10^{2}	2×10^{3}

(a) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

(b) RS/NG = retrievably stored and newly generated. The radionuclide distributions of newly generated TRU resemble those of existing retrievably stored TRU.

(c) This waste form does not apply to the continued storage alternative.

(d) Major excavation is not credible for tank liquids; individual doses are for 1 hr of direct exposure to the liquids.

assumed population within 80 km (50 miles) are presented in Table R.56. Doses to individuals near the Site would be higher than to those farther away. Doses to a single person (in rem) a distance of 0.8 km (0.5 mile) from the initial excavation would be less than about a factor of 10^{-4} the magnitude of those shown in Table R.56 for the population. For even the worst-case excavation into strontium capsules at 100 years, the dose to such an individual would not be large enough to cause radiation-induced immediate effects.

R.5 RESETTLEMENT/FARMING/GARDENING

For purposes of analysis, the resettlement or reoccupation of the Hanford Site is assumed after its hypothetical abandonment. Though not an expected event, this case is analyzed to provide a basis of one aspect of radiologic impacts in the long term for unprotected waste sites.

It is believed that hypothetical resettlement would occur first along parts of the Hanford Site relatively close to the Columbia River because of the availability of water from both the river and groundwater at shallow depths. However, for the sake of conservatism, potential future occupancy is also assumed near or at locations of waste for the various disposal alternatives. For waste sites in the 200 Areas plateau, this type of resettlement is believed to be applicable only to a few individuals (rather than a systematic settlement). However, resettlement could occur near the river with neither knowledge nor consideration of the wastes located in the 200 Areas.

Resettlement could lead to the following types of plausible scenarios related to small farm/garden activities that could furnish exposure pathways to the individuals involved:

1. A home garden with exposure coming from consuming crops or garden produce grown over a shallow, unbarriered waste site. The mechanism would be plant uptake by roots growing into waste or contaminated soil. This scenario is described in detail in Section R.5.1.

2. A home garden where waste has been brought to the surface from an unbarriered waste site by plants, animals, and insects, resulting in surface contamination by biotic transport. The primary exposure pathways to individuals would be through direct exposure, inhalation of resuspended material, and ingestion of crops grown at the location. A detailed scenario for this event is described in Section R.5.2.

3. A home garden at the site of former drilling or excavation activity. This drilling has resulted in a higher level of radioactivity at the land surface where individuals carry out their activities. Direct exposure, resuspension, and ingestion of food products grown in contaminated soil are the primary exposure pathways to the inhabitants. This scenario is detailed in Section R.5.3.

4. A small garden/livestock operation where the exposure pathway is by use of water from a domestic well that intercepts water from a contaminated aquifer. The

aquifer is assumed to have been contaminated by waste leached through the unsaturated zone and into the groundwater. Because of the existing uncertainties in the groundwater leaching and transport, this scenario was described in detail for individuals separately in Section R.1. This scenario has the potential to impact a larger number of families. The possibilities of population exposure via this scenario are discussed in Section R.5.4.

R.5.1 Residential/Home Garden

Without active institutional controls, and with disregard of passive institutional controls such as permanent markers and public records, waste disposal areas could possibly be used eventually for residential purposes. People could build homes over buried waste sites and conduct routine activities. Food crops, for either domestic or animal consumption, could be grown over the waste site. The resident would consequently be exposed to low levels of direct radiation from the buried material and also to ingestion of radionuclides via crops grown in the site. Crop contamination would be a function of the depth of waste burial, the integrity of the waste container, the overall surface area used for gardening, and other considerations that affect the fraction of plant roots that contact the waste.

The fraction of roots in the contaminated zone is given in Table R.57. These fractions include the effects of depth of burial versus time (allowing surface erosion); package integrity (decay of strontium/cesium canisters, decomposition of grout product, loss of tank integrity); surface area; and waste-form toxicity (nitrates in tanks), as described by Napier (1982).

TABLE R.57. Fraction of Roots in Deeply Buried Waste as a Function of Time (derived from Napier 1982)

Waste Type	Fraction of Roots in Waste at Time, yr			
	100	400	1,000	10,000
Tank Waste	4×10^{-6}	4×10^{-6}	4×10^{-4}	9×10^{-4}
TRU-Contaminated Soil	0.3	0.3	0.35	0.7
600 Area Sites and Pre-1970 Buried TRU	0.3	0.3	0.35	0.7
Retrievably Stored and Newly Generated TRU	0.3	0.3	0.35	0.7

Sources of waste inventories and concentrations used in the calculations are given in Table R.58.

The protective barrier and marker system (Appendices B and M) to be applied to the waste site can be designed, among other things, to prevent penetration of roots to the waste and to discourage farming there. Removal of waste to a deep geologic repository makes any farming

TABLE R.58. Source of Inventory Used for Farmer Scenario

Waste Type	Example Waste Site Source of Inventory	Volume or Area for Concentration of Waste
Tank Waste	105-C	2,000 m^3
TRU-Contaminated Soil	216-Z-1	8,300 m^3
Pre-1970 Buried TRU	218-W-2	23,000 m^3
Retrievably Stored and Newly Generated TRU	218-W-4C	4,900 m^3

harmless in terms of radioactive contamination. Thus, only for no disposal action (continued storage) followed by loss of site control is this scenario applicable.

Calculated potential total-body radiation doses to resident individuals are given in Table R.59 for the various waste forms. People are assumed to live on the land and to grow much of their total food in gardens. The dominant exposure pathway is ingestion of contaminated food crops. The dominant radionuclide for the early time periods is ^{90}Sr. After long periods, the controlling nuclides would be ^{239}Pu and ^{241}Am. The high concentration of fission products at some of the waste sites (^{90}Sr, ^{137}Cs) leads to relatively large dose rates for times less than 400 years in the future for this scenario (although the strontium/cesium capsules do not contribute because of assumed capsule integrity). No fatalities would be expected from doses of the magnitude given in Table R.59.

The effects of this scenario on populations depend directly on the number of people involved; if a family of five were to reside over the unprotected waste site as postulated for this scenario, each would receive the dose indicated.

R.5.2 Biotic Transport

Transport of buried radioactive waste to the soil surface by indigenous plants and animals is a very slow process, but, continued over long periods, it may result in substantial exposure to humans from unprotected waste sites. At Hanford biotic transport has resulted in "nuisance" contamination from past practices. The overall processes of waste-form degradation, followed by plant or animal uptake, are relatively poorly understood, but are continuing to be researched. A preliminary model of biotic transport processes has recently been developed (McKenzie et al. 1982a,b). This model indicates that, for sites without barriers to prevent intrusion by plants and animals, the quantity of radionuclides transported to the soil surface can be significant. However, radionuclides could be transported to the surface only under the no disposal action (continued storage), followed by loss of maintenance and controls. Any positive action to dispose of the waste greatly reduces or eliminates the potential exposure, because the barrier is designed to preclude this pathway.

TABLE R.59. Potential Doses Resulting from the Residential/Home Garden Scenario for the No Disposal Action (continued storage) Alternative

Time, yr	Organ	Waste Form: Single-Shell Tanks — Tank Residuals	Single-Shell Tanks — Grouted Process Residuals	Existing Double-Shell Tanks — Tank Residuals	Existing Double-Shell Tanks — Grouted Process Residuals	Future Double-Shell Tanks — Tank Residuals	Future Double-Shell Tanks — Grouted Process Residuals	Sr/Cs Capsules	TRU-Contaminated Soil	600 Area[a] Sites and Pre-1970 TRU	RS/NG[b] TRU
		Individual Maximum Annual Doses, rem/yr									
100	Total Body	6×10^{-1}	(c)	(d)	(c)	(d)	(c)	(e)	5×10^{-2}	4×10^{-2}	6×10^{1}
	Bone	2	--	--	--	--	--	--	1	8×10^{-1}	2×10^{2}
	Lung	5×10^{-3}	--	--	--	--	--	--	8×10^{-7}	1×10^{-6}	1×10^{-2}
	Thyroid	5×10^{-3}	--	--	--	--	--	--	5×10^{-9}	2×10^{-8}	6×10^{-5}
	LLI	8×10^{-2}	--	--	--	--	--	--	2×10^{-1}	1×10^{-1}	--
400	Total Body	6×10^{-4}	--	--	--	--	--	--	4×10^{-2}	3×10^{-2}	3×10^{-1}
	Bone	3×10^{-3}	--	--	--	--	--	--	9×10^{-1}	7×10^{-1}	5
	Lung	7×10^{-6}	--	--	--	--	--	--	2×10^{-9}	1×10^{-8}	1×10^{-5}
	Thyroid	3×10^{-5}	--	--	--	--	--	--	2×10^{-9}	9×10^{-9}	1×10^{-7}
	LLI	3×10^{-4}	--	--	--	--	--	--	1×10^{-1}	1×10^{-1}	9×10^{-1}
1,000	Total Body	1×10^{-2}	--	--	--	--	--	--	4×10^{-2}	3×10^{-2}	2×10^{-1}
	Bone	7×10^{-2}	--	--	--	--	--	--	9×10^{-1}	6×10^{-1}	5
	Lung	3×10^{-5}	--	--	--	--	--	--	2×10^{-9}	9×10^{-9}	5×10^{-8}
	Thyroid	2×10^{-3}	--	--	--	--	--	--	2×10^{-9}	9×10^{-9}	5×10^{-8}
	LLI	2×10^{-2}	--	--	--	--	--	--	1×10^{-1}	1×10^{-2}	9×10^{-1}
10,000	Total Body	1×10^{-2}	--	--	--	--	--	--	5×10^{-2}	4×10^{-2}	3×10^{-1}
	Bone	5×10^{-2}	--	--	--	--	--	--	1	7×10^{-1}	7
	Lung	7×10^{-5}	--	--	--	--	--	--	2×10^{-9}	9×10^{-9}	5×10^{-8}
	Thyroid	5×10^{-3}	--	--	--	--	--	--	2×10^{-9}	9×10^{-9}	5×10^{-8}
	LLI	4×10^{-2}	--	--	--	--	--	--	2×10^{-1}	1×10^{-1}	1

(a) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).
(b) RS/NG = retrievably stored and newly generated.
(c) This waste form does not apply to the continued storage alternative.
(d) This scenario is not credible for tank liquids.
(e) Capsules have sufficient integrity to prevent plant uptake until the contents have decayed.

Maintenance and vegetation control are assumed for unprotected sites for 100 years, thus preventing the accumulation of nuclides at the surface before institutional control is assumed to be lost. Following loss of site control, a plant and animal community representative of arid, western sites is assumed to establish itself over the wastes. The description of the biotic community is taken from McKenzie et al. 1982b. The animal community is summarized in Table R.60 and the plant community in Table R.61. The plant community is assumed to be established after loss of site control, with the initial distribution shown in Table R.61 changing as larger plants become dominant in the final community in 100 years.

The nuclide inventories used in the calculations are the same as those used in the farming scenario (Table R.58). Estimated potential radiation doses to individuals living near the waste are given in Table R.62 for the waste classes that could be affected (grout forms, always assumed to have barriers installed, are not affected, and residual moisture would drain away before tanks were sufficiently degraded to allow plant and animal penetration). An individual is assumed to live on the land and grow gardens in the soil. The individual residing on the site contaminated under the biotic transport scenario is exposed by inhalation of resuspended dusts, ingestion of crops grown in the soil, and direct exposure. Initially, the radionuclides preferentially moved by the biotic transport are those readily taken up by plants. The dominant radionuclide, ^{90}Sr, is usually considered to be environmentally mobile. At longer times, the doses tend to come from the less mobile but longer-lived nuclides, such as ^{239}Pu, through resuspension. No doses are given for times of 100 years or less, because institutional control up to that time would prevent biotic transport.

Only localized concentrations of radionuclides would be expected near the waste sites; once the material is brought to the surface, normal erosional processes would tend to disperse it. The effects of this scenario on populations also depend directly on the number of people involved.

R.5.3 Postdrilling/Excavation Habitation

The doses to persons contacting wastes presented in Sections R.3 and R.4 represent only a portion of the impact of intrusion into waste. Drilling or excavation results in waste being physically disturbed and distributed in the local environment. These wastes could represent a source of radiation exposure to people living on or near the site of the original disturbance long after the original redistribution. As in the example of the residential/home-garden scenario (Section R.5.1), people who live on or near the waste would be exposed to direct radiation from it in the soil, to inhalation of resuspended material, and to ingestion of garden-grown foods.

The protective barrier and marker system planned for the waste sites (with the disposal alternatives) is designed to discourage human use of that land. Hence this scenario is most likely if the waste is left with no remedial actions. It is effectively prevented by removing the waste to a geologic repository, or made less likely by installing barriers, since the

TABLE R.60. Burrowing Habits of Potential Animal Intruders at an Unprotected Waste Burial Site (McKenzie 1982b)

Animals	% Distribution of Burrow System Below Ground Depth Interval, m					Density animals/ha		Burrow Vol., m^3		Estimated Vol. of Soil Brought Surface in First Yr, m^3/ha	Proportion of New Burrow Systems/Yr
	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	>2.0	Range	Average	Range	Average		
Ground Squirrels[a]	50	30	15	5	0	5.7 - 74	25	0.008 - 0.077	0.020	0.500	0.50 - 1
Pocket Mice and Kangaroo Rats[a]	50	40	5	5	0	0.8 - 180	25	0.003 - 0.103	0.014	0.350	0.75 - 1
Pocket Gophers[a]	85	15	0	0	0	2 - 124	--	0.510 - 81.518[b]	8.300[b]	8.300	0.75 - 1
Prairie Dogs[a]	20	20	20	20	20	3.5 - 31.9[c]	10[c]	0.120 - 0.356	0.196	1.960	0.02
Badgers	70	15	5	5	5	--	--	--	0.170	0.211	1.00
Ants	70	10	10	5	5	--	50[d]	--	0.002[e]	0.100	0.10

(a) Represents several species.
(b) Estimate of volume of soil excavated per hectare.
(c) Represents density in an indivivdual colony.
(d) Colonies per hectare.
(e) Represents average burrow volume per colony.

TABLE R.61. Plant Community Composition for the Waste Burial Site (McKenzie 1982b)

	Percent Vegetation Cover					
	Annual Grass	Annual Forb	Perennial Grass	Perennial Forb	Shrub	Total
Initial Plant Community[a]						
Percent Cover[b]	20.0	13.0	0.1	0.6	5.5	39.2
Relative Percent Cover[c]	51.0	33.2	0.3	1.5	14.0	100.0
Final Plant Community[d]						
Percent Cover	3.0	1.0	90.0	1.0	18.0	113.0
Relative Percent Cover	2.6	0.9	79.6	0.9	15.9	99.9

(a) Average for ten south-central Washington (Hanford Site) low-level waste burial grounds (Fitzner et al. 1979, Table 3).
(b) Percent ground area covered.
(c) Percent composition of plant community (by area covered).
(d) Data for Benton County, south-central Washington.

barriers result in an inhospitable environment even after an intrusive event. For the purposes of analysis, the drilling event is assumed to occur regardless of the presence of barriers and markers.

Waste brought to the surface by the drilling scenario (Section R.3) is assumed to be spread uniformly throughout a 15-cm plow layer in a garden 2,500-m^2 in area. Twenty-five percent of the individual's vegetable intake is assumed to come from this garden. The individual is assumed to spend 2000 hr/yr outside, exposed to resuspended dust and to surface contamination.

Calculated maximum annual total-body doses to individuals living on the site of an intrusive event at various future times are presented in Tables R.63 through R.66 for the various disposal alternatives. The doses given in the table are for habitation of the site following contamination by the drilling scenario. Doses from the ^{137}Cs capsules are controlled by external direct radiation. Doses from the TRU-contaminated soils, pre-1970 buried TRU sites, and the tank waste have major contributions from inhalation of resuspended material. Fatalities could be expected from habitation on a contaminated drilling site any time during the first century from existing tank waste and from strontium and cesium capsules, and for nearly 10,000 years for pre-1970, buried TRU solid waste, and retrievably stored and newly generated TRU waste. The differences among waste classes in terms of fatalities are due principally to the concentration of nuclides in the waste.

Persons living beyond the immediate vicinity of the contaminated area would be exposed to much lower concentrations of radionuclides than would the residents. Atmospheric dispersion and dilution of resuspended contaminants would reduce the doses (Healy 1980). The residents of the farm are assumed regularly to resuspend the contaminated soil by plowing or

TABLE R.62. Potential Doses Resulting from the Biotic Transport Scenario for the No Disposal Action (continued storage) **Alternative**

Time, yr	Organ	Waste Form: Single-Shell Tanks, Tank Residuals	Single-Shell Tanks, Grouted Process Residuals	Existing Double-Shell Tanks, Tank Residuals	Existing Double-Shell Tanks, Grouted Process Residuals	Future Double-Shell Tanks, Tank Residuals	Future Double-Shell Tanks, Grouted Process Residuals	Sr/Cs Capsules	TRU-Contaminated Soil	600 Area[a] Sites and Pre-1970 TRU	RS/NG[b] TRU
		Individual Maximum Annual Doses, rem/yr									
100	Total Body	(c)	(d)	(e)	(d)	(e)	(d)	(f)	(c)	(c)	(c)
	Bone	--	--	--	--	--	--	--	--	--	--
	Lung	--	--	--	--	--	--	--	--	--	--
	Thyroid	--	--	--	--	--	--	--	--	--	--
	LLI	--	--	--	--	--	--	--	--	--	--
400	Total Body	7×10^{-3}	--	--	--	--	--	--	2×10^{-2}	3×10^{-2}	1×10^{-2}
	Bone	3×10^{-2}	--	--	--	--	--	--	2×10^{-1}	6×10^{-1}	1×10^{-1}
	Lung	4×10^{-4}	--	--	--	--	--	--	2×10^{-2}	2×10^{-1}	2×10^{-2}
	Thyroid	3×10^{-4}	--	--	--	--	--	--	1×10^{-3}	6×10^{-3}	7×10^{-5}
	LLI	1×10^{-3}	--	--	--	--	--	--	6×10^{-3}	3×10^{-2}	5×10^{-3}
1,000	Total Body	8×10^{-3}	--	--	--	--	--	--	2×10^{-2}	6×10^{-2}	1×10^{-2}
	Bone	8×10^{-2}	--	--	--	--	--	--	3×10^{-1}	2	3×10^{-1}
	Lung	2×10^{-2}	--	--	--	--	--	--	3×10^{-3}	3×10^{-1}	6×10^{-2}
	Thyroid	3×10^{-2}	--	--	--	--	--	--	1×10^{-3}	6×10^{-2}	5×10^{-5}
	LLI	6×10^{-1}	--	--	--	--	--	--	1×10^{-2}	9×10^{-2}	1×10^{-2}
10,000	Total Body	1×10^{-1}	--	--	--	--	--	--	6×10^{-2}	3×10^{-1}	7×10^{-2}
	Bone	6×10^{-1}	--	--	--	--	--	--	1	9	1
	Lung	1	--	--	--	--	--	--	3×10^{-1}	2	4×10^{-1}
	Thyroid	5×10^{-1}	--	--	--	--	--	--	3×10^{-4}	1×10^{-3}	2×10^{-4}
	LLI	1×10^{1}	--	--	--	--	--	--	6×10^{-2}	3×10^{-1}	7×10^{-2}

(a) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).
(b) RS/NG = retrievably stored and newly generated.
(c) Institutional controls are assumed to be available to mitigate biotic transport until such controls are lost.
(d) This waste form does not apply to the continued storage alternative.
(e) This scenario is not credible for tank liquids.
(f) Capsules have sufficient integrity to prevent biotic transport until the contents have decayed.

TABLE R.63. Potential Doses Resulting from the Postdrilling Scenario for the Geologic Disposal Alternative

Time, yr	Organ	Waste Form: Single-Shell Tanks, Tank Residuals	Single-Shell Tanks, Grouted Process Residuals	Existing Double-Shell Tanks, Tank Residuals	Existing Double-Shell Tanks, Grouted Process Residuals	Future Double-Shell Tanks, Tank Residuals	Future Double-Shell Tanks, Grouted Process Residuals	Sr/Cs Capsules	TRU-Contaminated Soil	600 Area Sites and Pre-1970 TRU	RS/NG[a] TRU
Onsite Individual Maximum Annual Doses, rem/yr											
100	Total Body	5	2×10^{-2}	3×10^{-2}	(b)	1×10^{-1}	5×10^{-2}	(c)	(c)	(c)	(c)
	Bone	3×10^{1}	9×10^{-2}	1×10^{-1}	--	3×10^{-1}	2×10^{-1}	--	--	--	--
	Lung	5×10^{-2}	2×10^{-3}	3×10^{-3}	--	1×10^{-2}	1×10^{-2}	--	--	--	--
	Thyroid	5×10^{-2}	2×10^{-3}	3×10^{-3}	--	1×10^{-2}	1×10^{-2}	--	--	--	--
	LLI	1	5×10^{-3}	5×10^{-3}	--	2×10^{-2}	2×10^{-2}	--	--	--	--
400	Total Body	5×10^{-3}	5×10^{-4}	3×10^{-5}	--	5×10^{-5}	4×10^{-4}	--	--	--	--
	Bone	5×10^{-2}	2×10^{-3}	1×10^{-4}	--	5×10^{-4}	2×10^{-3}	--	--	--	--
	Lung	1×10^{-2}	1×10^{-5}	1×10^{-5}	--	2×10^{-4}	8×10^{-5}	--	--	--	--
	Thyroid	5×10^{-4}	2×10^{-4}	5×10^{-6}	--	2×10^{-5}	3×10^{-4}	--	--	--	--
	LLI	4×10^{-3}	3×10^{-4}	3×10^{-5}	--	3×10^{-5}	3×10^{-4}	--	--	--	--
1,000	Total Body	3×10^{-3}	4×10^{-4}	5×10^{-6}	--	1×10^{-5}	4×10^{-4}	--	--	--	--
	Bone	3×10^{-2}	2×10^{-3}	4×10^{-5}	--	2×10^{-4}	2×10^{-3}	--	--	--	--
	Lung	5×10^{-3}	6×10^{-6}	4×10^{-6}	--	5×10^{-5}	3×10^{-5}	--	--	--	--
	Thyroid	4×10^{-4}	2×10^{-4}	3×10^{-6}	--	4×10^{-6}	2×10^{-4}	--	--	--	--
	LLI	3×10^{-3}	3×10^{-4}	3×10^{-5}	--	1×10^{-6}	3×10^{-4}	--	--	--	--
10,000	Total Body	1×10^{-3}	1×10^{-4}	2×10^{-6}	--	5×10^{-7}	1×10^{-4}	--	--	--	--
	Bone	1×10^{-2}	7×10^{-4}	1×10^{-5}	--	1×10^{-6}	7×10^{-4}	--	--	--	--
	Lung	2×10^{-3}	3×10^{-6}	3×10^{-7}	--	3×10^{-6}	1×10^{-5}	--	--	--	--
	Thyroid	3×10^{-4}	2×10^{-4}	3×10^{-6}	--	1×10^{-6}	2×10^{-4}	--	--	--	--
	LLI	2×10^{-3}	1×10^{-4}	3×10^{-5}	--	5×10^{-6}	1×10^{-4}	--	--	--	--
Offsite Individual Lifetime Doses, rem											
100	Total Body	4×10^{-3}	1×10^{-5}	1×10^{-5}	(b)	6×10^{-5}	3×10^{-5}	(c)	(c)	(c)	(c)
400	Total Body	6×10^{-4}	7×10^{-7}	6×10^{-7}	--	1×10^{-5}	6×10^{-6}	--	--	--	--
1,000	Total Body	4×10^{-4}	3×10^{-7}	2×10^{-7}	--	4×10^{-6}	3×10^{-6}	--	--	--	--
10,000	Total Body	2×10^{-4}	2×10^{-7}	6×10^{-9}	--	3×10^{-7}	1×10^{-6}	--	--	--	--
Cumulative Population Lifetime Doses, man-rem											
100	Total Body	7×10^{-1}	2×10^{-3}	2×10^{-3}	(b)	9×10^{-3}	5×10^{-3}	(c)	(c)	(c)	(c)
400	Total Body	9×10^{-2}	1×10^{-4}	9×10^{-5}	--	2×10^{-3}	9×10^{-4}	--	--	--	--
1,000	Total Body	7×10^{-2}	5×10^{-5}	4×10^{-5}	--	7×10^{-4}	5×10^{-4}	--	--	--	--
10,000	Total Body	4×10^{-2}	4×10^{-5}	9×10^{-7}	--	5×10^{-5}	2×10^{-4}	--	--	--	--

(a) RS/NG = retrievably stored and newly generated. The radionuclide distributions of newly generated TRU resemble those of existing retrievably stored TRU.
(b) Included in existing SST grout.
(c) This waste form does not apply to the geologic disposal alternative.

TABLE R.64. Potential Doses Resulting from the Postdrilling/Excavation Scenario for the In-Place Stabilization and Disposal Alternative

Time, yr	Organ	Waste Form: Single-Shell Tanks — Tank Residuals	Single-Shell Tanks — Grouted Process Residuals	Existing Double-Shell Tanks — Tank Residuals	Existing Double-Shell Tanks — Grouted Process Residuals	Future Double-Shell Tanks — Tank Residuals	Future Double-Shell Tanks — Grouted Process Residuals	Sr/Cs Capsules — Sr	Sr/Cs Capsules — Cs	TRU-Contaminated Soil	600 Area[a] Sites and Pre-1970 TRU	RS/NG[b] TRU
Onsite Individual Maximum Annual Doses, rem/yr												
100	Total Body	1×10^{2}	(c)	3×10^{-2}	6	1×10^{-1}	3×10^{1}	3×10^{4}	5×10^{3}	7×10^{-2}	8	1
	Bone	5×10^{2}	--	1×10^{-1}	2×10^{1}	3×10^{-1}	1×10^{2}	1×10^{5}	5×10^{3}	1	3×10^{1}	7
	Lung	1	--	3×10^{-3}	6×10^{-1}	1×10^{-2}	3×10^{-1}	3×10^{1}	5×10^{3}	4×10^{-1}	9×10^{-1}	2
	Thyroid	1	--	3×10^{-3}	6×10^{-1}	1×10^{-2}	3×10^{-1}	2×10^{1}	5×10^{3}	4×10^{-3}	7×10^{-1}	1×10^{-1}
	LLI	2×10^{1}	--	5×10^{-3}	1	2×10^{-2}	4	4×10^{3}	5×10^{3}	1×10^{-2}	2	3×10^{-1}
400	Total Body	1×10^{-1}	--	3×10^{-5}	6×10^{-3}	5×10^{-5}	2×10^{-2}	2×10^{1}	5	6×10^{-2}	5×10^{-2}	2×10^{-1}
	Bone	1	--	1×10^{-4}	3×10^{-2}	5×10^{-4}	2×10^{-3}	8×10^{1}	5	1	9×10^{-1}	3
	Lung	2×10^{-1}	--	1×10^{-5}	3×10^{-3}	2×10^{-4}	5×10^{-2}	2×10^{-2}	5	4×10^{-1}	3×10^{-1}	1
	Thyroid	1×10^{-2}	--	5×10^{-6}	1×10^{-3}	2×10^{-5}	3×10^{-3}	2×10^{-2}	5	2×10^{-3}	2×10^{-3}	2×10^{-3}
	LLI	7×10^{-2}	--	3×10^{-5}	9×10^{-3}	3×10^{-5}	7×10^{-3}	3	5	8×10^{-3}	7×10^{-3}	2×10^{-2}
1,000	Total Body	5×10^{-2}	--	5×10^{-6}	1×10^{-3}	1×10^{-5}	3×10^{-3}	1×10^{-5}	5×10^{-6}	5×10^{-2}	4×10^{-2}	2×10^{-1}
	Bone	5×10^{-1}	--	4×10^{-5}	1×10^{-2}	2×10^{-4}	6×10^{-2}	4×10^{-5}	5×10^{-6}	1	8×10^{-1}	3
	Lung	1×10^{-1}	--	4×10^{-6}	1×10^{-3}	5×10^{-5}	2×10^{-2}	8×10^{-9}	5×10^{-6}	3×10^{-1}	2×10^{-1}	1
	Thyroid	7×10^{-3}	--	3×10^{-6}	7×10^{-4}	4×10^{-6}	1×10^{-3}	7×10^{-9}	5×10^{-6}	9×10^{-4}	7×10^{-4}	1×10^{-4}
	LLI	5×10^{-2}	--	3×10^{-5}	8×10^{-3}	1×10^{-6}	3×10^{-3}	1×10^{-6}	5×10^{-6}	6×10^{-3}	5×10^{-3}	2×10^{-2}
10,000	Total Body	2×10^{-2}	--	2×10^{-6}	5×10^{-4}	5×10^{-7}	3×10^{-4}	0	0	4×10^{-2}	3×10^{-2}	1×10^{-1}
	Bone	2×10^{-1}	--	1×10^{-5}	2×10^{-3}	1×10^{-6}	4×10^{-3}	0	0	8×10^{-1}	5×10^{-1}	2
	Lung	4×10^{-2}	--	3×10^{-7}	7×10^{-5}	3×10^{-6}	1×10^{-3}	0	0	2×10^{-1}	2×10^{-1}	7×10^{-1}
	Thyroid	5×10^{-3}	--	3×10^{-6}	7×10^{-4}	1×10^{-6}	4×10^{-4}	0	0	3×10^{-5}	1×10^{-4}	1×10^{-4}
	LLI	4×10^{-2}	--	3×10^{-5}	7×10^{-3}	5×10^{-6}	2×10^{-3}	0	0	4×10^{-3}	3×10^{-3}	1×10^{-2}
Offsite Individual Lifetime Doses, rem												
100	Total Body	8×10^{-2}	(c)	1×10^{-5}	3×10^{-3}	6×10^{-5}	2×10^{-2}	1×10^{1}	1	4×10^{-2}	3×10^{-2}	1×10^{-1}
400	Total Body	1×10^{-2}	--	6×10^{-7}	2×10^{-4}	1×10^{-5}	3×10^{-3}	9×10^{-3}	1×10^{-3}	3×10^{-2}	2×10^{-2}	1×10^{-1}
1,000	Total Body	9×10^{-3}	--	2×10^{-7}	8×10^{-5}	4×10^{-6}	1×10^{-3}	4×10^{-9}	1×10^{-9}	3×10^{-2}	2×10^{-2}	1×10^{-1}
10,000	Total Body	3×10^{-3}	--	6×10^{-9}	2×10^{-6}	3×10^{-7}	1×10^{-4}	--	--	2×10^{-2}	1×10^{-2}	7×10^{-2}
Cumulative Population Lifetime Doses, man-rem												
100	Total Body	1×10^{1}	(c)	2×10^{-3}	5×10^{-1}	9×10^{-3}	4	2×10^{3}	2×10^{2}	7	5	2×10^{1}
400	Total Body	2	--	9×10^{-5}	4×10^{-2}	2×10^{-3}	5×10^{-1}	1	2×10^{-1}	5	4	2×10^{1}
1,000	Total Body	1	--	4×10^{-5}	1×10^{-2}	7×10^{-4}	2×10^{-1}	7×10^{-7}	2×10^{-7}	5	4	2×10^{1}
10,000	Total Body	5×10^{-1}	--	9×10^{-7}	4×10^{-4}	5×10^{-5}	2×10^{-2}	--	--	4	2	1×10^{1}

(a) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).
(b) RS/NG = retrievably stored and newly generated. The radionuclide distributions of newly generated TRU resemble those of existing retrievably stored TRU.
(c) This waste form does not apply to the in-place stabilization and disposal alternative.

TABLE R.65. Potential Doses Resulting from the Postdrilling Scenario for the Reference Alternative

Time, yr	Organ	Waste Form: Single-Shell Tanks, Tank Residuals	Single-Shell Tanks, Grouted Process Residuals	Existing Double-Shell Tanks, Tank Residuals	Existing Double-Shell Tanks, Grouted Process Residuals	Future Double-Shell Tanks, Tank Residuals	Future Double-Shell Tanks, Grouted Process Residuals	Sr/Cs Capsules	TRU-Contaminated Soil	600 Area[a] Sites and Pre-1970 TRU	RS/NG[b] TRU
Onsite Individual Maximum Annual Doses, rem/yr											
100	Total Body	1×10^{2}	(c)	3×10^{-2}	1	1×10^{-1}	1	(c)	7×10^{-2}	8	(c)
	Bone	5×10^{2}	--	1×10^{-1}	3	3×10^{-1}	4	--	1	3×10^{1}	--
	Lung	1	--	3×10^{-3}	6×10^{-1}	1×10^{-2}	3×10^{-1}	--	4×10^{-1}	9×10^{-1}	--
	Thyroid	1	--	3×10^{-3}	6×10^{-1}	1×10^{-2}	3×10^{-1}	--	4×10^{-3}	7×10^{-1}	--
	LLI	2×10^{1}	--	5×10^{-3}	7×10^{-1}	2×10^{-2}	4×10^{-1}	--	1×10^{-2}	2	--
400	Total Body	1×10^{-1}	--	3×10^{-5}	2×10^{-3}	5×10^{-5}	1×10^{-3}	--	6×10^{-2}	5×10^{-2}	--
	Bone	1	--	1×10^{-4}	9×10^{-3}	5×10^{-4}	9×10^{-3}	--	1	9×10^{-1}	--
	Lung	2×10^{-1}	--	1×10^{-5}	8×10^{-4}	2×10^{-4}	2×10^{-3}	--	4×10^{-1}	3×10^{-1}	--
	Thyroid	1×10^{-2}	--	5×10^{-6}	1×10^{-3}	2×10^{-5}	8×10^{-4}	--	2×10^{-3}	2×10^{-3}	--
	LLI	7×10^{-2}	--	3×10^{-5}	9×10^{-3}	3×10^{-5}	2×10^{-3}	--	8×10^{-3}	7×10^{-3}	--
1,000	Total Body	5×10^{-2}	--	5×10^{-6}	1×10^{-3}	1×10^{-5}	3×10^{-4}	--	5×10^{-2}	4×10^{-2}	--
	Bone	5×10^{-1}	--	4×10^{-5}	6×10^{-3}	2×10^{-4}	4×10^{-3}	--	1	8×10^{-1}	--
	Lung	1×10^{-1}	--	4×10^{-6}	1×10^{-4}	5×10^{-5}	9×10^{-4}	--	3×10^{-1}	2×10^{-1}	--
	Thyroid	7×10^{-3}	--	3×10^{-6}	6×10^{-4}	4×10^{-6}	4×10^{-4}	--	9×10^{-4}	7×10^{-4}	--
	LLI	5×10^{-2}	--	3×10^{-5}	8×10^{-3}	1×10^{-6}	2×10^{-3}	--	6×10^{-3}	5×10^{-3}	--
10,000	Total Body	2×10^{-2}	--	2×10^{-6}	5×10^{-4}	5×10^{-7}	9×10^{-5}	--	4×10^{-2}	3×10^{-2}	--
	Bone	2×10^{-1}	--	1×10^{-5}	2×10^{-3}	1×10^{-6}	7×10^{-4}	--	8×10^{-1}	5×10^{-1}	--
	Lung	4×10^{-2}	--	3×10^{-7}	3×10^{-5}	3×10^{-6}	1×10^{-4}	--	2×10^{-1}	2×10^{-1}	--
	Thyroid	5×10^{-3}	--	3×10^{-6}	6×10^{-4}	1×10^{-6}	4×10^{-4}	--	3×10^{-5}	1×10^{-4}	--
	LLI	4×10^{-2}	--	3×10^{-5}	7×10^{-3}	5×10^{-6}	2×10^{-3}	--	4×10^{-3}	3×10^{-3}	--
Offsite Individual Lifetime Doses, rem											
100	Total Body	8×10^{-2}	(c)	1×10^{-5}	4×10^{-4}	6×10^{-5}	7×10^{-4}	(c)	4×10^{-2}	3×10^{-2}	(c)
400	Total Body	1×10^{-2}	--	6×10^{-7}	2×10^{-5}	1×10^{-5}	1×10^{-4}	--	3×10^{-2}	2×10^{-2}	--
1,000	Total Body	9×10^{-3}	--	2×10^{-7}	8×10^{-6}	4×10^{-6}	7×10^{-5}	--	3×10^{-2}	2×10^{-2}	--
10,000	Total Body	3×10^{-3}	--	6×10^{-9}	3×10^{-7}	3×10^{-7}	1×10^{-5}	--	2×10^{-2}	2×10^{-1}	--
Cumulative Population Lifetime Doses, man-rem											
100	Total Body	1×10^{1}	(c)	2×10^{-3}	7×10^{-2}	9×10^{-3}	1×10^{-1}	(c)	7	5	(c)
400	Total Body	2	--	9×10^{-5}	4×10^{-3}	2×10^{-3}	2×10^{-2}	--	5	4	--
1,000	Total Body	1	--	4×10^{-5}	1×10^{-3}	7×10^{-4}	1×10^{-2}	--	5	4	--
10,000	Total Body	5×10^{-1}	--	9×10^{-7}	5×10^{-5}	5×10^{-5}	2×10^{-3}	--	4	2	--

(a) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).

(b) RS/NG = retrievably stored and newly generated. The radionuclide distributions of newly generated TRU resemble those of existing retrievably stored TRU.

(c) This waste form does not apply to the reference alternative.

TABLE R.66. Potential Doses Resulting from the Postdrilling Scenario for the No Disposal Action Alternative

Time, yr	Organ	Waste Form: Single-Shell Tanks, Tank Residuals	Single-Shell Tanks, Grouted Process Residuals	Existing Double-Shell Tanks, Tank Residuals	Existing Double-Shell Tanks, Grouted Process Residuals	Future Double-Shell Tanks, Tank Residuals	Future Double-Shell Tanks, Grouted Process Residuals	Sr/Cs Capsules, Sr	Sr/Cs Capsules, Cs	TRU-Contaminated Soil	600 Area[a] Sites and Pre-1970 TRU	RS/NG[b] TRU
						Onsite Individual Maximum Annual Doses, rem/yr						
100	Total Body	1×10^{2}	(c)	5×10^{1}	(c)	2×10^{2}	(c)	3×10^{4}	5×10^{3}	7×10^{-2}	8	1
	Bone	5×10^{2}	--	2×10^{2}	--	6×10^{2}	--	1×10^{5}	5×10^{3}	1	3×10^{1}	7
	Lung	1	--	5	--	2×10^{1}	--	3×10^{1}	5×10^{3}	4×10^{-1}	9×10^{-1}	2
	Thyroid	1	--	5	--	2×10^{1}	--	2×10^{1}	5×10^{3}	4×10^{-3}	7×10^{-1}	1×10^{-1}
	LLI	2×10^{1}	--	1×10^{1}	--	4×10^{1}	--	4×10^{3}	5×10^{3}	1×10^{-2}	2	3×10^{-1}
400	Total Body	1×10^{-1}	--	5×10^{-2}	--	1×10^{-1}	--	2×10^{1}	5	6×10^{-2}	5×10^{-2}	2×10^{-1}
	Bone	1	--	2×10^{-1}	--	1	--	8×10^{1}	5	1	9×10^{-1}	3
	Lung	2×10^{-1}	--	2×10^{-2}	--	3×10^{-1}	--	2×10^{-2}	5	4×10^{-1}	3×10^{-1}	1
	Thyroid	1×10^{-2}	--	1×10^{-2}	--	3×10^{-2}	--	2×10^{-2}	5	2×10^{-3}	2×10^{-3}	2×10^{-3}
	LLI	7×10^{-2}	--	6×10^{-2}	--	6×10^{-2}	--	3	5	8×10^{-3}	7×10^{-3}	2×10^{-2}
1,000	Total Body	5×10^{-2}	--	1×10^{-2}	--	2×10^{-2}	--	1×10^{-5}	5×10^{-6}	5×10^{-2}	4×10^{-2}	2×10^{-1}
	Bone	5×10^{-1}	--	7×10^{-2}	--	4×10^{-1}	--	4×10^{-5}	5×10^{-6}	1	8×10^{-1}	3
	Lung	1×10^{-1}	--	7×10^{-3}	--	1×10^{-1}	--	8×10^{-9}	5×10^{-6}	3×10^{-1}	2×10^{-1}	1
	Thyroid	7×10^{-3}	--	6×10^{-3}	--	7×10^{-3}	--	7×10^{-9}	5×10^{-6}	9×10^{-4}	7×10^{-4}	1×10^{-4}
	LLI	5×10^{-2}	--	5×10^{-2}	--	2×10^{-2}	--	1×10^{-6}	5×10^{-6}	6×10^{-3}	5×10^{-3}	2×10^{-2}
10,000	Total Body	2×10^{-2}	--	4×10^{-3}	--	1×10^{-3}	--	0	0	4×10^{-2}	3×10^{-2}	1×10^{-1}
	Bone	2×10^{-1}	--	2×10^{-2}	--	2×10^{-3}	--	0	0	8×10^{-1}	5×10^{-1}	2
	Lung	4×10^{-2}	--	5×10^{-4}	--	6×10^{-3}	--	0	0	2×10^{-1}	2×10^{-1}	7×10^{-1}
	Thyroid	5×10^{-3}	--	5×10^{-3}	--	2×10^{-3}	--	0	0	3×10^{-5}	1×10^{-4}	1×10^{-4}
	LLI	4×10^{-2}	--	5×10^{-2}	--	1×10^{-2}	--	0	0	4×10^{-3}	3×10^{-3}	1×10^{-2}
						Offsite Individual Lifetime Doses, rem						
100	Total Body	8×10^{-2}	(c)		(c)		(c)	1×10^{1}	1	4×10^{-2}	3×10^{-2}	1×10^{-1}
400	Total Body	1×10^{-2}	--		--		--	9×10^{-3}	1×10^{-3}	3×10^{-2}	2×10^{-2}	1×10^{-1}
1,000	Total Body	9×10^{-3}	--		--		--	4×10^{-9}	1×10^{-9}	3×10^{-2}	2×10^{-2}	1×10^{-1}
10,000	Total Body	3×10^{-3}	--		--		--	--	--	2×10^{-2}	1×10^{-2}	7×10^{-2}
						Cumulative Population Lifetime Doses, man-rem						
100	Total Body	1×10^{1}	(c)		(c)		(c)	2×10^{3}	2×10^{2}	7	5	2×10^{1}
400	Total Body	2	--		--		--	1	2×10^{-1}	5	4	2×10^{1}
1,000	Total Body	1	--		--		--	7×10^{-7}	2×10^{-7}	5	4	2×10^{1}
10,000	Total Body	5×10^{-1}	--		--		--	--	--	4	2	1×10^{1}

(a) A recently completed study (DOE 1986a), which examined records of inactive waste disposal locations on the Hanford Site, showed that two 618 sites (618-1 and 618-2) each contained 1.0 g of plutonium, rather than the previously listed 1000 g (Rockwell 1985). As a result of this lower quantity, both sites are now designated as low-level waste sites (Rockwell 1987).
(b) RS/NG = retrievably stored and newly generated. The radionuclide distributions of newly generated TRU resemble those of existing retrievably stored TRU.
(c) This waste form does not apply to the continued storage alternative.

otherwise working it. Because it is assumed that other people have also moved onto the Hanford Site and live in the vicinity of the waste sites, a uniform population density of 250 persons/km^2 (640/$mile^2$) is assumed (see Section R.4). A resuspension rate of 10^{-10} sec^{-1} (3×10^{-3} yr^{-1}) is used, compatible with the assumed mass loading of 10^{-4} g/m^3. The radioactive materials are assumed to be distributed by winds described by 200 Area annual average meteorology. Because the drilled wastes could remain a source of release for many years under this scenario, lifetime doses to the projected population within 80 km (50 mi) are presented in Tables R.63 through R.66 for the various alternatives. Doses to individuals in this population would be higher at close distances than those to individuals far away. Dose to a single person, in rem, at a distance of only 0.8 km (0.5 mi) from the site of the drilling would be about a factor of 10^{-4} of the magnitude of those shown in Tables R.63 through R.66 for the population.

R.5.4 Multiple Small Farms

The water-well scenarios presented in Section R.1 were developed to describe the potential impact on individuals. It is likely that, should such an event occur, it would affect more than one person. A simple analysis of the flow of groundwater provides an estimate of the total population that could be supported in this irrigated homestead scenario.

Infiltration at a rate of 0.5 cm/yr results in a low water table with gradients sloping gently to the east. Integration of the flow across a north-south line connecting Gable Mountain and Rattlesnake Mountain east of the 200 East Area (see Figure Q.1) provides a conservative estimate of the total amount of water that could possibly become contaminated. The quantity of available groundwater in the unconfined aquifer can thus be estimated to be about 2×10^6 m^3/yr (1,600 acre-ft/yr).

The scenario with a 5-cm/yr infiltration rate results in a changed water table with flow beneath the 200 Areas funneling northward through the gap between Gable Mountain and Gable Butte (see Figure Q.3). The total flow northward through this gap for the 5-cm/yr infiltration scenario is about 1×10^7 m^3/yr (9,500 acre-ft/yr). The most conservative assumption would be to assume that all the water is uniformly contaminated.

The individual farms described in Section R.1.4.2 are postulated to be about 2 ha (5 acres), each providing food for a family of four persons. Present irrigation practices in the Columbia Basin area include use of about 6×10^3 m^3 of water per ha (about 5 acre-ft/yr per acre) for typical crops. For a 2-ha farm, about 3×10^4 m^3/yr of water (25 acre-ft/yr) are required. The flow of potentially contaminated water beneath the 200 Areas plateau is therefore sufficient to supply the requirements of only 65 family farms in the 0.5-cm/yr recharge case. This implies an affected population of about 260 people at any one time. (It may be assumed that radionuclides brought to the surface by the wells would eventually erode to the Columbia River, and thus the total population doses downstream would remain about as presented in Section R.1.4.3.) As illustrated in Figure R.3, the water could become contaminated about 5,000 years from the time of disposal, and essentially remain constantly

contaminated from then on. Assuming the area is continuously populated and that the groundwater is uniformly contaminated at the highest levels of Section R.1.4.2, the cumulative population doses could be as shown in Table R.67.

TABLE R.67. Potential Integrated Population Doses from the Multiple-Small-Farm Scenario for the Waste Disposal Alternatives

Disposal Option	0.5-cm/yr Recharge		5-cm/yr Recharge	
	Dose, man-rem	Health Effects	Dose, man-rem	Health Effects
Geologic Disposal	4×10^3	0-4	1×10^3	0-1
In-Place Stabilization and Disposal	2×10^3	0-2	2×10^3	0-2
Reference Alternative	2×10^3	0-2	2×10^3	0-2

The population doses presented in Table R.67 for the various disposal alternatives are slightly lower in the 5-cm/yr recharge case, in which the contamination is more dilute because of the higher flow rate. The somewhat higher results for the geologic disposal alternative result from ^{79}Se removed from existing single-shell tanks and placed in grout, in which it is not as well retained.

The impacts of this scenario are more difficult to quantify for the no disposal action (continued storage) alternative. The water contamination would be sporadic, as described in Section R.1.4.2, with periods of high contamination interspersed with periods of relatively clean water. This phenomenon was illustrated for 200 West Area single-shell tanks in Figure R.2, here repeated as Figure R.10. The other waste forms would contribute similar bursts of contamination, resulting in an irregular sequence of periods of high water contamination. Radiation doses to individuals at any time would be dependent on the quantity of contamination; the largest individual doses resulting from each waste form are reported in Table R.68. It can be seen from this table that the major sources of potential contamination are the waste tank farms.

The largest doses to individuals farming with water contaminated by the releases postulated for the no disposal action alternative could occur within about 300 to 400 years after the assumed loss of institutional control over the site, for either 0.5 or 5 cm/yr recharge. Projected individual doses for the 5 cm/yr case are very large, and would result in acute lethality. Doses projected for the 0.5 cm/yr case are smaller, but could still lead to significant life shortening and chronic health deterioration.

Potential numbers of health effects for this scenario are reported in Table R.69. The number of health effects shown for the 0.5-cm/yr recharge case represent a range of presumed health effects based on dose to health effects ratios given in Appendix N. The number of health effects shown for the 5-cm/yr recharge case are based on fatality from a very large

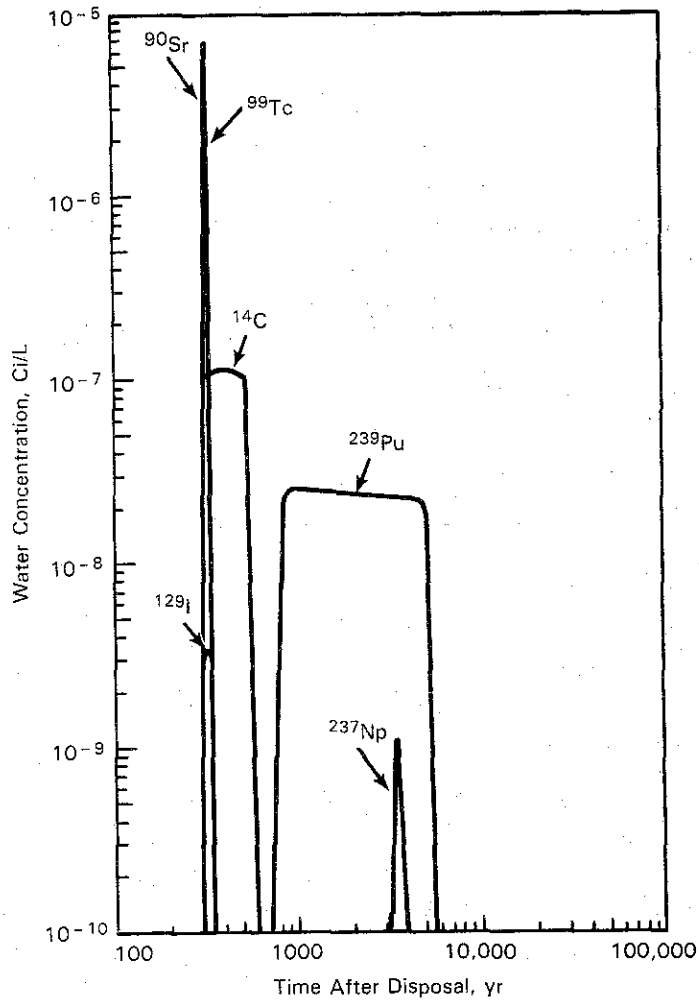

FIGURE R.10. Water Concentration of Selected Radionuclides in Well from 200 West Area Single-Shell Tanks, No Disposal Action (continued storage), **5-cm/yr Recharge**

acute dose, the effects of which are much more certain. Because the potential exists for this scenario to occur more than once, the results are given on the basis of disruption of one community.

R.6 GLACIAL FLOODING

A study performed at Kent State University has examined the potential for ice-age flooding affecting the Hanford Site as a result of climatic changes in the next 10,000 years.(a) The study focuses on evidence for ice-dammed lakes created during various past glacial stages, particularly on the catastrophic releases of impounded water from Lake Missoula, the largest of these lakes. There is considerable documented evidence

(a) Craig, R. G. 1983. "Analysis of Ice-Age Flooding from Lake Missoula." Unpublished report, Kent State University, Kent, Ohio.

TABLE R.68. No Disposal Action Alternative--Individual Maximum Potential Lifetime Dose for the Multiple-Small-Farm Scenario

Waste Form	0.5 cm/yr Recharge						5 cm/yr Recharge					
	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide	Transport Assessment Table	Total-Body Dose, rem	Critical Organ	Critical Organ Dose, rem	Time, Years After Disposal	Dominant Nuclide
200 East Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.5	2×10^1	GI-LLI	2×10^3	1,300	^{99}Tc	Q.15	4×10^5	Bone	2×10^6	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Existing Double-Shell Tanks												
Tank Residuals	Q.5	3×10^2	GI-LLI	2×10^4	400	^{99}Tc	Q.15	5×10^5	Bone	2×10^6	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Future Double-Shell Tanks												
Tank Residuals	Q.5	1×10^2	Bone	2×10^3	4,200	^{239}Pu	Q.15	1×10^6	Bone	5×10^6	300	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
Sr/Cs Capsules	--	NR[b]	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--	--	--
RS/NG[c] TRU	--	NR	--	--	--	--	--	--	--	--	--	--
200 West Area Wastes												
Single-Shell Tanks												
Tank Residuals	Q.5	5×10^1	GI-LLI	5×10^3	1,400	^{99}Tc	Q.15	2×10^6	Bone	8×10^6	400	^{90}Sr
Existing Double-Shell Tanks												
Tank Residuals	Q.5	3×10^2	GI-LLI	2×10^4	400	^{99}Tc	Q.15	9×10^6	Bone	3×10^7	400	^{90}Sr
Grouted Process Residuals[a]	--	--	--	--	--	--	--	--	--	--	--	--
TRU-Contaminated Soil	--	NR	--	--	--	--	--	--	--	--	--	--
Pre-1970 TRU	--	NR	--	--	--	--	--	--	--	--	--	--
RS/NG TRU	--	NR	--	--	--	--	--	--	--	--	--	--
600 Area Wastes												
300 Area Burial Sites[d]	--	--	--	--	--	--	--	--	--	--	--	--
300 Wye Site[d]	--	--	--	--	--	--	--	--	--	--	--	--

(a) This waste form does not apply to the no disposal action alternative.
(b) NR = no release calculated for at least 10,000 years.
(c) RS/NG = retrievably stored and newly generated.
(d) Sites are not on the 200 Area plateau and do not contribute to the multiple farm scenario.

TABLE R.69. Potential Radiological Health Effects from the Multiple-Small-Farm Scenario for No Disposal Action Followed by Loss of Institutional Control of the Site

0.5 cm/yr Recharge	5 cm/yr Recharge
10-100	300

for effects of these floods in the Pasco Basin, where it has been estimated that as much as 2,000 km^3 of water flowed through in a period of a few weeks.

The Kent State study is based on a link between climatic variability and variations in the orbital parameters of the earth. The global volume of ice is related to orbital variability through various modeling techniques.

Based on current modeling techniques and current data, the Kent State study predicts three major continental glaciations within the next 100,000 years. None of these, however, is within the next 10,000-year period. The first major continental glaciation is not predicted to begin for about 15,000 years and is not expected to be of sufficient magnitude and duration to significantly affect the Hanford Site by catastrophic flooding from a recurrence of glacial Lake Missoula. Glacial flooding is not, therefore, considered in this EIS as a release event for the disposal alternatives within the next 10,000 years.

During previous ice ages, ice dams on upper tributaries of the Columbia River have formed and, when the dams broke, resulted in floods almost unimaginably large--about 2,000 km^3 of water in a period of a few weeks (Baker 1973) compared to the present average annual flow of the Columbia River of about 100 km^3/yr. Studies conducted in support of this EIS effort suggest that recurrence of the advance and retreat of ice flows sufficient to result in catastrophic floods of this magnitude might arise 40,000 to 50,000 years from now.

In the 40,000 to 50,000 years time frame (Craig and Hanson 1985) predicted for recurrence of these glacial floods, the total inventory of wastes included in this EIS will have decayed to a hazard index about one-fifth of the hazard index of the uranium ore from which the wastes originally came. While the radioactive decay has reduced the hazard from these wastes markedly by the time of the postulated glacial flood, a study was initiated to determine whether the fate of the waste following such a flood can be estimated. Results of this study (Craig and Hanson 1985) indicate that the first wave of such a flood could reasonably scour out the waste sites to a considerable depth; and, as flood waters backed up at Wallula Gap and the water velocity decreased markedly, the sediments and wastes would probably be reworked, and then be redeposited within the Pasco Basin.

If all of ^{239}Pu (the radionuclide of principal interest at 40,000 years after disposal) in the scope of this EIS were entrained uniformly in just the upper 4 m of the sediments of the 6 km by 13 km waste disposal area, the resulting concentration of ^{239}Pu would be about 0.05 nCi/g. The lifetime dose one might receive if residing on such sediments once the waters had receded would be about 0.3 rem. This may be compared to 7 rem the individual

would have received from natural background. If larger areas of scour and reworking of sediments were involved, as they reasonably might be, this concentration would be further reduced. Because of the low residual hazard index of the wastes and the low concentrations of plutonium, the radiological consequences of a glacial flood would not appear important in contrast to the effects of the flood itself.

R.7 OTHER SURFACE FLOODING

Three statistical floods described in a Corps of Engineers publication (1969a) have been considered along with three catastrophic floods due to failure of Grand Coulee Dam (ERDA 1976). One of the Grand Coulee floods is due to earthquake damage; the other two result from nuclear detonations on the dam. The peak flows resulting from each of these flood types are summarized in Table R.70.

TABLE R.70. Summary of Peak Flow Rates for Various Types of Floods at the Hanford Area, m^3/sec

Flood Type	Regulated Flow	Unregulated Flow
Columbia River:		
100-Year Flood	13,000	--
Standard Project Flood	21,000-40,320	--
Probable Maximum Flood	41,000	88,480
25% Grand Coulee Failure	--	150,000
50% Grand Coulee Failure	--	227,000
Yakima River:		
100-Year Flood[a]		1,600
Probable Maximum Flood		45,000
Cold Creek:		
100-Year Flood[b]		580
Probable Maximum Flood[b]		2300

(a) Seattle District Corps of Engineers.
(b) Skaggs and Walters 1981.

Based on a review of available literature and correspondence from the Corps of Engineers (1969b) concerning Columbia River floods, the following discussion addresses three possible events: 1) the 100-year flood; 2) the standard project flood (SPF); and 3) the probable maximum flood (PMF).

The 100-year flood was developed based on historical annual peak-flow data that were used to compute a peak-flow frequency curve of 13,000 m^3/sec with an average recurrence interval of 100 years. The flow includes adjustments to reflect regulation by projects completed by 1975 and a 1985 level of irrigation development (Corps of Engineers 1969b).

Both the SPF and PMF are similar to the annual spring floods of the Columbia River, caused primarily by snow melt. The SPF derivation combines the most severe conditions reasonably characteristic of the Columbia River Basin. The PMF derivation considers the most severe conditions thought reasonably possible. The following basic assumptions were included in both derivations: 1) exceptionally cold and wet weather occurs during the 7-month season of snow accumulation from October to April; 2) nearly all precipitation falls as snow and remains in natural storage until spring melting; 3) unusually rapid melt rates occur during May and June over the entire basin; and 4) two basin-wide rainstorms occur during the snow-melt period--one in mid-May and the other in early June (Corps of Engineers 1969a). The flood data were developed for the lower Columbia River, and hydrographs were predicted for upstream stations. Only the PMF with an unregulated peak flow of 88,480 m^3/sec and a regulated flow of 41,000 m^3/sec was determined for the Hanford area (Corps of Engineers 1969a and ERDA 1976).

An SPF flow of 21,000 m^3/sec for the Columbia River near Hanford was obtained from a Corps of Engineers report (1969a) on the then-proposed Ben Franklin Dam. This is a regulated flow with a return period of one in 500 to 1000 years.

Catastrophic flooding for downstream communities would result if Grand Coulee Dam failed. The ERDA (1976) report hypothesizes three conditions under which Grand Coulee Dam might fail: 1) earthquake damage to the dam; 2) a 25% failure of the dam due to a nuclear detonation in time of war; and 3) a 50% failure of the dam due to nuclear detonation in time of war. (Effects of the detonation of nuclear weapons would be expected to have additional far-reaching effects.)

Earthquake damage is not believed to result in sufficient failure to cause flooding as severe as from a 25% breach caused by a nuclear detonation. It has also been noted that for flooding with respect to dam failure, earthquakes represent historically the smallest percentage of failures (Leonhart 1980). Floods due to breaches in Grand Coulee caused by a nuclear detonation are attributed to instantaneous vaporization of the dam's center section. The destruction of 25% of the section would result in a flow of about 150,000 m^3/sec at the 100 Areas; a 50% destruction would result in a flow of 227,000 m^3/sec.

The locations and elevations of the disposal areas were determined using U.S. Geological Survey (USGS) topographic maps. Backwater profiles for each flood event were plotted versus river mile. Stage-discharge rating curves were developed at selected cross-section locations near the present waste areas. The competent flow velocity near the channel bed was then estimated and compared with the velocity necessary to erode a particular area. The various flood events were compared in terms of river-water surface profiles and ground elevations of Hanford sites. It was determined that the 200 Areas are at sufficient elevations to be safe from even the 50% breach of Grand Coulee Dam.

Flooding by a rise in sea level is not considered a plausible event for the Hanford Site. Rise and fall of worldwide sea level has been well documented over the past 2 million years. These changes have occurred generally with the advance and retreat of the world's ice sheets and ice caps and have a general time span of 10^5 yr, with sea level changes of up to

±100 m (Scott et al. 1979). Present sea level has been essentially stable for the last 3,000 to 5,000 years, following a rise after the ebb of the Wisconsin glacial stage, about 17,000 years ago. The present time is generally considered interglacial; if a sea-level change occurs in the future, it will most likely be a decrease as ice builds up again on land. It has been estimated (John 1979) that if the Antarctic and Greenland ice sheets melted, worldwide sea level would rise approximately 75 m. This would pose no threat from surface flooding to the 200 Areas plateau or to the Hanford Site in general, which is 150 m or more above present sea level. Flooding of the 618-11 and 618-1 and 2 sites would occur, however [see footnote (a) in Table R.66].

Lands along the southernmost boundary of the Hanford Site near Horn Rapids on the Yakima River could be subject to flooding by a 100-year flood on the Yakima River. However, these flood waters would not reach to the 200 Areas where defense wastes would be disposed of under the alternatives in this EIS. The Yakima River upstream from Horn Rapids is physically separated from the Hanford Site by Rattlesnake Mountain. This topographic barrier prevents potential floods of the Yakima River from reaching the 200 Areas.

The 200 Areas lie within the Cold Creek watershed. The drainage system within the watershed may be described as ephermeral and discontinuous. This means that the stream flows only in direct response to precipitation events (i.e., it receives no contribution from discharging groundwater or sustained snowmelt runoff). Further, for most runoff events, the water within the channel infiltrates within a given distance of the flow. Cold Creek, trending northwest to southeast, is the only defined channel within the southeastern portion of the watershed. This channel passes within about 2 mi of the southwest corner of the 200 West Area. The potential for flash floods along Cold Creek, southwest of the 200 West Area is identified in the BWIP Environmental Assessment (DOE 1986b). The peak of the probable maximum flood is identified as flooding a small portion of the southwestern corner of the 200 West Area. This area has not been specified for permanent disposal of defense wastes in this EIS.

Because of the location of the waste within the scope of this study, flooding other than that associated with glacial melt is not considered a plausible release event for any of the three disposal alternatives or for the no disposal action (continued storage) alternative.

Surface streams are a means of moving surface material; however, stream erosion in general is not considered a disruptive process for the Hanford Site. No perennial streams occur in the area, and even with a climatic change of two to three times the present annual precipitation, the area is not likely to develop an integrated drainage system or to support perennial streams. The generally unconsolidated soil material and depth of the water table over most of the Hanford Site are believed to prevent the formation of streams. The potential for surface stream formation is discussed in Appendix Q.

R.8 WIND EROSION

Both erosion and deposition of soils occur on the Hanford Site as a result of wind. On sites considered for waste disposal, erosion of surface covering is slight. Even when the

rate of wind erosion is temporarily high during windstorms, the amount of fine-grained material removed is limited by the formation of lag concentrates from coarser material. This "armoring effect" is quite stable and tends to prevent further wind erosion unless the surface is disturbed, after which another armored surface begins to form. Wind action can also fill depressions and deposit material as effectively as it removes it.

Denudation is the total of all processes, including continuous wind and water action, that reduce land surface relief. Rates of denudation are generally estimated by sediment sampling from rivers in a given drainage basin. Tubbs (in Scott et al. 1979) cites evidence of a total denudation rate for a drainage basin tributary to the Columbia River in the Pasco Basin of about 0.25 cm/100 years (0.025 mm/yr) and suggests that a small drainage basin tributary to the Columbia River in the Pasco Basin might have a denudation rate of about 0.5 cm/100 years (0.05 mm/yr).

There are no definitive estimates to separate effects of wind erosion from these estimated denudation rates. Because they include the effects of stream erosion, and because erosion is not an effective process on the Hanford Site, 0.025 mm/yr is used for an estimated rate for wind erosion. Assuming this rate were to continue for 10^4 yr, the land surface would be lowered by only 25 cm.

The Hanford record of tornados occurring in this area indicates they are rare events, and those observed have been small with little effect on soil surface. A tornado touched down near the east end of Rattlesnake Hills on June 16, 1948 (Stone et al. 1983). Funnel clouds were also observed in 1961 to the south-southeast and in 1970 to the south-southwest of Rattlesnake Mountain. So-called dust devils are frequently seen over plowed fields and burned-over areas in the region but would not be significant in terms of wind erosion in the 200 Areas.

Because of the estimated low rate of wind erosion and rather large depth to waste horizons, tornados are not considered a plausible release event for any of the disposal alternatives. Even for no disposal action (continued storage), where additional protective measures are not implemented, no release can reasonably be postulated. The disposal alternatives provide additional barriers and further assurance against releases; waste in a geologic repository would be unaffected. Wind erosion is not seen as a discriminator for choice among the waste disposal alternatives. However, because there is no quantitative measure of erosion rates at the area of interest, additional research on selection of soils, rock armoring and vegetative cover is needed and planned under the protective barrier development plan (see Section M.7).

R.9 MAGMATIC ACTIVITY

Magma is mobile molten rock generated within the earth, and it may be intruded into other rock or extruded onto the surface of the earth. Magmatic activity resulting from this mobility is discussed for the following three cases.

1. Basalt Flows. The Hanford Site is located in the north-central part of one of the largest known continental accumulations of basaltic lava flows. The flows are

plateau-type features and are believed to have been emitted between 14 and 18 million years ago, with the most recent about 6 million years ago (Caggiano and Duncan 1983). If future basalt flows of a similar type were to occur, they would be more likely to further isolate the waste than form a release mechanism, unless the fissures open in the Pasco Basin instead of farther east as in the past.

2. Volcanism. A different type of magmatic activity is the more violent, and sometimes explosive, activity that produces volcanic peaks or cones. A number of these volcanos exist in the Cascade Mountains, a few hundred kilometers west of the Hanford Site. The molten rock associated with this activity is often more viscous, allowing pressure to build up and release in a spectacular and explosive way as demonstrated by the 1980 eruption of Mt. St. Helens.

   Volcanos, generally formed by a more locally restricted conduit than the linear fissures that yield flood basalts, can cause considerable destruction to nearby areas. Eruptions may scatter ash and rock particles over a wide area. Volcanoes are generally associated with growing mountain ranges, island arcs along crustal plate margins, or large faults that extend to molten-rock reservoirs.

   The Cascade Range volcanos closest to the Hanford Site are Mount Adams, 160 km west-southwest, and Mt. St. Helens, 220 km west-southwest. A major eruption of St. Helens on May 18, 1980, resulted in about 1 mm of ash fall at the Hanford Site over a 9-hr period. The main ash dispersal plume was to the north; as Hanford was near the southern edge of the plume, it did not receive the maximum effect of ash fallout. It has been estimated that if the axis of the main downwind thickness had been centered over Hanford, the thickness of ash would have been 2.5 to 5 cm.

   Major volcanic effects such as mudflows, avalanches, pyroclastic rock flows, lava flows, and shock waves are generally confined to a relatively local area around a volcano. Because of the distances to the Hanford Site from these nearest volcanos, the only potential hazard to Hanford is believed to be an ash fall from a major eruption of one of these volcanos. Ash falls are not expected to have any significant effect on long-term waste disposal.

3. Igneous Intrusion. A third type of molten rock movement, generally described as igneous intrusion, moves magma from depths toward the earth's surface but without reaching the surface. No igneous intrusions are known to exist within the Hanford Site or its vicinity. This event is not, therefore, considered as a potential waste release mechanism.

None of these types of magmatic activity is believed to lead to plausible release scenarios. In addition, lava flows and volcanism, should they occur, might be beneficial by creating additional cover over waste sites.

R.10 SEISMIC EVENTS

Seismic activity is not believed to be a plausible event for directly releasing waste, except in the case of continued storage of tanked waste near the end of tank life. Waste disposed of near-surface is expected to respond to vibratory motion as part of the subsurface. A discussion of seismic activity is provided for completeness (see also Section 4.3).

Seismicity in the Columbia Plateau is attributed to a north-south-oriented compressional stress regime that has resulted in thrust or reverse dip-slip faulting that occurs in east-west-oriented zones (Scott et al. 1979; Smith 1979). The USGS and the University of Washington have monitored earthquake activity in the Hanford region since 1969. Earthquakes recorded at the Hanford Site generally have Richter magnitudes with intensities less than four. These observations are consistent with the historical record of large earthquakes known to have occurred in the Pacific Northwest since 1872. These data indicate that historically most large earthquakes have occurred at distances greater than 200 km from the Pasco Basin.

Work performed to establish seismic design criteria for nuclear reactors of Hanford (Blume and Associates 1971; NRC 1982) provides conservative estimates of the maximum credible earthquake associated with a known geologic structure on the Site. Blume and Associates (1981) estimated that a reasonably conservative design basis earthquake would be an earthquake located at the northwest end of the Rattlesnake-Wallula zone of deformation, with a Richter magnitude of 6.8 and which would result in a 0.25-g acceleration on the Hanford Site. For a similar earthquake, a magnitude of 6.5 was estimated (NRC 1982). The largest earthquake not associated with a fault structure is estimated to be a replicate of the 1936 Milton-Freewater earthquake and of magnitude 5.75 (NRC 1982). This event, designated as the Hanford Regional Historic Earthquake, had a peak horizontal ground acceleration of 0.10 (Blume and Associates 1981) and is assumed to be able to occur in the vicinity of the Site. Wight (Scott et al. 1979) calculated that the annual probability of the maximum ground acceleration exceeding 0.20 g in the area is 10^{-4}. Over a 100-year period from the year 2000, the probability of sites, tanks, or repositories being subjected to vibratory motion is 10^{-2}.

Blume and Associates (1978) performed a seismic analysis of the 241-AX tank structures, using a 0.25-g maximum horizontal ground surface acceleration. This level of acceleration corresponds to the Hanford Site Shutdown Earthquake (SSE). The analyses reported the combined effect of dead, thermal, hydrostatic and seismic loads and indicate that the tanks can withstand the SSE with the existing 2.1 m (7 ft) of soil cover (DeFigh-Price 1982). Dahlke and DeFigh-Price (1983) examined expected failure modes for the waste tanks. They concluded that the tanks were found to have an adequate margin of safety against failure, given present and planned future operating limits plus the SSE, but suggested that large soil overburdens, or excessive heat together with the occurrence of the SSE, might lead to structural failure. The low probability of SSE-type ground accelerations together with the addition of dome fill, to mitigate subsidence or collapse, suggest that seismic activity in itself is not a plausible scenario for the direct release of waste.

Reservoir-induced seismicity (earthquake activity caused by loading of the land surface with water and sediment in the pool behind a dam) is not yet a widely accepted concept. It has, however, been examined for the Priest Rapids Dam and Reservoir as the nearest impoundment to Hanford that might be capable of triggering seismic activity.

In general, observations have shown that reservoir-induced seismicity (RIS) appears only with deep and/or large reservoirs, although at many large or deep reservoirs no significant changes in seismic activity have been noted (Leonhart 1980). Priest Rapids Dam and Reservoir are significantly smaller than those reported to have RIS. Partly because of a lack of historical baseline data for Priest Rapids, RIS effects cannot be ruled out completely. However, from comparison with case studies reported in the literature, it seems that the probability of any associated significant seismic activity, as well as any event of significant magnitude, is low (Leonhart 1980).

Historical observations and instrument recordings indicate that the Hanford Site is an area of relatively low seismicity compared to the rest of eastern Washington. Seismicity in the Central Columbia Plateau, which includes the Pasco Basin and the Hanford Site, is generally confined to a thin 28-km crust. It is characterized by temporally and spatially limited swarms of low magnitude (less than 3.5), shallow (less than 6-km depth) earthquakes (Caggiano and Duncan 1983). Deep earthquakes (greater than 6-km depth) do not appear to be related to shallow events and generally occur as single events. Earthquakes in the central Columbia Plateau are currently not associated with known faults, nor does their alignment suggest unmapped faults.

Other seismic related phenomena such as liquefaction, fault rupture and subsidence have been investigated at specific sites over much of the Hanford Site. NRC (1982), in their Safety Evaluation Report on the WPPSS No. 2 plant, found "no areas of actual or potential subsurface uplift, subsidence, or collapse,...or structural weakness that could adversely affect plant safety" and "that the foundation soils are not potentially liquefiable." Bechtel (1970) found that "the underlying dense sand" (beneath FFTF) would "make a very suitable foundation for supporting heavy foundation loads" as "evident from the excellent performance of structures founded on the glaciofluvial materials elsewhere at Hanford." They also found that "the high relative density combined with the great depth to the groundwater table eliminates the possibility of liquefaction." Thus, seismic-related phenomena are also not considered plausible release scenarios for the waste.

R.11 CRITICALITY

Because of relatively large quantities of plutonium in some wastes, the possibility of a criticality event was investigated. However, there appears to be no credible basis for a criticality event among wastes disposed of in accordance with alternatives addressed in this EIS (Wallace et al. 1980).

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APPENDIX S

PROBABILITY AND CONSEQUENCE ANALYSIS OF RADIONUCLIDE RELEASE AND TRANSPORT AFTER DISPOSAL

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APPENDIX S

PROBABILITY AND CONSEQUENCE ANALYSIS OF RADIONUCLIDE RELEASE AND TRANSPORT AFTER DISPOSAL

The methods and results of the probability and consequence analysis performed for this EIS are presented in this appendix. The purpose of this analysis is to evaluate the comparative risks of the proposed alternatives on the basis of risk assessment methods used by the U.S. Environmental Protection Agency (EPA) in 40 CFR 191. There is insufficient information to make any absolute risk analysis and comparison with EPA levels in this document. The only purpose for comparing the relative risk of this analysis with EPA levels is to provide perspective on the levels derived from the very rough assumptions used. The basic advantage of a probabilistic approach is that the probabilities of events occurring and their consequences are taken into account together and thus give a broader perspective of the performance assessment than a consequence analysis by itself. In general, the larger consequences have a lower probability of occurrence; hence, a large consequence will not necessarily constitute a significant risk (where risk is defined as the product of the consequence and its probability). A range of events and their consequences is considered in this appendix along with a treatment of variability in important parameters.

In this appendix a preliminary analysis is made of the three disposal alternatives and the no disposal action alternative with respect to the EPA's standard for disposal systems (40 CFR 191). The preferred alternative presented in this EIS adopts the reference alternative for double-shell tank waste, encapsulated strontium and cesium, retrievably stored TRU waste and the 618-11 site, and will elect waste disposal action within the range of the reference or geologic disposal alternatives for the remaining waste classes following additional development and evaluation. Therefore, a probability and consequence analysis for the preferred alternative would yield results that would fall between those of the reference and geologic disposal alternatives. Since no confirmed statistical basis is available for such key parameters as retardation coefficients for nuclide transport in soils and barrier performance parameters, it is necessary to assume such values in order to perform the probability and consequence analysis called for in 40 CFR 191 (EPA 1985).

The analysis performed here assumes that all of the waste classes included in this EIS are subject to the release provisions of the EPA standard. While this is not the case, this approach permits comparison of the impacts of near-surface disposal activities of each of the alternatives. Until more experimental data are available, such calculations as those shown in Appendix S are useful for illustration of the relative features of each disposal alternative. They are not intended, however, to be used to demonstrate compliance, or lack thereof, with the EPA standard.

The analysis compares the disposal alternatives and the no disposal action (continued storage) alternative (see Chapter 3 for descriptions of alternatives) by calculating a release-consequence/probability curve for each alternative, and is essentially that called

for in EPA's standard for protection of the environment from disposal of high-level and TRU waste (Subpart B of 40 CFR 191). All waste classes are included in the analysis as though the standard applied to them. Only those wastes that are disposed of near surface are considered; hence, any wastes sent to a geologic repository or WIPP are not included in the analysis (see Section 5.1.4 for a discussion of repository disposal). This analysis calculates the radionuclide release-ratio consequences (over a 10,000-year time period) as called for by the EPA's 40 CFR 191.13 containment standard, which is described in Section S.1. The variability of the consequences as a function of the variability of assumed parameter values is included. In some cases (such as barrier performance) no experimental data are available at this time. Assumptions are made on the distributions of parameter values. The limits of the assumed distributions are based on engineering judgment.

Two mechanisms for radionuclide release and transport to the accessible environment were considered: 1) release of radionuclides through diffusion and/or leaching (with and without failure of the protective barrier) followed by their advection through the unsaturated zone to the groundwater, and 2) exploratory drilling that brings the radionuclides to the land surface. The scenarios are described in Section S.2. The corresponding mathematical models for calculating the amount of radionuclides released to the accessible environment for each release mechanism are described in Sections S.3 and S.4. The probabilistic and statistical methods are described in these same sections. The geohydrologic models for release by both leaching and diffusion are described in detail in Appendices P and Q. A hypothetical failure of the protective barrier described in Appendix M is also included in the analysis.

The results of the probability and consequence analysis are displayed and discussed in Section S.5; and the results of a sensitivity analysis are presented in Section S.6. Although more data would be required to develop probability density functions for the key parameters, the preliminary probability density functions (as well as the postulated scenarios and models) are the same for all the disposal alternatives; hence, the results of this analysis should provide a valid relative comparison of the disposal alternatives.

In summary, this preliminary analysis shows that both the reference alternative and the in-place stabilization and disposal alternative would meet EPA standard 40 CFR 191.13 under the assumed conditions, even when the protective barrier failure scenarios are considered. The geologic disposal alternative can meet the EPA standard 40 CFR 191.13 with the release-limit allocation allowed in Note 4 to Table 1 of 40 CFR 191, even if the postulated barrier failures are included. Table S.7 gives the summary results numerically, and Figure S.10 shows the results graphically.

The EPA standard clearly is not applicable to the no disposal action alternative; however, it is illustrative when comparing the no disposal action alternative to the three disposal alternatives. The no disposal action alternative does not meet EPA standard 40 CFR 191.13 under any of the assumed conditions or scenarios.

S.1 RELEASE-RATIO CONSEQUENCE

The release ratio for each radionuclide in a disposal system is its activity (expressed in curies) postulated to reach the accessible environment over the next 10,000 years divided by the activity (expressed in curies) established by the 10,000-year cumulative release limit in EPA standard 40 CFR 191.13. The release-ratio consequence is then the sum of all individual radionuclide release ratios. The consequence guideline in the EPA standard requires that the release-ratio consequence should not exceed a value of 1 with a probability of more than 0.1 (the 90th percentile) and should not exceed a value of 10 with a probability of more than 0.001 (the 99.9 percentile, the low-probability part of EPA standard 40 CFR 191.13).

The release-ratio consequence, C_A, for each disposal alternative A (A = alternative index) is expressed mathematically by:

$$C_A = \sum_{n=1}^{N} RQ_{n,A}/RL_{n,A} \qquad (S.1)$$

where $RQ_{n,A}$ is the accumulated activity in curies of radionuclide n reaching the accessible environment over the next 10,000 years (see Section S.3 for details) and $RL_{n,A}$ is the nth radionuclide's release limit in curies for alternative A. N is the total number of radionuclides in the waste that are modeled. Eleven radionuclides were used for this analysis (N = 11). The selection of the eleven radionuclides was based primarily on the inventory of each radionuclide divided by its release limit (i.e., the inventory-to-release-limit ratio). The radionuclides corresponding to the ten largest inventory-to-release-limit ratios were selected, and ^{129}I was also included because it is highly soluble and transportable. The eleven radionuclides therefore are ^{90}Sr, ^{137}Cs, ^{151}Sm, $^{239\text{-}240}Pu$, ^{241}Am, ^{63}Ni, ^{14}C, ^{238}U, ^{93}Zr, ^{99}Tc, and ^{129}I. The radionuclides that were omitted from this analysis are not expected to contribute significantly to the release-ratio consequence over the next 10,000 years. This expectation is based on the assumption that at least one of the following statements is true: the inventories of the remaining radionuclides are small relative to their allowed release limits; their high retardation factors cause their travel times to the groundwater to be greater than 10,000 years; or their radioactive decay half-lives are short compared to their travel times.

The release limits for the reprocessed irradiated fuel throughput used in this EIS are based on approximately 94,000 metric tons of heavy metal (MTHM), before processing, represented in existing waste and 12,000 MTHM projected for future waste. Release limits in curies are calculated for each radionuclide based on Table 1 of EPA standard 40 CFR 191, the fuel throughputs, the fuel burnup, and the amount of radionuclide inventory that is disposed of near surface on site for each disposal alternative.

For the reference and the geologic disposal alternatives, the majority of the radionuclide inventories are disposed of in a geologic repository. The EPA release limits for the

radionuclides disposed of near surface in these two disposal alternatives are lower than for the other alternatives when the release limits are proportioned by the amount of inventory disposed of on site.

The release limit, $RL_{n,A}$, for each radionuclide, n, for each alternative, A, is calculated by the following equation:

$$RL_{n,A} = TB1_n \times Bu \times (kMTHM_e \times eFRAC_{n,A} + kMTHM_f \times fFRAC_{n,A}) \quad (S.2)$$

where $TB1_n$ = the release limit from Table 1 of 40 CFR 191 for each radionuclide n per 1,000 MTHM of fuel throughput

Bu = burnup correction factor = 5,000 MWd/30,000 MWd = 1/6 (see Note 3 of 40 CFR 191; 5000 MWd is the designated burnup for low-burnup fuels)

$kMTHM_e$ = number of thousand MTHM already processed and existing (e) as waste at Hanford

= 94; i.e. 94,000 MTHM in existing waste

$kMTHM_f$ = number of thousand MTHM projected to be processed in the future (f) at Hanford

= 12; i.e., 12,000 MTHM in future waste

$eFRAC_{n,A}$ = existing inventory of radionuclide n disposed of by alternative A (Tables P.19 to P.22) divided by the total existing inventory of radionuclide n before disposal (Table P.18); i.e., the fraction of existing waste that will be disposed of near surface on site by disposal alternative A (see Equation S.3).

$$eFRAC_{n,A} = \frac{eQ_{n,A}}{eTQ_n} \quad (S.3)$$

where $eQ_{n,A}$ = existing inventory (Ci) of radionuclide n disposed of by disposal alternative A

eTQ_n = total existing inventory (Ci) of radionuclide n before disposal

$fFRAC_{n,A}$ = projected future inventory of radionuclide n to be disposed of by alternative A (Tables P.19 to P.22) divided by the total future inventory of radionuclide n before disposal (Table P.18); i.e., the fraction of future waste remaining on site by disposal alternative A (see Equation S.4).

$$fFRAC_{n,A} = \frac{fQ_{n,A}}{fTQ_n} \qquad (S.4)$$

where $fQ_{n,A}$ = future inventory (Ci) of radionuclide n disposed of by alternative A
fTQ_n = total future inventory (Ci) of radionuclide n before disposal.

Both the existing and future inventory-remaining fractions defined above are all equal to 1 for the no disposal action and the in-place stabilization and disposal alternatives. For these alternatives all radionuclide inventories remain near surface on site. Hence, these alternatives use the "total" release limits, which are not "partitioned." The radionuclide inventory fractions for the geologic disposal and reference alternatives are shown in Table S.1. The radionuclide inventory-remaining fractions shown in Table S.1 are used in Equation (S.2) to calculate the "partitioned" release limits for each radionuclide in the geologic disposal and reference alternatives. The inventory-remaining fraction of each radionuclide is directly proportional to the "partitioned" release limit for each. The partitioned release limits were motivated by Note 4 of the 40 CFR 191, which states that a different release limit allocation scheme may be used. The calculated release limits for each radionuclide for each alternative are shown in Table S.2.

TABLE S.1. Fractions of Existing and Future Radionuclide Inventories Disposed of Near Surface for Geologic Disposal and Reference Alternatives

		Geologic Disposal		Reference (combination disposal)	
n	Radionuclide	$eFRAC_{n,A=1}$	$fFRAC_{n,A=1}$	$eFRAC_{n,A=2}$	$fFRAC_{n,A=2}$
1	^{90}Sr	0.029	0.006	0.53	0.034
2	^{137}Cs	0.010	0.03	0.29	0.081
3	^{151}Sm	0.045	0.006	0.81	0.031
4	$^{239\text{-}240}Pu$	0.017	0.009	0.72	0.02
5	^{241}Am	0.029	0.009	0.72	0.048
6	^{63}Ni	0.051	0.001	0.93	0.001
7	^{14}C	1.0	1.0	1.0	1.0
8	^{238}U	0.046	0.75	1.0	0.75
9	^{93}Zr	0.053	0.032	1.0	0.075
10	^{99}Tc	0.037	0.034	1.0	1.0
11	^{129}I	1.0	1.0	1.0	1.0

The burnup correction factor (Bu= 1/6) effectively reduces the existing fuel throughput from 94,000 MTHM to about 16,000 equivalent MTHM (eMTHM), and the future fuel throughput from 12,000 MTHM to 2,000 eMTHM (i.e., 18,000 eMTHM in total) for calculating the EPA release limits. The burnup correction factor used here is based on 5,000 MWd, the value permitted by

TABLE S.2. **40 CFR 191 Table 1 Values and Partitioned Release Limits** (Equation S.2) **for Each Radionuclide Disposed of Near Surface for Each Alternative, Ci**

n	Radionuclide	40 CFR 191 $TB1_n$	Geologic Disposal $RL_{n,A=1}$	Reference (combination disposal) $RL_{n,A=2}$	In-Place Stabilization and Disposal $RL_{n,A=3}$	No Disposal Action $RL_{n,A=4}$
1	^{90}Sr	1,000	470	8,300	18,000	18,000
2	^{137}Cs	1,000	210	4,750	18,000	18,000
3	^{151}Sm	1,000	720	12,500	18,000	18,000
4	$^{239\text{-}240}Pu$	100	28	1,100	1,800	1,800
5	^{241}Am	100	47	1,100	1,800	1,800
6	^{63}Ni	1,000	800	14,500	18,000	18,000
7	^{14}C	100	1,800	1,800	1,800	1,800
8	^{238}U	100	220	1,700	1,800	1,800
9	^{93}Zr	1,000	900	15,800	18,000	18,000
10	^{99}Tc	10,000	6,500	180,000	180,000	180,000
11	^{129}I	100	1,800	1,800	1,800	1,800

the EPA in Note 3 of 40 CFR 191 for low-burnup fuels. Note however, that for assigning eMTHM for purposes of estimating the amount of commercial geologic repository capacity that would be needed for Hanford defense waste, the typical estimated burnup factors should be used. The result is an estimate of 3,100 eMTHM of existing, future and capsule wastes from Hanford to be disposed of in the commercial geologic repository (DOE 1987).

S.2 RADIONUCLIDE RELEASES TO ACCESSIBLE ENVIRONMENT

Based on EPA standard 40 CFR 191, events and processes occurring over the next 10,000 years with probabilities less than 0.0001 are not included in this appendix. Based on Appendix M, the protective barrier and marker system is expected to reduce the probability of large-scale excavation to less than 0.0001 over the next 10,000 years; hence, excavation scenarios were not analyzed here. Only two major release mechanisms were identified by which radionuclides would be transported to the accessible environment. The first of these is the dissolution of the waste source followed by transport to the groundwater. The second is an intrusive one by which the radioactive materials are brought to the surface by drilling.

Two sets of scenarios were chosen for the annual recharge (infiltration) to the groundwater. One set of scenarios assumed that the current climate would remain about the same for the next 10,000 years, and the second set of scenarios assumed that the climate would change to a wetter climate for the next 10,000 years. Because of the expected orbital changes of

the earth, a significant change in the climate (i.e., a glacier) is not expected for the next 10,000 years.[a] However, for "what-if" purposes, a change to a wetter climate by the year 2500 was assumed for some scenarios.

For this analysis, the annual recharge under the 200 Area soils with no vegetation, with the current climate, was assumed to have a median value of 1.5 cm. A log-normal probability density function (pdf) was assumed for the current climate's annual recharge under unvegetated soils, with an assumed median value of 1.5 cm and an assumed range of 0.0 to 5 cm. In effect, the assumed pdf gives the current climate annual recharge some variability, which can be a result of the variability in rainfall and in soil/vegetation conditions.

According to Fayer, Gee, and Jones (1986, Table B.2 and B.3), the recharge rates can approach zero in the 200 Area if the soil surface is vegetated and can approach 1.3 cm/yr if the soil is not vegetated. However, the annual recharge can approach 12 cm/yr (Fayer et al. 1986, App. A) for unvegetated gravel-covered soil sites at the tank farms. Hence, the simulations performed here do not use conservative annual recharges for the tank waste under the no action alternative, but do use conservative recharge values for other waste classes and for the disposal alternatives. The pdf for annual recharge assumes that the current climate and the current soil/vegetation conditions with their existing variability will stay about the same for the next 10,000 years. The wetter climate's average annual recharge under the same soil/vegetation conditions was given a much higher assumed median value of 5 cm and a higher assumed range of 1.5 cm to 15 cm. The sampled values from the current climate's annual recharge pdf are shown in Figure S.1 as the sampled pdf. The sampled values from the wetter climate's annual recharge pdf are shown in Figure S.2 as the sampled pdf.

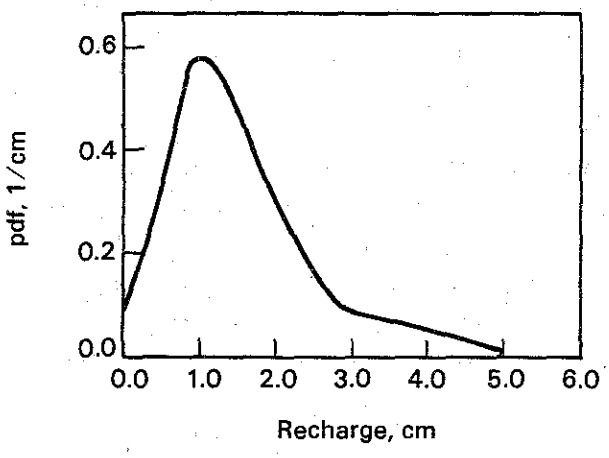

FIGURE S.1 Assumed Probability Density Function of Annual Groundwater Recharge of Current Climate for the Next 10,000 years

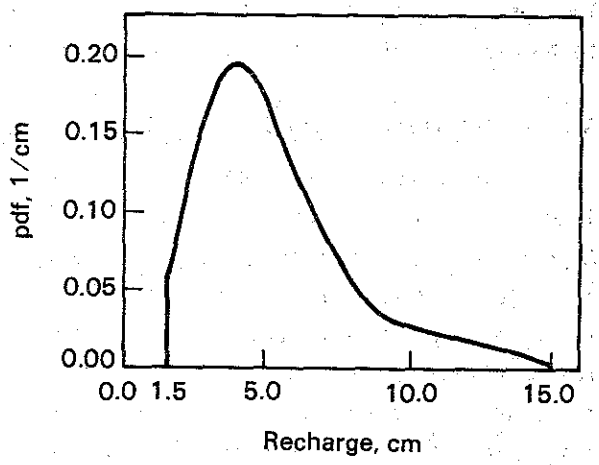

FIGURE S.2. Assumed Probability Density Function of Annual Groundwater Recharge of Wetter Climate for the Next 10,000 years

(a) R. G. Craig. 1983. "Analysis of Ice-Age Flooding from Lake Missoula." Unpublished report, Kent State University, Kent, Ohio, cited in this chapter as Craig 1983.

For the no disposal action (no barrier), and in the assumed absence of active institutional control (an assumption employed to permit parallel analysis with the disposal alternatives), waste storage sites would be monitored and the projected releases to the accessible environment would occur. The radionuclides are postulated to begin leaching out of the disposal sites in the year 2150. Although tanks are expected to remain substantially intact for several centuries, they are assumed in this analysis to admit water freely by the year 2150 if no protective barrier is used.

In the case of the other alternatives, which all have the protective barrier, two sets of scenarios are hypothesized. The first set of scenarios assumes that water never penetrates the protective barrier; i.e., the protective barrier is assumed to preclude infiltration of water to the waste. For the scenarios with perfect barrier performance, the waste is assumed to diffuse out to the edge of the protective barrier and then to be transported to the groundwater by advection. The second set of scenarios concerning barrier performance assumes that the protective barrier fails in the year 2500. The hypothetical barrier failure model has two probability density functions; one pdf is for the annual recharge under the area where the barrier fails and the other pdf is for the fraction of the waste area affected by the barrier failure.

Although no data are available on barrier performance, it was assumed to fail in the simulations for both the current climate and the wetter climate. A bimodal pdf was constructed that has two uniform sections whose areas represent the probabilities of the barrier failures that allow infiltration of water. The two barrier failure modes described in Appendix M were modeled here with variability. A functional barrier failure with the current climate (represented by the lower section of the two-step pdf) has a median recharge value of 0.05 cm/yr and an integrated probability of 0.95. The disruptive barrier failure (represented by the high section of the pdf) has a median recharge of 7.5 cm/yr with an integrated probability of 0.05. Under wetter climate conditions the medians are increased to 0.1 and 15 cm/yr for the functional and disruptive failures, respectively; the integrated probabilities of barrier failures with a wetter climate were assumed to be the same as those of the current climate.

The pdf (which completes the barrier failure model) for the fraction of the waste area affected by the barrier failure is described in the next section along with the mathematical model. In brief, a log-normal pdf was assumed for the waste area fraction with a range from 0.0 to 1.0 and a median value of 0.08.

The second mechanism considered for releases (to be combined with those above) is human intrusion. Representative human intrusion events include drilling boreholes and excavations. The marker system is assumed to prevent any systematic intrusion, excavation or habitation. If the mitigating effect of the marker system is assumed (Appendix M), then the probability of a major excavation occurring over the waste over the next 10,000 years is less than 0.0001. The 40 CFR 191 guidelines do not require inclusion of events with probabilities less than 10^{-4} over 10,000 years so major excavation was not considered in the probabilistic analysis here.

For the human intrusion mechanism, the accessible environment is the land surface and atmosphere above the waste sites. Of the human intrusion events that could be postulated to occur over the next 10,000 years, the borehole event is considered representative of the more probable events (events with probability of occurrence, over a 10,000-year period, greater than 0.001) and is set forth in the 40 CFR 191 standard. Furthermore, no credit was taken in this analysis for the marker system reducing the probabilities of boreholes (see Appendix M for discussion of reduced numerical values).

Three potentially disruptive scenarios associated with borehole drilling were modeled. Drilling is postulated to occur 100, 400, and 1,000 years after disposal (in the year 2050). The 100-year borehole scenario (2150) is assumed to be very unlikely, with a probability less than 0.0001, and is not directly incorporated into the composite release analysis; the 100-year scenario is used in Section S.5 to illustrate the relatively smaller releases from drilling boreholes compared to the releases from dissolution.

To summarize the scenarios described above, an event tree or probabilistic scenario tree is shown in Figure S.3. The tree shows eight scenarios (S_1 to S_8) for the three disposal alternatives. The eight scenarios are generated by listing all of the combinations of the current or wetter climates, barrier failure or no barrier failure, and 400-year intrusion or 1,000-year intrusion. Each branching point or node requires a conditional probability for each branch segment; the probabilities of all branches from each node (branching point) should add to one. The assumed probabilities for the branch segment are displayed in the parentheses by each branch segment in Figure S.3. These are conditional probabilities since each branch segment in this event tree is conditional on the event represented by the preceding branch segment.

The current climate recharge under unvegetated soil (Figure S.1) was assumed to be nine times more likely over the next 10,000 years than the wetter climate (Figure S.2); hence, the probability values for the current and wetter climates become 0.9 and 0.1, respectively. As stated earlier, based on the earth's expected orbital changes (Craig 1983), a significant change in the climate is not expected for the next 10,000 years. For simulation purposes, however, it was assumed that climate had a 10% chance to get wetter by the year 2500 and to stay that way for an additional 9,500 years. For sensitivity analysis purposes in Section S.6, the wetter climate was given a 90% chance of occurring by the year 2500.

The barrier failure was assumed to have just as great a probability as no barrier failure. Likewise, the 400-year and 1,000-year intrusions were assumed to be just as likely. Hence, the probability value for each of these latter branch segments is 0.5 (see Figure S.3).

The probability of each scenario S_s, that is, $P(S_s)$, is obtained by multiplying all the conditional probabilities of all of the branch segments making up a total branch or scenario. These scenario probabilities are shown to the right of each scenario or total branch and will be used later when the release-ratio curves of the scenarios are combined into a single composite release-ratio curve in Section S.5.

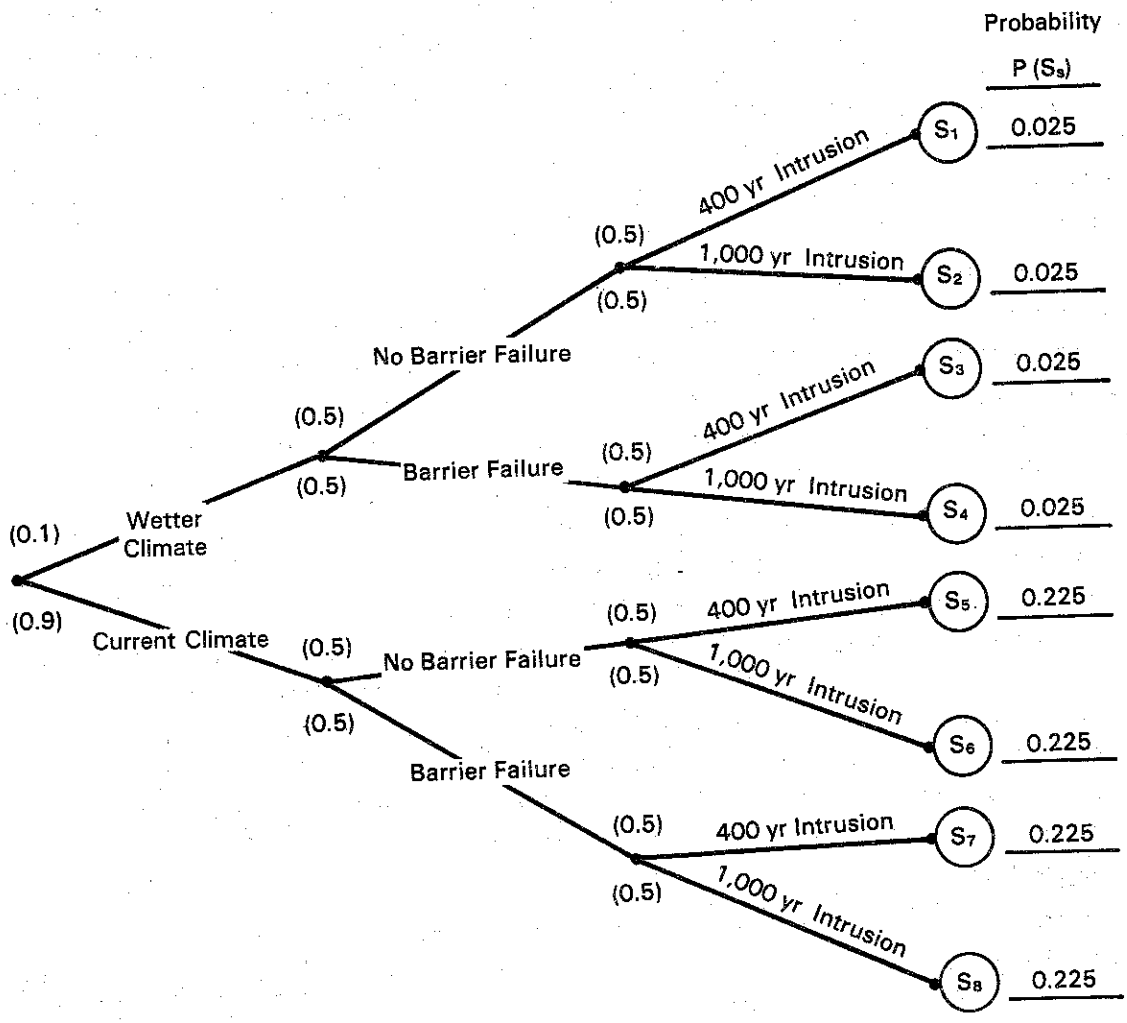

FIGURE S.3. Probabilistic Scenario Tree

S.3 MATHEMATICAL MODEL OF NATURAL RELEASE CONSEQUENCES AND UNCERTAINTY

A Monte Carlo simulation was performed to calculate the distribution of release-ratio consequences due to the natural release and transport of the radionuclides. With this approach, many values of variable or uncertain input parameters are obtained by sampling from the appropriate probability density functions, and the consequences of each set of sampled values of input parameters are realized or calculated by summary performance assessment models. Simplified models are used in lieu of long-running sophisticated models, since many realizations or runs (2,000 for this analysis) are desired to adequately sample the entire parameter space.

Conservative values were used for the parameters whose values are well known and for those parameters not contributing significantly to consequences in each of the 2,000 runs (see Figure S.4). In some instances, parameter values were fixed for all 2,000 runs, e.g.,

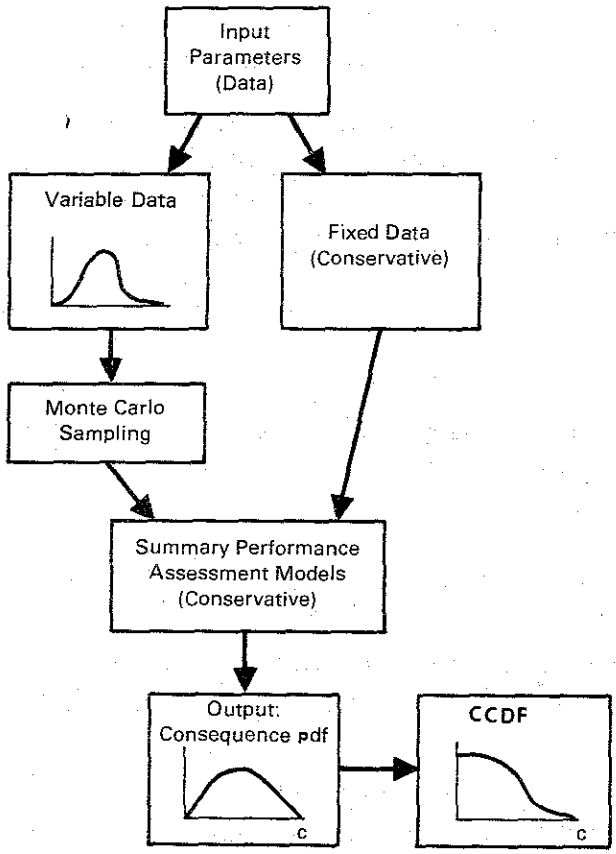

FIGURE S.4. Flow Diagram of Natural Release Simulation Model for Calculating Probabilities and Consequences

the K_d values (set at zero) for ^{14}C, ^{99}Tc, and ^{129}I. The output of the Monte Carlo simulation is a set of consequence values from which a pdf can be generated. From this pdf, a complementary cumulative distribution function (CCDF) or release-ratio curve can be generated. The main steps discussed above are shown in Figure S.4. These steps are explained in more detail later in this appendix.

Radionuclide inventories in the Hanford Site 200 East and 200 West Areas were summed for each waste class for each alternative. The radionuclide inventories for each of the waste classes were then modeled as one radioactive source term for each alternative. As discussed in Appendix Q, the released radionuclides from all the waste sites were assumed to travel nominally 64 m to groundwater. The groundwater (aquifer) was considered to be the accessible environment for this model. The nuclide transport time in the groundwater from the waste disposal site to a distance of 5 km (the location of accessible environment as specified in EPA standard 40 CFR 191) is not considered in this analysis since the groundwater travel time is small in comparison to the travel time from the waste site through the vadose zone to the groundwater. Because the travel time within the aquifer is not included, this analysis is slightly more conservative than the analysis that appears in Appendix Q. As discussed in

Appendix Q, the radionuclide release time and the travel time in the vadose zone are the controlling delays in the arrival of radionuclides to the accessible environment.

In lieu of precise data on soil/water/radionuclide interactions in the unsaturated zone, the following equations based on movement in the saturated zone were used to calculate as a first approximation the radionuclide travel time in the unsaturated zone. The equation used for the radionuclide travel time from the waste sites to the groundwater is:

$$T_n = T_w \cdot R_n \qquad (S.5)$$

where T_w is the travel time for water from the waste site to groundwater and R_n is the retardation factor given by:

$$R_n = 1 + (B/\theta) \cdot (K_d)_n \qquad (S.6)$$

where $(K_d)_n$ is the distribution coefficient for nuclide n (in mL/g, see Appendix P), B is the soil bulk density (1.8 g/mL), and θ is the soil moisture content fraction (conservatively taken to be 0.33).

The water travel time (T_w) was calculated by linearly interpolating the annual recharge/water travel time pairs shown in Table S.3. The values of T_w in Table S.3 were based on layered soils at the AP tank farm construction site in the 200 East Area (see Appendix Q), with more conservative (i.e., smaller) water travel times used here for the recharges greater

TABLE S.3. Annual Recharge and Water Travel Times

Annual Recharge, q, cm/yr	Water Travel Time, T_w, yr
0.1	4,200
0.5	925
1.3	500
2.5	220
3.8	140
5.0	100
6.5	92
7.5	85
10.0	67
15.0	50
20.0	45

than 5 cm/yr. Accumulated releases are not sensitive to the water travel times (see Section S.6). Shorter water travel times can be effectively achieved by increasing the annual recharge in the simulations.

S.3.1 Dissolution-Controlled Release

The dissolution-controlled release process (linear-release model) is used for calculating the release of radionuclides from existing and future grout waste for postulated protective barrier failures and subsequent infiltration of water. The linear release model assumes that infiltrating water directly contacts the waste form, becomes saturated with the dissolving chemicals and radionuclides in the waste, and carries the entire solution vertically downward. The number of curies of nuclide n reaching the groundwater per year, Q_n', is given for grout by the following equation (see Appendix P):

$$Q_n' = Q_{on} \cdot [\exp(-\lambda_n \cdot t)]/T_L \qquad \text{for } T_{LOW} < t < T_{HIGH} \qquad (S.7)$$

where λ_n = the radioactive decay constant, 0.693/half-life, yr^{-1} of the nth radionuclide

Q_{on} = the initial inventory of nuclide n, Ci

T_{LOW} = minimum of $T_n + T_H$ and 10,000 years = initial arrival time of radionuclide n to groundwater

T_{HIGH} = minimum of $T_n + T_H + T_L$ and 10,000 years (for grout, 10,000 years is always the minimum) = final arrival time

T_H = the holdup time before leaching starts (taken as 505 years from the year 1995 for barrier failure cases)

T_n = the nuclide travel time from waste site to groundwater, year (see Equation S.5)

T_L = the time required to dissolve (leach) all of the radionuclides from the waste form, year (14,000 years was derived in Appendix P for grout waste).

Integrating the release rate (Equation S.7) over time from the initial radionuclide arrival time at the groundwater, T_{LOW}, to the time of final radionuclide arrival, T_{HIGH}, yields the following expression for the number of curies of nuclide n accumulated in the groundwater under the waste sites over the next 10,000 years:

$$RQ_n \text{ (Dissolution)} = Q_{on} \cdot \exp(-\lambda_n \cdot T_{LOW}) \cdot [1 - \exp(-\lambda_n \cdot TD)]/(T_L \cdot \lambda_n) \qquad (S.8)$$

where $TD = T_{HIGH} - T_{LOW}$. If $TD = 0$, then $RQ_n = 0$. Equation (S.8) is used for only the grout waste for scenarios with a barrier failure.

S.3.2 Diffusion-Controlled Release

The analysis here summarizes the diffusion model results of Appendix P. The simplified model includes only the most transportable radionuclides, ^{14}C, ^{99}Tc, ^{129}I, and ^{238}U (each was given a zero K_d value for analysis of movement under the barrier for the diffusion model). These are the only radionuclides calculated to diffuse to the barrier's edge in less than 10,000 years (see Appendix P).

In the simplified diffusion model a fraction of the waste, FR, is assumed to diffuse out at a constant rate (ignoring radioactive decay) over a time period, TP. This period starts from the time the diffusion rate to the barrier's edge is non-zero, which is about 4,800 years (for zero K_d) after the year 2150 [see Appendix P, T_o defined after Equation (P.24)]. In other words, the rate at which the most transportable radionuclides reach the groundwater (considering radioactive decay) is the following:

$$Q_n' = FR \cdot Q_{on} \cdot \exp(-\lambda_n \cdot t)/TP \qquad \text{for } T_{LOWD} < t < 10{,}000 \tag{S.9}$$

where $T_{LOWD} = T_n + T_H + 4{,}800$ years and the exponential function is the radioactive decay term.

The fraction FR is 0.03 and time period TP is 6,000 years for the tank waste (single-shell tank, double-shell tank, future double-shell tank). The fraction and time period for grout waste were equal to 0.05 and 19,000 years, respectively.

Equation (S.9) is integrated from T_{LOWD} years (the initial arrival time of radionuclides to the groundwater) to 10,000 years. The grout waste values of FR (0.05) and TP (19,000) are substituted into the integrated result, yielding the following equation for release of nuclides from grout waste by diffusion:

$$RQ_n \text{ (grout diffusion)} = 0.05 \cdot Q_{on} \cdot \exp(-\lambda_n \cdot T_{LOWD}) \cdot \{1 - \exp[-\lambda_n \cdot (10{,}000 - T_{LOWD})]\}/(19{,}000 \cdot \lambda_n) \tag{S.10}$$

Substituting appropriate values for tank waste for the parameters FR (0.03) and TP (6,000) into Equation (S.10) yields the following equation for release of nuclides from tank waste by diffusion:

$$RQ_n \text{ (tank diffusion)} = 0.03 \cdot Q_{on} \cdot \exp(-\lambda_n \cdot T_{LOWD}) \cdot \{1 - \exp[-\lambda_n \cdot (10{,}000 - T_{LOWD})]\} / (6{,}000 \cdot \lambda_n) \tag{S.11}$$

S.3.3 Solubility-Controlled Release

The solubility-controlled release model (derived in Appendix P) is used here to model the radionuclide release from the single-shell tank waste and the double-shell tank waste residuals to the groundwater. The solubility-controlled release assumes that the solute

(radionuclide) concentration remains constant (except for radionuclide decay) in the waste form. The activity in curies of radionuclide n reaching the groundwater per year, Q_n', for the solubility-controlled release is given by the following equation:

$$Q_n' = A_W \cdot q \cdot C_n \cdot 10 \cdot \exp(-\lambda_n \cdot t) \quad \text{for } T_1 < t < T_2 \tag{S.12}$$

where A_W = surface area of waste for waste class W, m^2
q = annual recharge infiltrating waste and reaching groundwater, cm/yr
C_n = fixed concentration of radionuclide n in tank waste, see Appendix P for values, Ci/L here
10 = conversion factor (10 liters = 1 m^2cm), L/m^2cm
λ_n = radioactive decay constant, 1/yr
T_1 = initial arrival time to groundwater = minimum of $T_n + T_H$ and 10,000 years
T_H = holdup time before leaching starts (taken as 505 years for barrier failure--the year 2500, and 155 years for no barrier--the year 2150)
T_2 = minimum of $T_1 + T_R$ and 10,000 years = final arrival time to groundwater
T_R = time duration of solubility-controlled release, year, see Equation (S.13) below:

$$T_R = \log_e [Q_{on} \cdot \exp(-\lambda_n \cdot T_H) / (A_W \cdot q \cdot C_n \cdot 10) + 1]/\lambda_n \tag{S.13}$$

where $\log_e$ is the natural logarithm (see Appendix P).

Integrating radionuclide n's arrival rate to the groundwater (Equation S.12) from the initial arrival time, T_1, to the final arrival time, T_2, yields the following accumulated release:

$$RQ_n \text{ (solubility)} = A_W \cdot q \cdot C_n \cdot 10 \cdot \exp(-\lambda_n \cdot T_1) \cdot [1 - \exp(-\lambda_n \cdot (T_2 - T_1)] / \lambda_n \tag{S.14}$$

If $T_1 = T_2$ (i.e., if the initial arrival time is equal to the final arrival time), then $RQ_n = 0$.

S.3.4 Adsorption-Controlled Release

The adsorption-controlled release model (derived in Appendix P) is used here to model the radionuclide release from the double-shell tank wastes for the no action alternative. The adsorption-controlled release assumes that infiltrating water comes into contact with the waste form and carries the solute (radionuclides) vertically downward. The concentration of the solute is varying with time even if the radioactive decay is negligible. The double-shell tank wastes under the no action alternative are the only wastes in liquid form; the adsorption-controlled release model is most appropriate for the liquid waste form. The number of curies of radionuclide n reaching the groundwater per year, Q_n', for the adsorption-controlled release is given by the following equation:

$$Q_n' = \lambda_{Ln} \cdot Q_{on} \cdot \exp\left[-\lambda_n \cdot t - \lambda_{Ln} \cdot (t - T_H - T_n)\right] \quad \text{for } T_a < t < 10{,}000 \qquad \text{(S.15)}$$

where

λ_{Ln} = leach rate parameter, 1/yr (S.16)
$= q \cdot 0.01 / (R_n \cdot \theta \cdot h)$

q = annual recharge infiltrating waste and reaching groundwater, cm/yr

0.01 = unit conversion factor, m/cm

R_n = retardation factor for radionuclide n, see Equation (S.6)

θ = soil moisture content fraction (0.078 for the wetter climate, 0.064 for the current climate)

h = effective waste class thickness (taken as 64 m for double-shell tank waste and 1 m for double-shell tank residuals, Appendix P)

T_a = initial arrival time of radionuclide n to groundwater = minimum of $T_H + T_n$ (holdup time plus nuclide travel time) and 10,000 years

T_H = holdup time before leaching starts (taken as 155 years from 1995 for no barrier cases).

Integrating Equation (S.15) from the initial arrival time, T_a, to the final arrival time of 10,000 years yields the following accumulated release:

$$RQ_n \text{ (adsorption)} = \lambda_{Ln} \cdot Q_{on} \cdot \exp(-\lambda_n \cdot T_a) \cdot \{1 - \exp[-(\lambda_n + \lambda_{Ln}) \cdot (10{,}000 - T_a)]\} / (\lambda_n + \lambda_{Ln}) \qquad \text{(S.17)}$$

If $T_a = 10{,}000$, then $RQ_n = 0$.

S.3.5 Combination Releases

For the scenarios with postulated barrier failures (for the three disposal alternatives), a combination of two release models is required because the barrier failure is modeled to affect only a fraction, F_L, of the waste class. This fraction, F_L, requires a non-diffusive or leaching release model and the complementary part of this waste, $1-F_L$, requires the diffusion-release model. F_L is a random variable assumed to have a log-normal distribution with median value of 0.08 and a standard deviation of 0.25.

The two parts are modeled by dividing the waste classes into two parts, one part with fraction F_L, described by the leaching-release models, and the other with fraction $1-F_L$, described by the diffusion-release model. Such a model ignores any interaction or coupling of the two parts which requires a much more complicated model. The simple combined release model described here should be considered as a first-order approximation to more complicated combination releases. The combined accumulated release from the waste to the groundwater for radionuclide n for the barrier failure scenarios is

$$RQ_n \text{ (tank waste)} = F_L \cdot RQ_n \text{ (solubility)} + (1-F_L) \cdot RQ_n \text{ (tank diffusion)} \qquad \text{(S.18)}$$

for the tank waste classes with a barrier (see Equations S.11 and S.14), and

$$RQ_n \text{ (grout)} = F_L \cdot RQ_n \text{ (dissolution)} + (1-F_L) \cdot RQ_n \text{ (grout diffusion)} \qquad \text{(S.19)}$$

for the grout waste classes with a barrier (see Equations S.8 and S.10). For the no barrier failure scenarios, F_L is set to 0 and only diffusion occurs.

For the no disposal action alternative, the accumulated release to the groundwater is just RQ_n (adsorption), Equation (S.17), for double-shell tank wastes, and RQ_n (solubility), Equation (S.14), for the single-shell tank waste.

The other waste classes (like the TRU sites) contribute very little to the accumulated releases over 10,000 years because the K_d values for Pu and Am are much higher in the TRU waste classes than in the tank and grout waste classes, and the other radionuclides existing in the TRU waste classes have small inventories relative to single-shell tank and grout wastes.

S.3.6 Parameter Values

The initial inventories of each radionuclide in each waste class for each alternative are listed in Tables P.19 through P.22. The inventory of ^{240}Pu, small in comparison to ^{239}Pu, was added to that of ^{239}Pu since their transport and release properties are expected to be the same; both have long radioactive half-lives and are often taken together for dosimetry calculations. The longer half-life of ^{239}Pu was used for this study.

The K_d values used here were obtained primarily from Appendix P. Fixed single-valued K_d values were used for grout waste and TRU wastes. For the single-shell and double-shell tank waste, this analysis used these values for all the radionuclides except plutonium, americium, uranium, strontium and nickel where pdfs were used. Log-normal pdfs of K_d values were used for plutonium, americium, strontium and nickel, and a uniform pdf was used for uranium. Adopting a range or distribution of K_d values permits a realistic analysis that includes provision for uncertainty. Representative log-normal pdfs (after sampling) are shown in Figures S.5, S.6, and S.7, for K_d values of each of the radionuclides, $^{239\text{-}240}Pu$, ^{241}Am, ^{90}Sr and ^{63}Ni. The minimum K_d values in the pdfs used here are the K_d values listed in Appendix P for concentrated and complexed nuclides. The maximum sampled K_d values in the pdfs were chosen to be the dilute noncomplexed values of soils reported by Delegard and Barney (1983). Nickel-63 was assumed to have the same K_d values as ^{90}Sr and ^{93}Zr was assumed to have a K_d value of 20 mL/g. The median K_d values were chosen to approximate the dilute complexed values reported in Delegard and Barney (1983) except for plutonium in the no action alternative where a median value closer to the concentrated complexed value was used. The plutonium K_d value is very important (see Section S.6). For ^{238}U, a uniform pdf of K_d values was used for all waste classes with a low K_d value of 0 and high K_d value of 16 mL/g. The K_d pdfs for single-shell and double-shell tank waste are summarized in Table S.4.

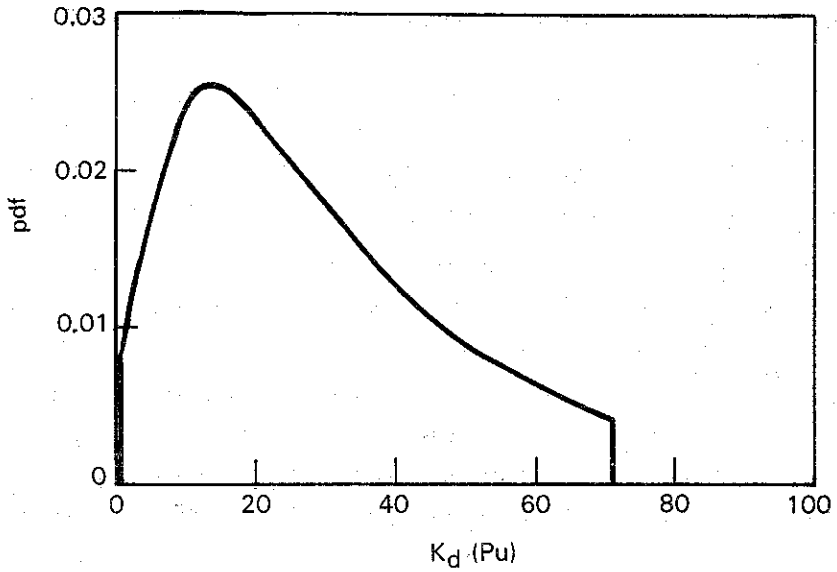

FIGURE S.5. Probability Density Function of K_d Values for Plutonium in Single-Shell and Double-Shell Tank Waste

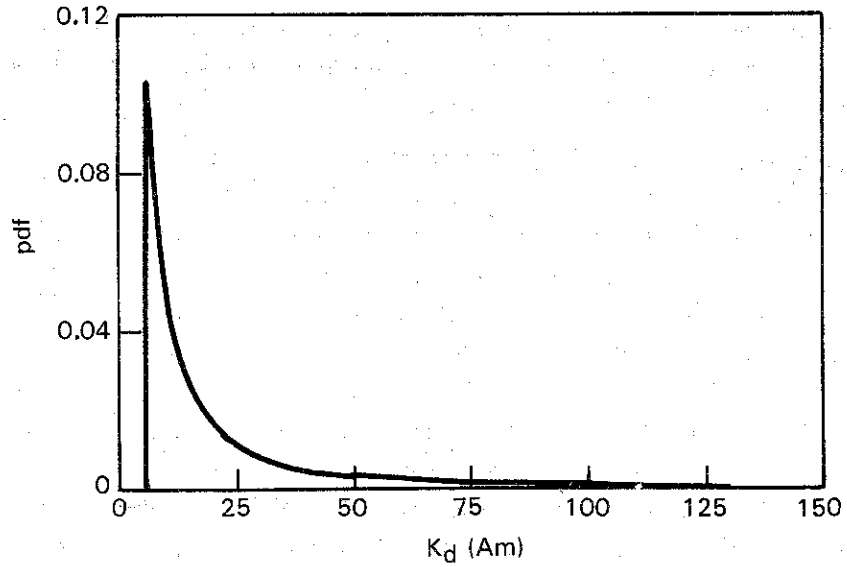

FIGURE S.6. Probability Density Function of K_d Values for Americium in Single-Shell and Double-Shell Tank Waste

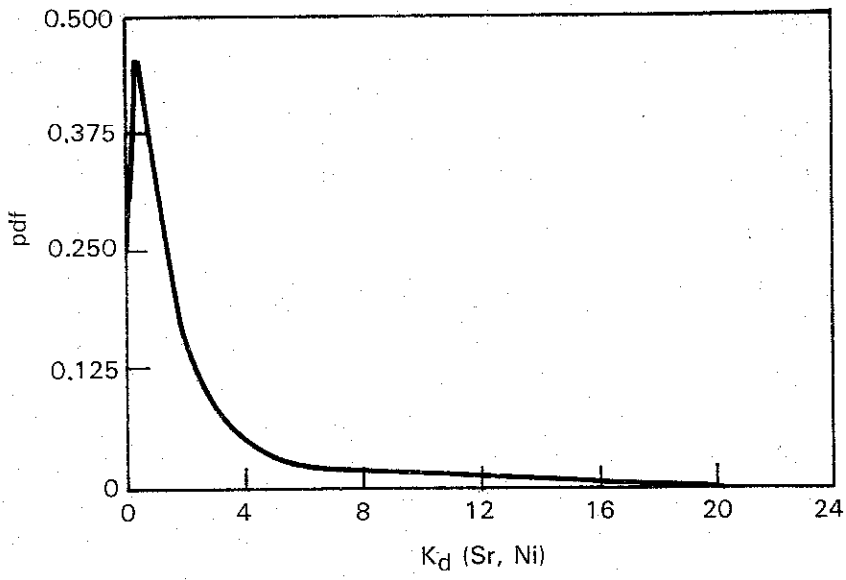

FIGURE S.7. Probability Density Function of K_d Values for Strontium and Nickel in Single-Shell and Double-Shell Tank Waste

TABLE S.4. Summary of Probability Density Functions and Corresponding Parameters

	Parameter (Units)	pdf Type	Parametric Values			
			Median	Low	High	Standard Deviation
1.	Current Climate Recharge (cm/yr)	log-normal	1.5	0	5	0.9
2.	Wetter Climate Recharge (cm/yr)	log-normal	5.0	1.5	15	2.5
3.	Current Climate Recharge Under Barrier Failure (cm/yr)	bimodal (0.95) uniform (0.05)	0.05 7.5	0 5	0.1 10	1.7
4.	Wetter Climate Recharge Under Barrier Failure (cm/yr)	bimodal (0.95) uniform (0.05)	0.1 15	0 10	0.2 20	3.3
5a.	Plutonium K_d for Disposal Alternatives (mL/g)	log-normal	26.0	0.63	71	17.0
5b.	Plutonium K_d for No Action Alternative (mL/g)	log-normal	6.0	0.63	71	10.7
6.	Americium K_d (mL/g)	log-normal	15.5	5.6	130	15.0
7.	Uranium K_d (mL/g)	uniform	8.0	0	16	4.6
8.	Strontium, Nickel K_d (mL/g)	log-normal	1.5	0.02	21	3.0
9.	Waste Fraction Under Barrier Failure	log-normal	0.08	0	1.0	0.25

All the input parameters that are described by a pdf are shown in Table S.4 with the assumed pdfs. The bimodal uniform (two-step) pdfs for the barrier failure recharges have a probability for the functional barrier failure of 0.95 (i.e., the area under the uniform section with the lower recharge values of the pdf is 0.95) and a probability of the disruptive barrier failure of 0.05 (i.e., the area under the uniform section with the higher recharge values of the pdf is 0.05).

S.4 MATHEMATICAL MODEL OF CONSEQUENCES RELATED TO HUMAN INTRUSION

A mathematical model is used to calculate the amount of each radionuclide that is brought to the surface (to accessible environment) by human intrusion. Estimates of annual frequencies or yearly probabilities for borehole drilling on each of the waste classes are given in Table S.5. The annual probabilities[a] were derived by multiplying the annual borehole frequency per square kilometer, $0.01/km^2/yr$, by the surface area occupied by each waste class. The drilling frequency per unit area varied from $0.0002/km^2/yr$ to $0.012/km^2/yr$ in Little (1980); a value of $0.01/km^2/yr$ was chosen for this study. This number is more than three times higher than the number recommended in EPA standard 40 CFR 191. The chosen value of $0.01/km^2/yr$ does not include any reduction for the probability that the protective barrier and marker system will discourage drilling (see Appendix M).

These annual frequencies were used with the Poisson distribution to generate 10,000-year probabilities. The Poisson distribution is well suited for calculating the probability of an event occurring randomly within a period of m years if the annual probability of the event, p, is known. The probability of i events occurring over m years is:

$$P(i) = \exp(-L) \cdot L^i/i! \qquad (S.20)$$

where $L = m \cdot p$ (m = 10,000 years here and p, the annual probability is shown in Table S.5) and i is an integer. The probability of more than i events occurring is:

$$P(j>i) = \sum_{j=i+1}^{\infty} \exp(-L) \cdot L^j/j! \qquad (S.21)$$

Equation (S.20) was used to calculate the probability of zero, one, two, etc., boreholes for each waste class shown in Tables S.5 and S.6. Equation (S.21) was used to determine how many boreholes should be counted in the analysis. The maximum number of boreholes included in the analysis was the value of i for which P(j>i) is less than 0.0001. This maximum number, the 99.99 percentile value of the number of boreholes, and other percentile values of the number of boreholes for each waste class are shown in Table S.6.

(a) "Annual probability" as used here is the probability per year of a borehole intercepting a given class of waste.

TABLE S.5. Annual Probabilities of Boreholes in Waste Classes and Waste-Class Surface Areas

Index W	Waste Class	Annual Probability, Intrusions/yr	Surface Area, A_W, km^2
1	Single-Shell Tanks	5.5×10^{-4}	0.055
2	Double-Shell Tanks	5.8×10^{-5}	0.0058
3a	Grout of Existing Waste (ISD and Reference)	5.8×10^{-4}	0.058
3b	Grout of Existing Waste (Geologic)	2.5×10^{-3}	0.25
4	Future Double-Shell Tanks	5.8×10^{-5}	0.0058
5	Grout of Future Waste	3.3×10^{-4}	0.033
6a	DWSF[(a)]/^{90}Sr Canisters	1.0×10^{-6}	0.00010
6b	DWSF/^{137}Cs Canisters (In-Place Stabilization and Disposal)	2.4×10^{-6}	0.00024
6c	DWSF/^{137}Cs Canisters (No Disposal Action)	1.3×10^{-6}	0.00013
7	TRU-Contaminated Soil	1.2×10^{-4}	0.012
8	Pre-1970 Buried TRU	7.5×10^{-4}	0.075
9	Retrievable TRU	2.5×10^{-4}	0.025
10	Future TRU	1.7×10^{-4}	0.017

(a) Drywell storage facility.

Even though the drilling of boreholes is not expected to be random but somewhat clustered in time, the random-based Poisson distribution is still adequate here. The Poisson distribution is adequate chiefly because the clustering effects from the past are included in the annual borehole probabilities (Table S.5). After the various percentile numbers of boreholes that could intercept each waste class over the next 10,000 years was determined, it was assumed that all the boreholes occur in one year. The year of drilling was chosen for three different times; 100, 400, and 1,000 years after disposal. Disposal was assumed to be completed in the year 2050. Having all the boreholes occurring in one year is extreme clustering in time. Furthermore, only the rather early years (100, 400, and 1,000) of the 10,000-year period were chosen as the drilling years; this is conservative because the mitigating effects of radioactive decay are minimized in these early years.

TABLE S.6. Percentile Values of the Number of Boreholes (in a 10,000-year period) **in Each Waste Class**

Index W	Waste Class	Number of Boreholes, $I_W(y)$ ($y = 50$) 50th Percentile	($y = 90$) 90th Percentile	($y = 99.9$) 99.9th Percentile	($y = 99.99$) 99.99th Percentile
1	Single-Shell Tanks	5	9	14	16
2	Double-Shell Tanks	0	2	14	15
3a	Grout of Existing Waste (In-Place Stabilization and Disposal & Reference)	6	9	14	17
3b	Grout of Existing Waste (Geologic)	25	31	41	45
4	Future DST	0	2	4	5
5	Grout of Future Waste	3	6	10	12
6a	DWSF[(a)]/^{90}Sr Canisters	0	0	0	1
6b	DWSF/^{137}Cs Canisters (In-Place Stabilization and Disposal)	0	0	1	2
6c	DWSF/^{137}Cs Canisters (No Disposal Action)	0	0	1	2
7	TRU-Contaminated Soil	1	3	6	7
8	Pre-1970 Buried TRU	7	11	17	19
9	Retrievable TRU	2	5	9	10
10	Future TRU	2	3	7	8

(a) Drywell storage facility.

The source terms (inventories) per borehole were calculated for each waste class listed in Table S.5 by dividing the waste class inventory (for each alternative) per radionuclide by the waste class surface area, and then multiplying this inventory areal density by the area of a 30-cm-dia borehole, 7×10^{-8} km^2 (0.07 m^2). The resulting product is the initial inventory per borehole for each radionuclide in each waste class for each disposal alternative. The following equation was used for calculating the yth percentile value of the accumulated release of radionuclide n from waste class W to the land surface due to drilling:

$$RQ_n\,[I_W(y)] = [Q_{on} \cdot \exp(-\lambda_n \cdot T_{DRILL})/A_W] \cdot A_{BH} \cdot I_W(y) \qquad (S.22)$$

where Q_{on} = initial inventory (Ci) of radionuclide n in waste class W; W = 1 to 10 (see Table S.5)

T_{DRILL} = time of drilling (year) after the year 1995; T_{DRILL} has three values in this study: 155 years, 455 years, and 1,055 years[(a)]

A_W = surface area of waste class W (km^2) (see Table S.5)

A_{BH} = area of borehole (km^2) = 7×10^{-8} km^2

$I_W(y)$ = the yth percentile value of the number of boreholes in waste class W where $0 < y \leq 99.99$ (see Table S.6 for I_W values at percentile values of y = 50, 90, 99.9, and 99.99).

$I_W(y)$ must satisfy the following relationship with the probabilities for i boreholes in waste class W, P(i), (Equation S.20):

$$\sum_{i=0}^{I_W(y)-1} P(i) < 0.01 \cdot y \leq \sum_{i=0}^{I_W(y)} P(i) \qquad (S.23)$$

which says that the yth percentile value of the number of boreholes in waste class W, $I_W(y)$, is the first integer number which causes the sum of probabilities for each borehole to exceed the probability value 0.01 1• y. The 0.01 factor converts percentile values into probability values.

The yth percentile value of the release-ratio consequence for waste class W for each alternative A (each alternative has a different set of waste classes) due to drilling boreholes is:

$$C_W(y) = \sum_n RQ_n \, [I_W(y)]/RL_{n,A} \qquad (S.24)$$

The yth percentile value of the release-ratio consequence for all waste classes was calculated by the following equation:

$$C(y) = \sum_W C_W(y) \qquad (S.25)$$

Equation (S.25) assumes that the yth percentile consequence value of each waste class can simply be added to obtain the total consequence value at the yth percentile. This total distribution of consequence values, Equation (S.25), is not the same as the total distribution found by adding Poisson distributions. In general, the yth percentile value of the distribution of the sum of random variables is not equal to the sum of the yth percentile value of the distribution of each random variable. The distribution defined by

(a) The 55 years included in the drilling time is the time between the used inventory year, 1995, and the year of disposal, 2050, and accounts for radioactive decay for that time period.

Equation (S.25) is conservative in the sense that C(y) is greater than or equal to the yth percentile value of the distribution found from the sum of random variables.

The complementary cumulative distribution function of the yth percentile consequence value, CCDF[C(y)], is defined by the following equation:

$$CCDF[C(y)] = 1.0 - 0.01 \cdot y \qquad (S.26)$$

Since the consequences due to drilling are discrete (depending on the integer number of boreholes in Equation S.22), the corresponding CCDF will be a step function indicating the discrete nature of the borehole model.

A special note needs to be made about Equation (S.22) and the drywell storage facility (DWSF) waste class (W = 6a, 6b, 6c) of strontium and cesium canisters. This is the only waste class that has a target waste area smaller than the borehole area. Each canister is about 6 cm in diameter, and the borehole is assumed to have a 30-cm dia. Hence, a larger area for the canisters was calculated based on Figure S.8 for use in Equation (S.22) and on the annual probabilities of a borehole hitting a canister (Table S.5). The calculated canister area for the drilling model is 3.4×10^{-7} km^2 based on a 33-cm radius. If a borehole intercepts anywhere within this 33-cm-radius circle, as shown in Figure S.8, then the canister is at least grazed by the borehole and is conservatively assumed to release all its inventory to the accessible environment. That is, the borehole area, A_{BH}, is set to 3.4×10^{-7} km^2 (0.34 m^2) for the DWSF canisters instead of 7×10^{-8} km^2 (0.07 m^2). The area for the DWSF canisters, A_W, in Table S.5 is the calculated larger area, A_{BH} (Figure S.8), times the number of canisters. For all other waste classes, the area of the borehole is negligible compared to the target waste area and hence does not show up in the waste class areas.

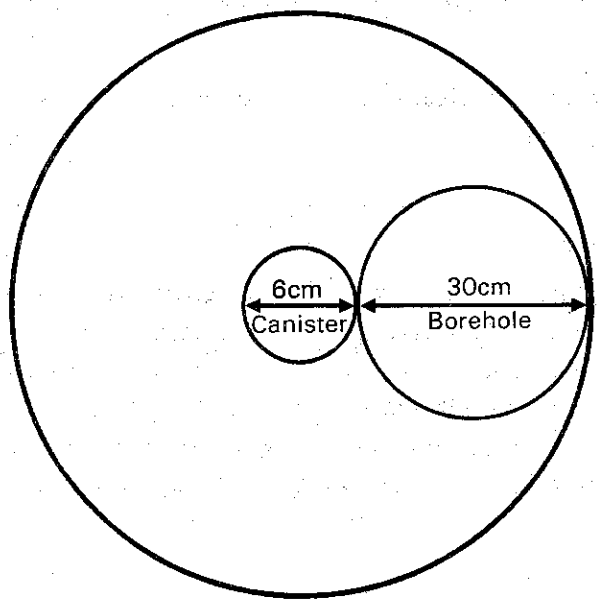

FIGURE S.8. Drywell Storage Facility Canister Area for Borehole Model

S.5 RESULTS

The results of 2,000 calculations made by the PROBCON (probability and consequences) systems code[a] for the scenario of the current climate, no barrier failure, and 400-year intrusion for all three disposal alternatives, and the current climate, 400-year intrusion scenario for the no disposal action alternative are shown graphically in Figure S.9. The CCDF is shown in Figure S.9 for each alternative. In discussing this curve it will be referred to as the release curve. The CCDF of C is the probability that the consequence is greater than or equal to the consequence value C. The 90th percentile consequence value has an ordinate (y-axis) value of 0.1. In other words, if a horizontal line is drawn across the graph at the ordinate value of 0.1, each intersection of the CCDF curve with that line will have an abcissa (x-axis) value which is the 90th percentile consequence value of the release-ratio consequence. The ordinate value of 0.001 corresponds to the 99.9th percentile consequence value. If a release-ratio curve for an alternative has a 90th percentile consequence value less than 1 and a 99.9th percentile consequence value less than 10, then that alternative meets EPA standard 40 CFR 191.13, which is represented by the far left boundary of the hatched area on Figure S.9. The hatched area on Figure S.9 represents the conditions under which the EPA release standard would not be met.

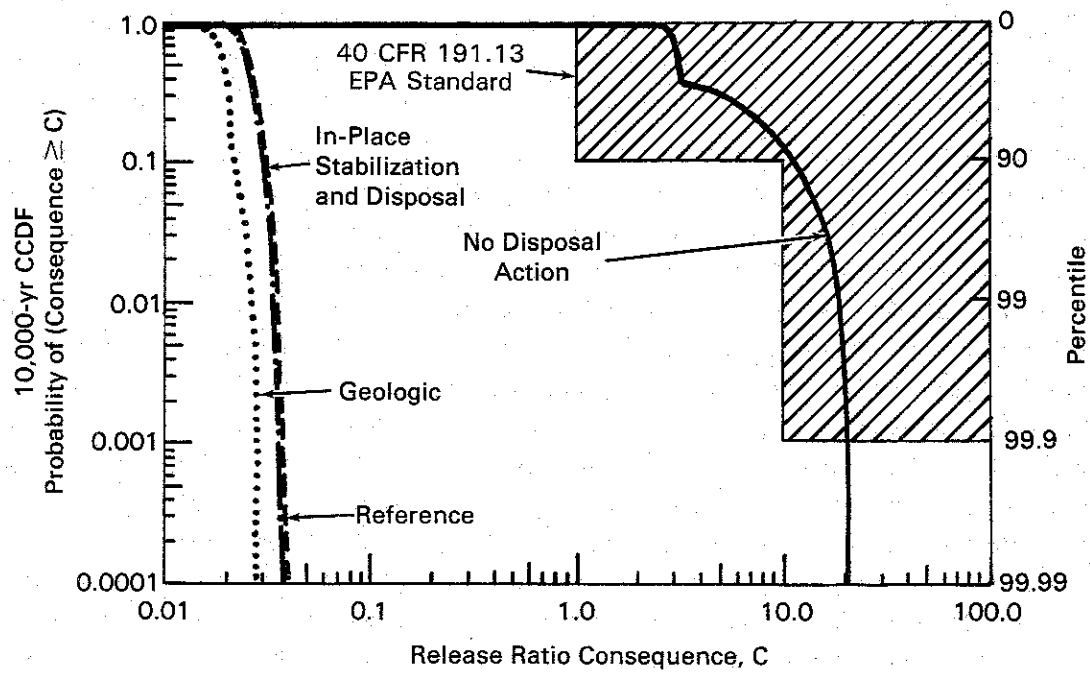

FIGURE S.9. Release Curves for Alternatives for the Scenario of Current Climate, No Barrier Failure, and 400-year Intrusion

(a) M. G. Piepho, Pacific Northwest Laboratory. Document in preparation.

As shown in Figure S.9, all three disposal alternatives for the scenario of current climate, no barrier failure, and 400-year intrusion meet the EPA standard. The no disposal action alternative for the scenario of current climate and 400-year intrusion does not meet the EPA standard at either the 90th percentile (the high-probability part of the standard) or the 99.9th percentile (the low-probability part of the standard).

Each scenario has its own release-ratio curve or CCDF. The release ratio curves shown in Figure S.9 are for one of the most probable scenarios (see Figure S.3 for scenario probabilities). After calculating a release curve for each scenario, the next step is to construct a composite release curve which is a composite of all the individual scenario CCDFs and their probability weighting factors. The scenario weighting factor for scenario S_s is its scenario probability, $P(S_s)$, as shown in Figure S.3. Mathematically, the composite CCDF can be calculated by the following:

$$\text{Composite CCDF}(C) = \sum_{s} P(S_s) \cdot \text{CCDF}(C/S_s) \tag{S.27}$$

$$\text{and} \sum_{s} P(S_s) = 1.0 \tag{S.28}$$

where $P(S_s)$ is the probability of scenario S_s occurring in 10,000 years, $\text{CCDF}(C/S_s)$ is the release-ratio/probability curve for scenario S_s (i.e., the CCDF is conditional on the assumptions of scenario S_s), and s is the scenario index (s = 1 to 8 as shown in Figure S.3).

The composite release-ratio/probability curves for the alternatives, based on the eight scenarios shown in Figure S.3 and the models described in Sections S.3 and S.4, are shown in Figure S.10. The numerical results for the 90th and 99.9th percentile values are shown in Table S.7. Two composite CCDFs are shown in Figure S.10 for each of the geologic and reference disposal alternatives. The two curves labeled with an A are calculated with the "partitioned" release limits defined and calculated in Section S.1 and shown in Table S.2. The allocation method for this partitioning is based on the fraction of radionuclide activity (see Table S.1) disposed of near surface. The two curves labeled with a B are calculated with the "total" release limits; that is, the release limits for the B curves are based on the total fuel equivalent (burnup corrected) of about 18,000 eMTHM. If there are zero releases from the deep repositories (geologic repository and WIPP), then the "total" nuclide release limits based on the total inventory can be allocated to the waste disposed of near surface (see Note 4 of 40 CFR 191). The B curves represent the limiting case of release limit allocation where zero release limit is allocated to each radionuclide sent to a geologic repository or WIPP and the total release limits are allocated to the radionuclides disposed of on site. The B curve for the reference alternative is essentially the same (slightly smaller due to fewer boreholes causing releases to the environment) as the in-place stabilization and disposal alternative.

The composite release-ratio/probability curves (Figure S.10) show that under the assumed conditions the in-place stabilization and disposal alternative and the reference alternative

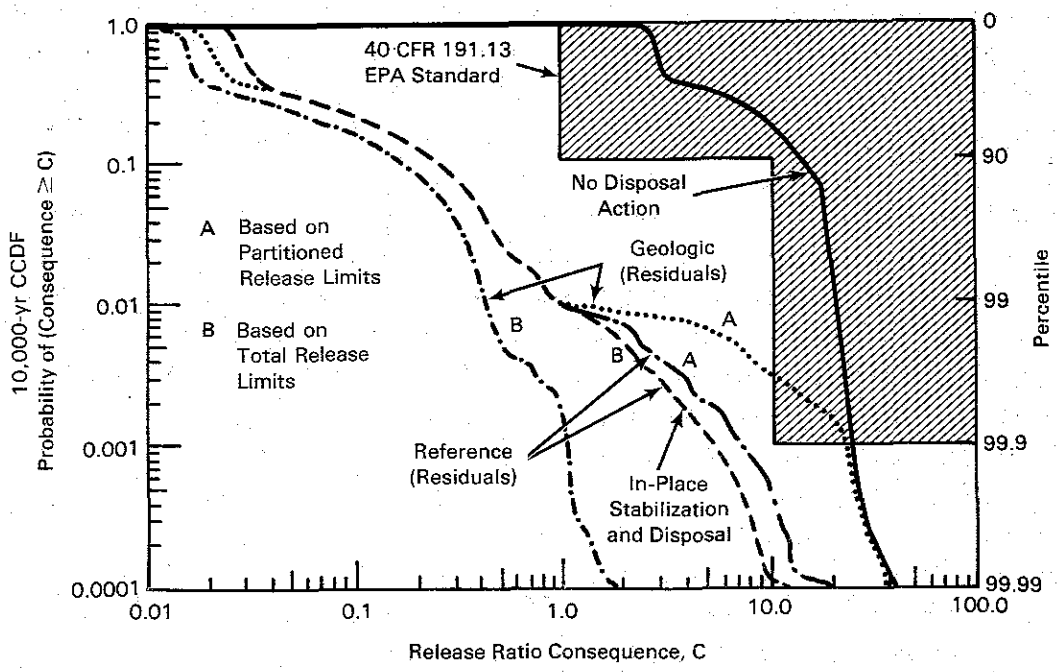

FIGURE S.10. Preliminary Composite CCDFs for All Alternatives Based on All Scenarios for Wastes Disposed of Near Surface

TABLE S.7. Numerical Comparison (ratios) of Calculated Consequences with EPA Standard
(Ratio greater than 1.0 shows standard is met.)

Alternative	EPA(90th percentile)/ C(90th percentile)	EPA(99.9th percentile)/ C(99.9th percentile)
ISD	4.3	1.9
Reference-A	4.3	1.4
Reference-B	4.3	1.9
Geologic-A	4.0	0.4
Geologic-B	5.5	9.0
No Action	0.07	0.4

A - Results for alternative are based on partitioned release limits.
B - Results for alternative are based on total release limits.

meet the EPA standard at the 99.9 percentile (this represents the low probability, 0.001, referred to in the standard). The geologic disposal alternative (curve B) can meet the low-probability (0.001) part of the EPA standard with the allocation allowed in Note 4 to Table 1 of 40 CFR 191. The no disposal action alternative does not meet the standard for either disposal probability level. Figures S.9 (no barrier failure) and S.10 (with barrier failure) together show the importance of the protective barrier's performance.

If only the "partitioned" release limits defined in Section S.1 were to be used for allocation, the geologic disposal alternative's release curve (curve A) would be greater than the EPA standard at the 99.9th percentile value, which is the low-probability (one chance in

1,000) part of the standard. However, the EPA standard makes provisions for assigning a release limit larger than the small "partitioned" release limits shown in Table S.2 for the geologic alternative in particular. As a result, there is a broad range of allowable allocations through which the geologic disposal alternative would meet the EPA standard.

The reason that the upper bound shown for the geologic alternative CCDF (curve A) is larger than the others is that the release curves are based on the release-ratio consequence, which depends on both the allowed release limit for each radionuclide (RL_n) and the amount of waste reaching the accessible environment (RQ_n), as shown in Equation S.1. The geologic disposal alternative has the lowest inventories of residual radionuclides disposed of near surface and, therefore, has the lowest release limits. With the partitioning used in curve A, the release limit for near-surface residual plutonium in the geologic disposal alternative is only 28 Ci (see Table S.3), and the single-shell tank 5% residual inventory alone is 1,400 Ci, which is large compared to only 28 Ci. Furthermore, the 5% single-shell tank residual waste in the geologic disposal alternative is assumed to contain plutonium in highly transportable form (i.e., low K_d values for concentrated and complexed plutonium; see Figure S.4) compared to that assumed for the plutonium in the TRU sites (waste classes 7 to 10, Table S.5). Hence, the accumulated release of plutonium to the groundwater for the geologic disposal alternative is about 5% of the release for the other disposal alternatives under wetter climate and disruptive barrier failure scenarios, but the partitioned release limit for plutonium for the geologic disposal alternative is only about 1.5% of the in-place stabilization and disposal alternative. In summary, removing the TRU waste sites substantially lowers the plutonium (n=4) release limit, RL_4, but does not lower the accumulated release, RQ_4, in the same proportion for the geologic disposal alternative. As a result, the plutonium release-ratio consequence, RQ_4/RL_4, is very high (greater than 10). This happens when both the plutonium K_d value is small and the postulated barrier failure recharge is high; these are low-probability events (less than one chance in ten over 10,000 years).

For both curve A and curve B of the geologic disposal alternative, the expected number of health effects (an absolute measure) is the same, is calculated to be very low, and is the lowest of all the alternatives (see Chapter 5). In 40 CFR 191, specific provisions are made for allocating release limit multipliers in cases where more than one disposal system is employed. By using these provisions, releases from residuals disposed of near surface in the geologic disposal alternative would comply, based on the preliminary analysis here, with the EPA containment standard.

The actual releases of each radionuclide, in curies at various percentile values (50th, 90th, 99.9th) for the groundwater transport part of the scenarios are shown in Tables S.8, S.9, and S.10 for each alternative for each dissolution scenario.

The releases resulting from the drilling intrusion were included in the release ratio curves. The drilling releases were also analyzed separately, as were the releases resulting from dissolution mechanisms, for comparative purposes. The releases from the drilling were very small compared to releases from dissolution mechanisms. The 100-year intrusion releases are shown in Table S.11. The 400-year and 1,000-year intrusion releases are smaller than the

TABLE S.8. Accumulated Radionuclide Releases (Ci) to the Accessible Environment Over 10,000 Years for Scenarios with No Barrier Failure

Scenario	Alternative	Radionuclide	10,000-yr Releases, Ci 50th Percentile	90th Percentile	99.9th Percentile
Current Climate and No Barrier Failure	Geologic	^{14}C	26.3	28.2	28.9
		^{238}U	0.0	0.3	1.0
		^{99}Tc	23.5	24.8	25.3
		^{129}I	0.71	0.75	0.77
		Others	0.0	0.0	0.0
	In-Place Stabilization and Disposal	^{14}C	38.8	41.6	42.7
		^{238}U	0.0	3.6	1.2
		^{99}Tc	580.0	612.0	624.0
		^{129}I	0.96	1.0	1.0
		Others	0.0	0.0	0.0
	Reference	^{14}C	38.8	41.6	42.7
		^{238}U	0.0	3.6	1.2
		^{99}Tc	580.0	612.0	624.0
		^{129}I	0.96	1.0	1.0
		Others	0.0	0.0	0.0
Wetter Climate and No Barrier Failure	Geologic	^{14}C	29.8	30.0	30.2
		^{238}U	0.03	0.48	0.6
		^{99}Tc	25.3	25.5	25.6
		^{129}I	0.77	0.77	0.77
		Others	0.0	0.0	0.0
	In-Place Stabilization and Disposal	^{14}C	42.7	43.0	43.3
		^{238}U	0.52	9.4	11.6
		^{99}Tc	624.0	628.0	631.0
		^{129}I	1.0	1.0	1.1
		Others	0.0	0.0	0.0
	Reference	^{14}C	42.7	43.0	43.3
		^{238}U	0.54	9.8	12.1
		^{99}Tc	624.0	628.0	631.0
		^{129}I	1.0	1.0	1.1
		Others	0.0	0.0	0.0

100-year intrusion releases and are not shown. At early times, strontium and cesium would dominate the postulated drilling releases; however, by 400 years after disposal, strontium and cesium would be about one ten-thousandth of initial quantities, and releases via drilling would contribute negligibly compared to the releases caused by dissolution mechanisms (diffusion and leaching).

S.6 SENSITIVITY ANALYSIS

A sensitivity analysis was performed to determine the most important parameters in both the dissolution release and human intrusion release models. The principal parameters

TABLE S.9. Accumulated Radionuclide Releases (Ci) to the Accessible Environment Over 10,000 Years for Scenarios with Current Climate and Barrier Failure

Scenario	Alternative	Radionuclide	10,000-yr Releases, Ci 50th Percentile	90th Percentile	99.9th Percentile
Current Climate and Barrier Failure	In-Place Stabilization and Disposal	^{90}Sr	0.0	0.0	0.7
		^{137}Cs	0.0	0.0	0.0
		^{151}Sm	0.0	0.0	0.0
		$^{239-240}Pu$	0.0	0.0	8,230.0
		^{241}Am	0.0	0.0	23.7
		^{63}Ni	0.0	0.0	591.0
		^{14}C	87.5	505.0	3,280.0
		^{238}U	0.0	3.5	43.9
		^{93}Zr	0.0	0.0	3,870.0
		^{99}Tc	2,070.0	12,500.0	25,700.0
		^{129}I	3.1	18.7	42.5
	Reference	^{90}Sr	0.0	0.0	0.7
		^{137}Cs	0.0	0.0	0.0
		^{151}Sm	0.0	0.0	0.0
		$^{239-240}Pu$	0.0	0.0	8,230.0
		^{241}Am	0.0	0.0	23.7
		^{63}Ni	0.0	0.0	591.0
		^{14}C	87.5	505.0	3,280.0
		^{238}U	0.0	3.4	40.8
		^{93}Zr	0.0	0.0	3,780.0
		^{99}Tc	2,070.0	12,500.0	25,700.0
		^{129}I	3.1	18.7	42.5
	Geologic	^{90}Sr	0.0	0.0	0.04
		^{137}Cs	0.0	0.0	0.0
		^{151}Sm	0.0	0.0	0.0
		$^{239-240}Pu$	0.0	0.0	610.0
		^{241}Am	0.0	0.0	1.3
		^{63}Ni	0.0	0.0	29.8
		^{14}C	84.6	482.0	1,870.0
		^{238}U	0.0	0.4	29.6
		^{93}Zr	0.0	0.0	196.0
		^{99}Tc	97.0	571.0	1,010.0
		^{129}I	2.3	12.5	34.7
Current Climate and No Barrier	No Disposal Action	^{90}Sr	0.0	0.0	2,970.0
		^{137}Cs	0.0	0.0	0.0
		^{151}Sm	0.0	0.0	0.0
		$^{239-240}Pu$	0.0	14,100.0	27,400.0
		^{241}Am	0.0	0.0	34.2
		^{63}Ni	0.0	66.0	15,700.0
		^{14}C	4,680.0	4,930.0	5,040.0
		^{238}U	0.0	51.9	73.6
		^{93}Zr	0.0	0.0	0.0
		^{99}Tc	34,700.0	34,800.0	34,800.0
		^{129}I	58.0	58.0	58.0

TABLE S.10. Accumulated Radionuclide Releases (Ci) to the Accessible Environment Over 10,000 Years for Scenarios with Wetter Climate and Barrier Failure

Scenario	Alternative	Radionuclide	10,000-yr Releases, Ci 50th Percentile	90th Percentile	99.9th Percentile
Wetter Climate and Barrier Failure	In-Place Stabilization and Disposal	^{90}Sr	0.0	0.0	4.1
		^{137}Cs	0.0	0.0	0.0
		^{151}Sm	0.0	0.0	0.1
		$^{239-240}Pu$	0.0	0.0	12,000.0
		^{241}Am	0.0	0.0	160.0
		^{63}Ni	0.0	0.0	1,080.0
		^{14}C	120.0	770.0	3,310.0
		^{238}U	0.0	8.7	82.6
		^{93}Zr	0.0	0.0	4,370.0
		^{99}Tc	2,250.0	13,400.0	25,700.0
		^{129}I	3.5	20.7	44.2
	Reference	^{90}Sr	0.0	0.0	4.1
		^{137}Cs	0.0	0.0	0.0
		^{151}Sm	0.0	0.0	0.1
		$^{239-240}Pu$	0.0	0.0	12,000.0
		^{241}Am	0.0	0.0	160.0
		^{63}Ni	0.0	0.0	1,080.0
		^{14}C	120.0	770.0	3,310.0
		^{238}U	0.0	8.6	78.6
		^{93}Zr	0.0	0.0	3,880.0
		^{99}Tc	2,250.0	13,400.0	25,700.0
		^{129}I	3.5	20.7	44.2
	Geologic	^{90}Sr	0.0	0.0	0.3
		^{137}Cs	0.0	0.0	0.0
		^{151}Sm	0.0	0.0	0.0
		$^{239-240}Pu$	0.0	0.0	704.0
		^{241}Am	0.0	0.0	8.9
		^{63}Ni	0.0	0.0	54.1
		^{14}C	93.6	541.0	1,880.0
		^{238}U	0.0	0.8	39.4
		^{93}Zr	0.0	0.0	214.0
		^{99}Tc	100.0	580.0	1,010.0
		^{129}I	2.4	13.5	34.8
Wetter Climate and No Barrier	No Disposal Action	^{90}Sr	0.0	815.0	97,500.0
		^{137}Cs	0.0	0.0	0.0
		^{151}Sm	0.0	0.0	1.1
		$^{239-240}Pu$	0.0	28,900.0	30,900.0
		^{241}Am	0.0	80.8	3,630.0
		^{63}Ni	57.3	11,500.0	46,100.0
		^{14}C	5,040.0	5,090.0	5,120.0
		^{238}U	53.3	89.0	127.0
		^{93}Zr	0.0	4,640.0	5,650.0
		^{99}Tc	34,800.0	34,800.0	34,800.0
		^{129}I	58.0	58.0	58.0

TABLE S.11. Radionuclide Releases (Ci) to the Accessible Environment for 100-Year Intrusion Scenario

Scenario	Alternative	Radionuclide	50th Percentile	90th Percentile	99.9th Percentile
Human Intrusion: Boreholes 100 yr After Disposal	Geologic	^{90}Sr	0.42	0.76	1.2
		^{137}Cs	0.42	0.82	1.3
		^{151}Sm	0.08	0.15	0.23
		$^{239-240}Pu$	0.012	0.022	0.034
		^{241}Am	0.024	0.049	0.080
		^{63}Ni	0.037	0.065	0.099
		^{14}C	0.039	0.050	0.068
		^{238}U	0.0004	0.0008	0.0012
		^{93}Zr	0.0020	0.0036	0.0056
		^{99}Tc	0.009	0.015	0.022
		^{129}I	0.0004	0.0006	0.0082
	In-Place Stabilization and Disposal	^{90}Sr	15.0	27.9	430.0
		^{137}Cs	5.2	8.8	5,320.0
		^{151}Sm	2.6	4.7	7.5
		$^{239-240}Pu$	0.84	1.6	3.0
		^{241}Am	2.1	4.0	6.7
		^{63}Ni	0.74	1.3	2.0
		^{14}C	0.036	0.060	0.096
		^{238}U	0.004	0.007	0.011
		^{93}Zr	0.043	0.079	0.13
		^{99}Tc	0.24	0.41	0.65
		^{129}I	0.0004	0.0007	0.0011
	Reference	^{90}Sr	7.1	12.8	20.0
		^{137}Cs	5.2	8.8	13.9
		^{151}Sm	1.4	2.5	4.0
		$^{239-240}Pu$	0.43	0.84	1.4
		^{241}Am	0.30	0.56	0.91
		^{63}Ni	0.67	1.2	1.9
		^{14}C	0.036	0.061	0.095
		^{238}U	0.004	0.007	0.011
		^{93}Zr	0.030	0.054	0.085
		^{99}Tc	0.24	0.41	0.65
		^{129}I	0.0004	0.0007	0.0011
	No Disposal Action	^{90}Sr	6.8	42.8	3,460.0
		^{137}Cs	2.1	48.0	5,290.0
		^{151}Sm	1.4	6.9	10.0
		$^{239-240}Pu$	0.80	1.7	2.4
		^{241}Am	2.4	7.2	11.0
		^{63}Ni	0.66	1.4	2.0
		^{14}C	0.020	0.092	0.13
		^{238}U	0.0035	0.008	0.01
		^{93}Zr	0.028	0.11	0.15
		^{99}Tc	0.11	0.66	0.96
		^{129}I	0.0002	0.0011	0.0017

analyzed in each model were the radionuclide inventories plus all the additional parameters of recharge (equivalently, the water travel time--see Table S.3), radionuclide K_d coefficients, and barrier failure parameters, which are all itemized in Table S.4. In

addition to these model parameters, the probabilities of scenario occurrence were also varied. The model parameters were in general varied by small amounts (a differential sensitivity analysis), and the probabilities of scenario occurrence were varied by large amounts.

For the scenarios with no barrier failure, the ^{14}C inventory was found to be the dominant parameter (based on the consequence changes due to small changes in the parameter) for each of the three disposal alternatives. Carbon-14 is responsible for about 60% to 70% of the release-ratio consequence at the higher percentiles (90 and 99.9) for the three disposal alternatives, with ^{238}U contributing about 15% to 20%, ^{99}Tc contributing about 10% to 15%, and ^{129}I contributing less than 2%.

Cumulative-release results for the scenarios with no barrier failure are not sensitive to the recharge value (or water travel times), provided it is not zero. This is because ^{14}C, ^{99}Tc, and ^{129}I have been modeled to always reach the groundwater once they have diffused out from under the protective barrier, regardless of the non-zero amount of recharge. However, for releases other than cumulative releases, e.g., concentrations, the recharge value (or water travel time) may be very important.

For the scenarios with barrier failure, the K_d coefficient (or equivalently, the retardation coefficient R_d) for plutonium is the most important parameter for the cumulative release-ratio consequence calculation. The plutonium K_d coefficient is important since the difference between the plutonium travel time and the water travel time to the groundwater is approximately proportional to its K_d value (see Equation S.6). If the K_d value is large enough, plutonium will not reach the groundwater in 10,000 years. If the K_d value is small enough, plutonium will reach the groundwater within 10,000 years. Sufficiently small K_d values cause the release-ratio consequence to exceed 10 for the geologic disposal alternative (curve A with partitioned release limits) at a low probability of occurrence (one chance in 1,000). Plutonium is responsible for about 74% to 93% of the release-ratio consequence (with partitioned release limits) at the 99.9th percentile for barrier-failure scenarios. The K_d values of most radionuclides are potentially important, particularly if the values are close to zero. The recharge under a barrier failure and the waste fraction affected by the barrier failure are also important parameters. As Figures S.9 and S.10 together have already pointed out, the barrier performance is important to the cumulative-release calculations.

For the human intrusion release model, only the radionuclide inventories were included in the sensitivity analysis. The importance of each radionuclide depends on the time of drilling (because of radioactive decay effects) and the alternative (because of the different waste classes). For the geologic disposal alternative, ^{137}Cs, ^{90}Sr and $^{239\text{-}240}Pu$ dominate the 100 years after disposal drilling time scenario, and $^{239\text{-}240}Pu$ and ^{241}Am dominate the 400-year and 1,000-year scenarios. For the in-place stabilization and disposal and reference disposal alternatives, and for the no disposal action alternative, ^{137}Cs, ^{90}Sr, and ^{241}Am dominate the 100-year drilling scenario, and ^{241}Am and $^{239\text{-}240}Pu$ dominate the 400-year and

1,000-year scenarios. Again, as stated earlier, the releases from drilling are small (less than 1%) compared to the releases from the dissolution (diffusion/leaching) mechanisms.

If the wetter climate is assumed to have a 90% chance of occurring, instead of a 10% chance, by the year 2500, then the reference disposal alternative, in addition to the geologic disposal alternative (for residuals), does not meet the EPA containment standard using the partitioned release limits. The composite release-ratio curves of the three disposal alternatives with the 90% chance of a wetter climate are shown in Figure S.11.

Furthermore, if it is also assumed that the barrier has a 100% chance of failure by the year 2500 in addition to the 90% chance of a wetter climate (i.e., $P(S_1) = P(S_2) = P(S_5) = P(S_6) = 0$, $P(S_3) = P(S_4) = 0.45$, and $P(S_7) = P(S_8) = 0.05$ in Figure S.3), then the cumulative release results shown in Figure S.12 are obtained. The figure shows that the in-place stabilization and disposal alternative would still meet the EPA standard under the conditions assumed here.

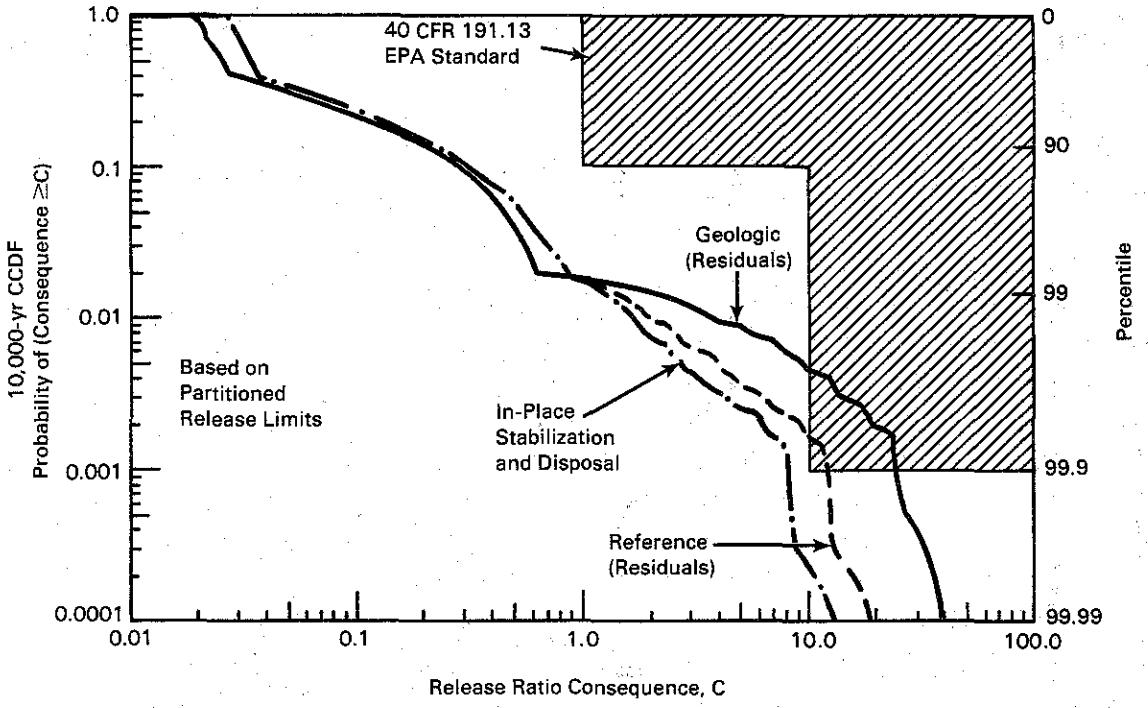

FIGURE S.11. Preliminary Composite CCDFs with 90% Chance of Wetter Climate and 50% Chance of Barrier Failure

On the other hand, if the base assumption of a 10% chance of a wetter climate (90% chance of the current climate) is used, which is believed to be conservative, and the 100% chance of barrier failure is used, then both the reference and in-place stabilization and disposal alternatives meet the EPA standard as shown in Figure S.13. For these composite CCDFs, the scenario probabilities in Figure S.3 were changed to $P(S_1) = P(S_2) = P(S_5) = P(S_6) = 0.0$, $P(S_3) = P(S_4) = 0.05$, and $P(S_7) = P(S_8) = 0.45$.

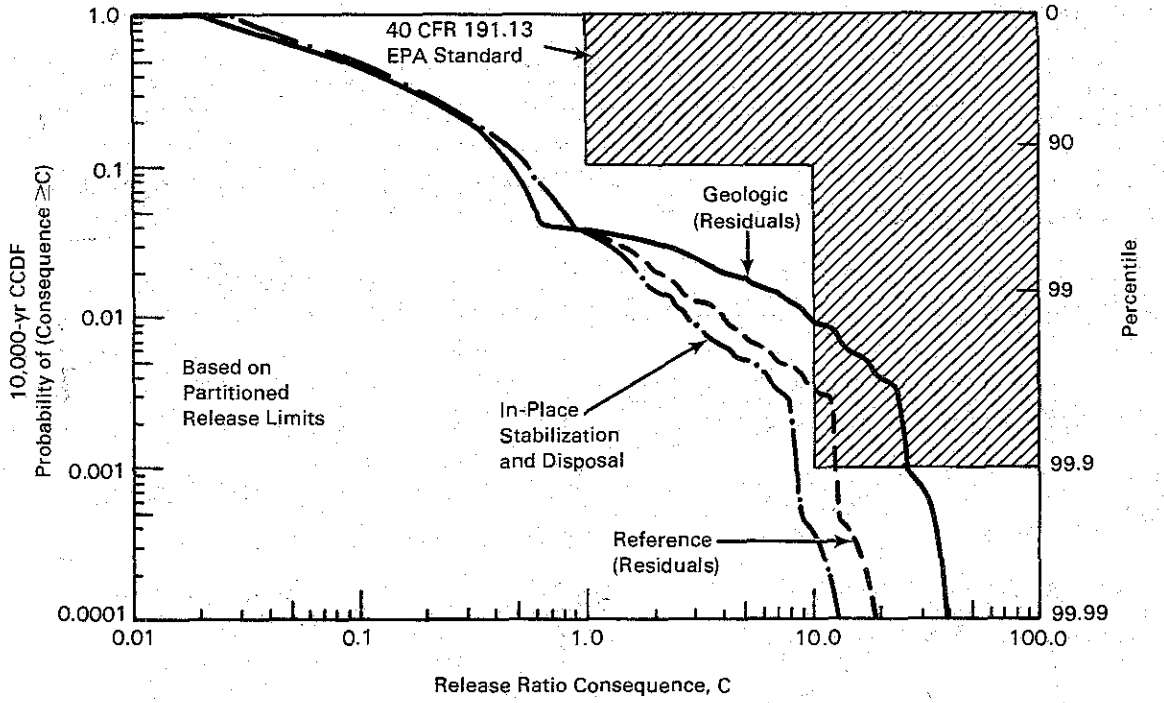

FIGURE S.12. Preliminary Composite CCDFs with 90% Chance of Wetter Climate and 100% Chance of Barrier Failure

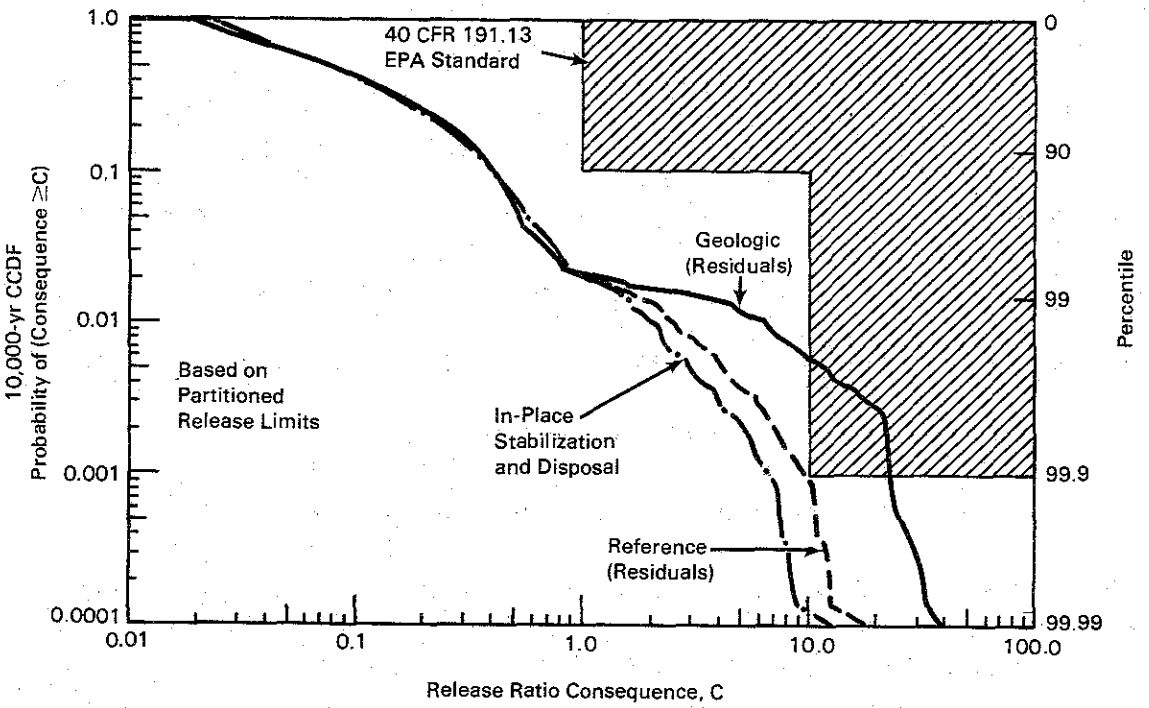

FIGURE S.13. Preliminary Composite CCDFs with 90% Chance of Current Climate and 100% Chance of Barrier Failure

S.7 REFERENCES

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APPENDIX T

METHOD FOR ESTIMATING NONRADIOLOGICAL AIR-QUALITY IMPACTS

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APPENDIX T

METHOD FOR ESTIMATING NONRADIOLOGICAL AIR-QUALITY IMPACTS

Nonradiological air-quality impacts reported in Chapter 5 were calculated for each disposal alternative using the Environmental Protection Agency's (EPA) Industrial Source Complex Dispersion Model. The model's receptor grid was set up to examine pollutant concentrations at areas of public access within Hanford and along the Hanford Site boundaries. Pollutants examined were CO, NO_x, SO_x, and total suspended particulates. Using five years of meteorological data and estimates of maximum pollutant emission rates, maximum air concentrations of each pollutant were calculated for selected averaging periods. Model results indicate that project activities will not violate federal, state or local ambient air-quality standards.

T.1 AIR-QUALITY GUIDELINES AND AMBIENT AIR-QUALITY STANDARDS

Under the authority of the Clean Air Act 1970 (amended 1977), the EPA established National Ambient Air Quality Standards (NAAQS) to protect the public health (primary standards) and the public welfare (secondary standards). At the state and local level, final Ambient Air Quality Standards (AAQS) are set. These final AAQS are equal to or more stringent than the NAAQS. Each standard specifies a concentration limit for a specific pollutant for a time period ranging from 1 hr to 1 year. The nonradiological pollutants that are governed by current AAQS and that would be emitted in significant quantities by Hanford defense waste activities are sulfur dioxide (SO_x), total suspended particulates (TSP), carbon monoxide (CO), and nitrogen dioxide (NO_x).

Current AAQS and maximum background pollutant concentrations are presented in Table T.1. Background measurements were made in the vicinity of the Hanford Site, and maximum values may be inflated by the proximity of local sources of pollution (NRC 1982, pp. 4-165 to 4-168). Many of these maximum values were also recorded during a period in which regional emissions were higher than their current level. Maximum ambient concentrations of pollutants may therefore be somewhat lower than indicated by the background measurements in Table T.1.

In this study, the Industrial Source Complex Dispersion Model (ISC) was used to simulate the nonradiological air-quality impacts of Hanford defense waste activities. The model employs EPA-approved methods (EPA 1977 and 1979) to determine short-term and annual average air-quality concentrations of pollutants for which AAQS have been established. Work with the ISC model was performed before final estimates of the maximum emission rates for each pollutant were available. The model was therefore run using a unit release rate for each pollutant. The pollutant concentrations produced by the model were interpreted as normalized concentrations and were later multiplied by maximum emission rates to obtain maximum pollutant concentrations.

TABLE T.1. **Ambient Air-Quality Standards and Maximum Measured Background Concentrations for Hanford** (Washington State, Benton County), $\mu g/m^3$

	Primary Standard	Secondary Standard	Supplementary State Standards	Maximum Background Concentrations
Sulfur Dioxide (SO_x)				
Annual arithmetic	80	80	52	0.5
24-hr maximum[a]	365	365	260	6
3-hr maximum[a]	--	1,300	--	20
1-hr maximum[a]	--	--	1,040	49
1-hr maximum[b]	--	--	650	49
Total Suspended Particulates (TSP)				
Annual geometric mean	75[c]	60[c]	40+background	56
24-hr maximum[a]	260[c]	150[c]	120+background	353
Carbon Monoxide (CO)				
8-hr maximum[a]	10,000	10,000	--	6,500
1-hr maximum[a]	40,000	40,000	--	11,800
Nitrogen Dioxide (NO_x)				
Annual arithmetic mean	100	100	--	36

(a) Not to be exceeded more than once per year.
(b) Not to be exceeded more than two times in any consecutive 7 days.
(c) Because concentrations may exceed standards due to rural fugitive dust, the primary and secondary standards are replaced by the supplementary Washington State standards.

T.2. AIR-QUALITY ANALYSIS PROCEDURES

ISC is a steady-state Gaussian plume model that predicts ground-level air concentrations of pollutants emitted from point, area, and volume sources. It is most appropriate for evaluating air-quality impacts from industrial complexes at which the cumulative impact from multiple sources must be considered (as in this study).

Hanford defense waste activities would involve the operation of numerous mobile sources of pollution (such as diesel-powered construction equipment). Rather than attempt to isolate each source, it was assumed for this analysis that the cumulative emissions from all sources constitute a single volume source within the Hanford Site. This approach is conservative because rarely, if ever, would all possible sources be emitting pollutants simultaneously. The 200 East Area was chosen to represent the source of the emissions. A volume source was specified encompassing the 200 East Area, with an effective emission height of 3 m. Initial lateral and vertical diffusion coefficients (σ_y and σ_z) were specified according to the ISC User's Guide (EPA 1979) criteria for evaluating emissions from a volume source.

For all model calculations a receptor grid was specified that included points along the Hanford Site boundary, Highway 240, and in other areas within the Hanford Site to which the public might have access. Specific receptor locations were selected to coincide with available meteorological data. In the meteorological data used in this study, wind direction

is given in terms of 16 sectors. The first of these 22.5°-wide sectors is for winds coming from the north and is centered at 0°. The second sector is for winds from the north-northeast and is centered at 22.5°. The remaining sectors follow in the same pattern, ending with the sixteenth sector, which is for winds coming from the north-northwest (centered at 337.5°). An ISC "preprocessor" computer code can randomly redistribute the winds within each 22.5°-wide sector to approximate natural variability. This option was not used because it is less conservative than orienting the winds along their sector centerlines. Grid points along the Hanford Site boundary were specified on the sector centerlines and on the dividing lines between the 16 sectors. All but four of the remaining grid points were also specified on either sector centerlines or dividing lines. Receptor locations are listed in Tables T.2 and T.3.

Preliminary modeling of Hanford defense waste emissions showed that the maximum environmental impact at publicly accessible locations would always occur within the Hanford Site or at its boundary. Because of the distances involved, ground-level pollutant concentrations will always be decreasing as project emissions are advected past the Hanford fenceline. Therefore it was not necessary to perform detailed modeling of the air quality beyond the Site boundary to determine maximum impacts.

The ISC model can produce average pollutant concentrations for periods of 1, 2, 3, 4, 6, 8, 12, and 24 hr. Annual average concentrations can also be computed. Concentrations for each averaging period can be tabulated so that highest and second-highest values are easily determined.

In computing the air concentration of particulates, the model considers gravitational settling and the resuspension of dust. Settling velocities, resuspension factors, and particle-size distributions are input by the user. In this study, settling velocities and resuspension factors were determined following the recommendations provided in the ISC User's Guide (EPA 1979). Particle-size distributions were based on data reported by PEDCo (1978).

T.3 METEOROLOGICAL INPUT

Hourly observations of wind speed, wind direction, temperature, mixing height and stability are required to compute hourly concentrations of pollutants. Five years of meteorological data were used in the analysis. The data were from the years 1960 through 1964, a period chosen because it is representative of Hanford's meteorology and because upper atmospheric measurements are available for this period. Detailed upper atmospheric data are not available for later years. Onsite meteorological data were collected and archived at the Hanford Meteorology Station (HMS), which is located between the 200 East and 200 West Areas. Hourly observations of wind speed, wind direction, and temperature were obtained from measurements made at several levels on the station's 125-m instrumented tower. Stability classes were determined from hourly values of the vertical temperature lapse rate ($\Delta T/\Delta Z$) following the recommendations in EPA (1979) and NRC (1974). The lapse rate was computed from

TABLE T.2. ISC Receptors Outlining the Hanford Site[a]

Receptor	Range, km	Direction, degrees[b]
1	27.3	360.0
2	28.5	11.3
3	28.5	22.5
4	26.9	33.8
5	23.1	45.0
6	21.1	56.3
7	18.8	67.5
8	17.7	78.8
9	20.9	90.0
10	21.8	101.3
11	23.9	112.5
12	26.5	123.8
13	28.9	135.0
14	26.9	146.3
15	20.9	157.5
16	21.6	168.8
17	20.9	180.0
18	20.1	191.3
19	18.1	202.5
20	17.4	213.8
21	21.5	225.0
22	23.7	236.3
23	21.9	247.5
24	20.9	258.8
25	20.5	270.0
26	21.0	281.3
27	24.2	292.5
28	22.5	303.8
29	22.2	315.0
30	22.3	326.3
31	22.4	337.5
32	24.6	348.8

(a) The position of each receptor is given in polar coordinates, with range (km) from the origin of the grid and direction in degrees from true north. The origin of the grid is located within the 200 East Area.

(b) Measured clockwise from true north.

TABLE T.3. ISC Receptors at Selected Locations of Interest[a]

Receptor	Range, km	Direction, degrees[b]	
33	29.3	140.0	Horn Rapids
34	22.9	152.0	
35	14.5	157.5	
36	11.1	168.8	
37	9.2	180.0	
38	7.8	202.5	
39	7.7	225.0	Highway 240
40	10.4	247.5	
41	12.1	270.0	
42	15.1	281.3	Yakima Barricade
43	16.5	292.5	
44	18.6	303.8	
45	17.3	315.0	
46	21.2	348.8	
47	20.7	360.0	Highway 240
48	21.0	11.3	
49	22.4	22.5	
50	29.5	45.0	
51	13.6	123.8	Wye Barricade
52	18.1	119.0	WNP 2
53	15.1	135.0	Wye Barricade to Highway 240
54	18.2	135.0	
55	18.0	146.3	Fast Flux Test Facility (FFTF)
56	5.5	285.5	Hanford Meteorological Station

(a) The position of each receptor is given in polar coordinates, with range (km) from the origin of the grid and direction in degrees from true north. The origin of the grid is located within the 200 East Area.
(b) Measured clockwise from true north.

temperature measurements made at the 15-m and 76-m levels on the tower. The lapse-rate stability classes used in this analysis are defined in Table T.4.

Mixing-height[a] data were estimated from measurements made at the Spokane International Airport (Spokane, Washington). Spokane is the station nearest to Hanford for which

(a) Mixing depths may be defined as the vertical extent of the atmosphere through which pollutants can disperse freely. Mixing heights are usually specified according to the height of the capping inversion that separates the air near the surface from the atmosphere above the inversion. Typical mixing depths can range from under a hundred meters at night to a few thousand meters during the day.

TABLE T.4. Lapse-Rate Stability Classes

Stability Class	$\Delta T/\Delta Z$, °C/100 m
1. Very unstable	$\Delta T/\Delta Z < -1.9$
2. Unstable	$-1.9 \leq \Delta T/\Delta Z < -1.7$
3. Slightly unstable	$-1.7 \leq \Delta T/\Delta Z < -1.5$
4. Neutral	$-1.5 \leq \Delta T/\Delta Z < -0.5$
5. Slightly stable	$-0.5 \leq \Delta T/\Delta Z < +1.5$
6. Stable	$+1.5 \leq \Delta T/\Delta Z$

radiosonde measurements of mixing height were available for a five-year period.(a) Spokane mixing heights were reported twice per day; hourly values were estimated by interpolations following the procedures used in the ISC preprocessor as recommended by the EPA. One adjustment to this procedure was made for this study. The preprocessor computes both an "urban" and a "rural" set of hourly mixing heights for a given day. Inspection of these values and comparison with limited data on mixing depth from HMS indicated that the urban mixing depths derived from the Spokane data were more realistic for application to the Hanford Site than were the estimated rural mixing heights. Urban mixing heights for all ISC runs were retained, although the model itself was run in a "rural" mode. This permitted the model to use atmospheric-stability classes E and F (AEC 1968), which frequently occur at the Hanford Site but which cannot be accounted for if ISC is executed in the "urban" mode.

T.4 SOURCE-DATA INPUT

In a support document by Rockwell Hanford Operations (1985) (which was used in this analysis), pollutant emission levels are estimated for the major tasks that comprise each disposal alternative. The starting year and the anticipated duration of most of the major tasks are also estimated. Annual emission levels of NO_x, SO_x, CO, and TSP for each task were computed using these data from Rockwell (1985). In the sizable number of instances in which there was uncertainty in the scheduling of a task, the highest possible annual emission level for each pollutant was assumed to occur during all the years the task could be performed. This resulted in the overestimation of annual emission levels; however, this approach was deemed the best way to ensure that annual emission levels would never be underestimated.

The total emission of each pollutant that would be generated during each year's activities was determined by summing the annual emission levels for each task. Both construction and operating emissions were summed to obtain this figure. The largest of these annual values are presented for each alternative in Table T.5.

(a) Data for Spokane were obtained from the archives of the National Climatic Data Center in Ashville, North Carolina.

TABLE T.5. Maximum Annual Emissions (kg/yr) and Emission Rates (g/s) for Pertinent Time Periods

Pollutant	Time Period	Disposal Alternatives: Geologic Disposal kg/yr	Geologic Disposal g/s	In-Place Stabilization and Disposal kg/yr	In-Place Stabilization and Disposal g/s	Reference (Combination) kg/yr	Reference (Combination) g/s	No Disposal Action: Continued Storage kg/yr	Continued Storage g/s
CO	Annual	248,000	7.9	207,000	6.6	219,000	6.9	28,000	0.89
	1-hr	--	33	--	28	--	29	--	3.7
	8-hr	--	33	--	28	--	29	--	3.7
NO_x	Annual	172,000	5.5	155,000	4.9	160,000	5.1	6,700	0.21
SO_x	Annual	173,000	5.5	280,000	8.9	137,000	4.3	20,000	0.63
	1-hr & 3-hr	--	23	--	37	--	18	--	2.7
	24-hr	--	7.7	--	12	--	6.0	--	0.88
TSP	Annual	325,000	10	1,380,000	44	1,178,000	37	7,400	0.23
	24-hr	--	14	--	62	--	52	--	0.32

The 24-hr emission rate is $(365/260)^{(a)}$ x maximum annual emission rate.
The 8-hr emission rate is 3 times the 24-hr emission rate.[(b)]
The 1- and 3-hr emission rates equal the 8-hr emission rate.

(a) This factor accounts for the 260 work days in a year of 365 days.
(b) Assumes all the emissions in a given day occur in an 8-hr period.

Maximum emission rates (mass per unit time) for each pollutant were computed by dividing the emission levels in Table T.5 by a work schedule that would be typical of Hanford construction and operation activities. An 8-hr workday, 5 days a week, 52 weeks a year was selected. The maximum emission rates for each pollutant and each alternative are presented in Table T.5.

T.5 AIR-QUALITY IMPACT CALCULATIONS AND RESULTS

The ISC model was run using hourly meteorological data and unit release rates for the various pollutants. Model output was in the form of normalized pollutant concentrations. For each pollutant and time period for which an AAQS exists, the highest or second-highest normalized concentration (depending on EPA guidelines) occurring on the receptor grid was identified. These values are presented in Table T.6.

Maximum applicable pollutant concentrations are obtained by multiplying the highest or second-highest normalized concentrations by their corresponding maximum emission rates (from Table T.5). These pollutant concentrations are presented for each alternative in Table T.6, along with the governing AAQS. The receptor locations corresponding to these values are also

TABLE T.6. Maximum Ambient Air-Quality Impacts for Each Alternative[a]

Pollutant	Normalized Concentration, $x10^{-6}$ s/m^3	Location km	Location degrees	Air Concentration, µg/m^3 Geologic Disposal	In-Place Stabilization and Disposal	Reference (combination)	No Disposal Action Continued Storage	AAQS µg/m^3
CO								
1-hr	16.8	7.7	225	556	464	490	62	40,000
8-hr	5.2	9.2	180	172	144	151	20	10,000
NO_x								
Annual	0.23	15	135	1.3	1.1	1.2	0.05	100
SO_x								
1-hr	16.8	7.7	225	389	627	308	45	1,040
3-hr	11.2	7.7	225	259	418	205	30	1,300
24-hr	2.1	7.8	202	16	25	13	1.9	260
Annual	0.23	15	135	1.3	2.1	1	0.14	52
TSP								
24-hr	0.49	12	270	6.9	32	2.5	0.2	120+background
Annual	0.03	15	135	0.3	1.3	1.6	0.01	40+background

(a) In accordance with AAQS, maximum annual average concentrations are reported for SO_x, TSP, and NO_x emissions. All short-term impacts (SO_x, TSP, and CO) are second-highest estimated concentrations, as specified by the EPA.

presented in Table T.6. Note that all these locations represent points well within the Hanford Site; none of the maximum concentrations occur at the receptor locations on the Site boundary.

Maximum pollutant concentrations due to project emissions do not exceed any of the AAQS. In fact, most of the maximum pollutant concentrations are more than an order of magnitude below their standard. When maximum pollutant concentrations are added to the available measurements of maximum background concentrations (from Table T.1), total pollutant concentrations are still well below AAQS. In all cases, AAQS are met, even though conservative assumptions were made in the determination of maximum emission rates, transport direction, background concentrations and the locations at which the AAQS apply. If the estimates of annual emission levels and the work schedules obtained from the working draft of Rockwell (1985) are not substantially changed, the nonradiological impacts of project emissions should not violate current federal, state or local AAQS.

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APPENDIX U

PRELIMINARY ANALYSIS OF THE FUTURE GROUNDWATER TRANSPORT OF CHEMICALS RELEASED

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APPENDIX U

PRELIMINARY ANALYSIS OF THE FUTURE GROUNDWATER TRANSPORT OF CHEMICALS RELEASED

U.1 INTRODUCTION

This appendix provides the results obtained in a preliminary analysis that illustrates the long-term transport of nonradioactive chemicals that might be disposed of near the surface at Hanford. Because they contain the highest known inventory of chemicals for waste classes in this EIS, single-shell tanks are analyzed for the release of chemicals. However, the fluoride in the future double-shell slurry shows a greater inventory and was also considered. Specific chemical compounds and their bulk quantities included in the inventory of Hanford single-shell tanks are given in Table U.1. Of the chemicals listed, only nitrite and nitrate ions, chromium, cadmium, mercury, and fluoride were analyzed because they represent key chemicals of concern and the analysis therefore provides insight into the potential for groundwater contamination by the chemicals called out in 40 CFR 141.

Organic compounds were not analysed in this EIS. The 200 tons of organic carbon shown in the inventory table for the single-shell tanks are primarily the chelating agents, EDTA, HEDTA, citric acid, and hydroxyacetic acid (ERDA 1975). These major organic components and their degradation products are not on the lists of Acutely Dangerous Chemical Products, Moderately Dangerous Chemical Products, or Dangerous Waste Constituents of the Washington Administrative Code (WAC 1984). There is little information on actual concentrations, solubilities, and adsorption reactions for organics, which makes the development and application of a conservative model difficult. There is also a lack of available information on the distribution of organic carbons already discharged to cribs and trenches at Hanford. These disposed wastes may contain higher quantities and more hazardous organics than chelating agents such that an analysis of the organics in single-shell tanks in all likelihood underestimate the environmental impacts. One objective of the current Hanford Comprehensive Emergency Response, Compensation and Liability Act (CERCLA) Coordination Program is to determine the disposition of hazardous organic compounds in the Hanford waste disposed of to ground.

Additional efforts to further characterize chemicals in all waste classes are planned under ongoing programs and as a part of the development and evaluation work identified under the preferred alternative discussed in Volume 1, Section 3.3.5. Hazardous-chemical disposal is discussed with respect to the preferred alternative and the RCRA and CERCLA regulations in Volume 1, Section 3.3.5.7 (which would be typical of chemical disposal in the other disposal alternatives as well).

U.2 THE SOURCE TERM

The release of each of the six chemicals is based on the solution concentration of each in water and on the assumption that water can freely enter and leave the single-shell tanks.

TABLE U.1. Estimated Mass of Chemical Components of Existing Single-Shell Tank Wastes After Completion of Jet Pumping[a]

Chemical	Total Bulk Sludge, t	Total Bulk Salt Cake, t	Nonpumpable Liquid, t
Inert Chemicals			
$NaNO_3$	20,000	110,000	2,500
$NaNO_x$	3,000	2,300	1,900
Na_2CO_3	1,700	730	70
NaOH	4,200	2,000	740
$NaAlO_2$	950	1,900	1,500
Na_2SO_4	740	1,700	
Na_3PO_4	12,500	2,100	280
Cancrinite[b]	2,700		
$Al(OH)_3$	2,300		
$Ce(OH)_3$	320		
$Cr(OH)_3$	190		
$Cd(OH)_2$	5		
$Fe(OH)_3$	1,200		
$Sr(OH)_2$	50		
$BiPO_4$	380		
$CaCO_3$	320		
Cl^-	40		
F^-	800		5
Hg^+	0.9		
MnO_2	190		
$Ni_2Fe(CN)_6$	500		
$P_2O_5 \cdot 24WO_2 \cdot 44H_2O$	20		
$ZrO_2 \cdot 2H_2O$	430		
Organic Carbon			200
H_2O	26,000	14,000	4,800
Totals	79,000	135,000	12,000

(a) Reproduced from Table 2.5, Rockwell 1985.
(b) Known silica additions are assumed to have reacted with aluminates and hydroxides to form cancrinite (assumed to be $2NaAlSiO_4 \cdot 0.52NaNO_3 \cdot 0.68H_2O$).

Two scenarios are studied: a protective barrier over the tank farms and no barrier over the tank farms; and each is analyzed for two annual average recharge rates: 0.5 cm/yr and 5 cm/yr, chosen to represent conditions under a current or wetter climate.

U.2.1 The Source Without a Barrier

If the protective barrier and marker system is not placed over the single-shell tanks, it is postulated in this analysis that, by the year 2150, infiltrating water would be able to freely enter and leave the tanks and therefore carry away solutions of the specified chemicals. A simple dissolution model is applied, with the period of release defined by the mass of chemical, its characteristic solution concentration (e.g., solubility limit) in water, the infiltration rate, and the surface area of the storage facility. The calculations utilize the maximum observed solution concentration data in Schulz (1980) to determine the release characteristics of each chemical except for cadmium and fluoride. The limiting solution concentration for cadmium is extrapolated from work by Rai et al. (1984). The cadmium concentration was extrapolated from the equilibrium relationship between alkaline carbonite-rich waters native to Hanford and the cadmium carbonate mineral otavite. The limiting concentration for fluoride comes from Lindsay (1979) and represents equilibrium with fluorite. The surface area of single-shell tanks in the 200 East and 200 West Areas are 2.7×10^4 m^2 and 3.4×10^4 m^2, respectively. The remaining data are given in Table U.2.

TABLE U.2. Parameters and Data for the Source Model of Selected Chemicals in Single-Shell Tanks

Chemical	Characteristic Solution Concentration, g/mL	Mass, g			Annual Infiltration Rate, cm/yr
		Total	200 East Area	200 West Area	
Nitrate (NO_3)	3.0×10^{-1}	1.3×10^{11}	3.6×10^{10}	6.1×10^{10}	0.5 5.0
Cadmium (Cd)	1.1×10^{-8}	3.8×10^{6}	1.4×10^{6}	2.4×10^{6}	0.5 5.0
Chromium (Cr)	1.1×10^{-2}	9.6×10^{7}	3.5×10^{7}	6.1×10^{7}	0.5 5.0
Mercury (Hg)	3.2×10^{-4}	9.0×10^{5}	3.3×10^{5}	5.7×10^{5}	0.5 5.0
Nitrite (NO_x)	1.4×10^{-1}	4.8×10^{9}	1.8×10^{9}	3.0×10^{9}	0.5 5.0
Fluoride (F^-)	1.9×10^{-6}	8.0×10^{8}	3.0×10^{8}	5.0×10^{8}	0.5 5.0

The chromium and mercury species in the tank are unknown, and given the high pH and high ionic strength of the tank contents it is possible that highly soluble species are prevalent. Because speciation is unknown and highly soluble species do exist for these two elements, the solution concentration shown in Table U.2 are used in this preliminary analysis. Experience has shown that these elements do not move far in the natural environment and this might justify less conservative concentration values. Recorded experience, however, may not apply to

solutions found in the single-shell tanks. The high ionic strength of the tank contents and the existence of organic chelating agents contributed to the decision to use the experimentally determined concentrations of tank contents.

U.2.2 The Source with a Barrier

When a protective barrier is in place over the tanks, the chemicals are assumed to be released from the tank at the characteristic solution concentration shown in Table U.2 for transport by diffusion in the sediments under the barrier until an advection-controlled zone is reached. It is assumed that vapor pressure differences existing between soil and waste would cause water to enter the single-shell tanks through existing openings (i.e., sampling ports, supply pipeline openings), failed welds, and corroded surfaces. Once inside, it is assumed that the water would become saturated with chemical constituents and then somehow eventually drain into the soil beneath or surrounding the tank. It is postulated that pore water saturated with chemical constituents would cause very slow transport to occur by diffusion. This transport mechanism would conduct the chemicals over long periods of time from the tank to the edge of the barrier, presently designed to be at least 10 m distant (Appendix M), and then downward via advection and diffusion to the water table. At this point, infiltrating water would conduct the chemicals down through the unsaturated soil profile and into the unconfined aquifer.

The conceptual and mathematical models for this analysis are described in Appendices P and O of this EIS. These are entitled "Diffusion-Controlled Release Model" and "Unit Hydraulic Gradient Model" in Appendix O and "Diffusion-Controlled Release Beneath a Protective Barrier" in Appendix P. The solution concentrations of chemical elements studied in the protective barrier case are given in Table U.2.

U.3 ATTENUATION

The linear distribution coefficient (K_d) model of attenuation could be employed in the transport analysis of chemicals. Due, however, to the high ionic strength of the solution and the existence of organic chelating agents in the solution, it was assumed that the chemicals would be as mobile as the water to ensure a conservative simulation of chemical migration. This conservative assumption is used since speciation and adsorption data for nonradioactive chemicals under conditions at Hanford are not available.

If a non-zero K_d were used, values at the low end of the K_d range for each chemical would be used. Commonly used is an effective K_d that is an average of high values indicative of relatively immobile species of the element and low values indicative of relatively mobile species of the element. Adsorption is a process by which ions compete for sorption sites on the solid. In a high-ionic-strength solution there would be an abundance of ions that could be more readily adsorbed than the key chemicals selected for analysis in this EIS. The existence of organic chelating agents introduces the possibility that the chemicals of concern will be complexed with the organic compounds and unavailable for adsorption. Because of the high-ionic-strength solution and organic chelating agents, low K_d values must be considered

indicative of the more mobile species of the element. To be conservative in the estimate of chemical transport, K_d values of zero have been used throughout this analysis.

U.4 RESULTS

The subsurface transport of chemicals was modeled using the same hydrologic and transport codes applied to radionuclide transport (see Appendices O and Q). The Variable Thickness Transient Groundwater Flow Model (VTT) (Reisenauer 1979) has been used to simulate flow via streamtubes in the unconfined aquifer, and the TRANSS code (see Appendix O) has been used to simulate transport through the vadose zone and the unconfined aquifer. Tables U.3 through U.6 show the migration results for the 5-cm/yr recharge rate and the 0.5-cm/yr recharge rate, in both cases with and without the barrier in place.

These tables show the input chemical, its inventory and the retardation factor to be consistent with a K_d=0. The results are the time it takes to release the inventory (release time) at the chemical solubility limit in the water available, the arrival of the peak concentration at the 5-km well, and the time and peak rate of release from the groundwater to the Columbia River.

The analysis conducted with a protective barrier over the tank farm is based on the assumption that release is controlled by limiting the influx of water and the diffusive pathway. Diffusion moves chemicals from the tank toward the barrier edge and downward to the water table. The mass diffused toward the barrier edge is picked up by the vertically downward flow of infiltrating water and is advected to the water table. Mass diffused directly to the water table beneath the barrier and mass carried by the advective flow in the vadose zone are integrated and form the source for transport in the aquifer.

The only chemical species among the six considered that is in larger amounts (1,200 t versus 800 t for single-shell tanks) in the future tank wastes is fluoride. Considering the solubility-limiting release it can be shown that peak concentrations at the 5-km well will be the same as those in Tables U.4 and U.6 regardless of the inventory.

U.5 CONSERVATISM

Conservatism in modeling the release of chemicals results from the use of relatively high maximum solution concentration values and the use of K_d values of zero. The former assumption leads to high concentrations and the latter leads to simultaneous travel with the water. Note that when the peak arrival event occurs is of less concern than the impacts associated with the mass released. Therefore the solution concentration data are of central importance and relatively high values have been used throughout this analysis.

If the release from single-shell tanks were modeled more realistically, a time distribution of tank corrosion and failure would be included, and more detailed analyses would be used to determine moisture movement into and out of the tanks. It is possible that water will not be able to supply chemicals at assumed characteristic solution concentrations outside the tank structure in sufficient quantity to satisfy the diffusive flux. In the

TABLE U.3. Chemical Transport from Salt and Sludge in Single-Shell Tanks--With Protective Barrier--5-cm/yr Average Annual Recharge

Chemical	Inventory Released, g	Retardation Factor	Release Time, yr	5-km Well: Peak Arrival, Years After Disposal	5-km Well: Peak Concentration, g/L	Columbia River Boundary: Peak Arrival, Years After Disposal	Columbia River Boundary: Peak Rate, g/yr
			200 East				
Cr	3.5×10^{7}	1	2.4×10^{6}	4,900	1.2×10^{-7}	4,920	1.4×10^{2}
Cd	1.4×10^{6}	1	9.9×10^{8}	4,900	3.4×10^{-12}	4,920	3.0×10^{-3}
Hg	3.3×10^{5}	1	2.4×10^{6}	4,900	1.1×10^{-9}	4,920	1.3
NO_3^-	3.6×10^{10}	1	2.5×10^{6}	4,900	1.8×10^{-5}	4,920	3.1×10^{4}
NO_x^-	1.8×10^{9}	1	2.4×10^{6}	4,900	5.5×10^{-6}	4,920	6.8×10^{3}
F^-	3.0×10^{8}	1	1.2×10^{9}	4,900	6.0×10^{-10}	4,920	5.2×10^{-1}
			200 West				
Cr	6.1×10^{7}	1	2.5×10^{6}	4,950	2.4×10^{-6}	5,000	2.1×10^{2}
Cd	2.4×10^{6}	1	1.3×10^{9}	4,950	4.4×10^{-10}	5,000	2.7×10^{-3}
Hg	5.7×10^{5}	1	2.5×10^{6}	4,950	2.2×10^{-8}	5,000	2.0
NO_3^-	6.1×10^{10}	1	2.7×10^{6}	4,950	3.8×10^{-4}	5,000	4.1×10^{4}
NO_x^-	3.0×10^{9}	1	2.5×10^{6}	4,950	9.4×10^{-5}	5,000	9.1×10^{3}
F^-	5.0×10^{8}	1	1.6×10^{9}	4,950	2.5×10^{-9}	5,000	6.4×10^{-1}

TABLE U.4. Chemical Transport from Salt and Sludge in Single-Shell Tanks--No Barrier--5-cm/yr Average Annual Recharge

Chemical	Inventory Released, g	Retardation Factor	Release Time, yr	5-km Well: Peak Arrival, Years After Disposal	5-km Well: Peak Concentration, g/L	Columbia River Boundary: Peak Arrival, Years After Disposal	Columbia River Boundary: Peak Rate, g/yr
			200 East				
Cr	3.5×10^{7}	1	2.4	270	9.2×10^{-3}	280	7.7×10^{6}
Cd	1.4×10^{6}	1	9.4×10^{4}	270	1.7×10^{-8}	280	1.5×10^{1}
Hg	3.3×10^{5}	1	7.7×10^{-1}	270	1.4×10^{-4}	280	1.1×10^{5}
NO_3^-	3.6×10^{10}	1	8.8×10^{1}	270	4.7×10^{-1}	280	4.1×10^{8}
NO_x^-	1.8×10^{9}	1	1.0×10^{1}	270	2.2×10^{-1}	280	1.9×10^{8}
F^-	3.0×10^{8}	1	1.2×10^{5}	270	3.0×10^{-5}	280	2.6×10^{3}
			200 West				
Cr	6.1×10^{7}	1	3.3	320	5.9×10^{-2}	340	6.9×10^{6}
Cd	2.4×10^{6}	1	1.3×10^{5}	320	2.2×10^{-7}	340	1.9×10^{1}
Hg	5.7×10^{5}	1	1.1	320	7.4×10^{-4}	340	9.4×10^{4}
NO_3^-	6.1×10^{10}	1	1.2×10^{2}	320	6.0	340	5.1×10^{8}
NO_x^-	3.0×10^{9}	1	1.3×10^{1}	320	1.6	340	1.6×10^{8}
F^-	5.0×10^{8}	1	1.6×10^{5}	320	3.8×10^{-5}	340	3.2×10^{3}

TABLE U.5. Chemical Transport from Salt and Sludge in Single-Shell Tanks--With Protective Barrier--0.5-cm/yr Average Annual Recharge

Chemical	Inventory Released, g	Retardation Factor	Release Time, yr	5-km Well		Columbia River Boundary	
				Peak Arrival, Years After Disposal	Peak Concentration, g/L	Peak Arrival, Years After Disposal	Peak Rate, g/yr
				200 East			
Cr	3.5×10^{7}	1	2.4×10^{6}	5,000	1.4×10^{-6}	5,500	1.4×10^{2}
Cd	1.4×10^{6}	1	1.2×10^{9}	5,000	3.0×10^{-11}	5,500	2.5×10^{-3}
Hg	3.3×10^{5}	1	2.4×10^{6}	5,000	1.3×10^{-8}	5,500	1.3
NO_3^-	3.6×10^{10}	1	2.6×10^{6}	5,000	3.1×10^{-4}	5,500	2.7×10^{4}
NO_x^-	1.8×10^{9}	1	2.4×10^{6}	5,000	9.1×10^{-5}	5,500	6.2×10^{3}
F^-	3.0×10^{8}	1	1.5×10^{9}	5,000	4.2×10^{-9}	5,500	4.3×10^{-1}
				200 West			
Cr	6.1×10^{7}	1	2.5×10^{6}	5,100	6.0×10^{-6}	5,300	2.2×10^{2}
Cd	2.4×10^{6}	1	1.6×10^{9}	5,100	8.6×10^{-11}	5,300	3.1×10^{-3}
Hg	5.7×10^{5}	1	2.5×10^{6}	5,100	5.6×10^{-8}	5,300	2.0
NO_3^-	6.1×10^{10}	1	2.9×10^{6}	5,100	1.0×10^{-3}	5,300	3.6×10^{4}
NO_x^-	3.0×10^{9}	1	2.5×10^{6}	5,100	2.3×10^{-4}	5,300	8.2×10^{3}
F^-	5.0×10^{8}	1	2.0×10^{9}	5,100	1.5×10^{-9}	5,300	5.3×10^{-1}

TABLE U.6. Chemical Transport from Salt and Sludge in Single-Shell Tanks--No Barrier--0.5-cm/yr Average Annual Recharge

Chemical	Inventory Released, g	Retardation Factor	Release Time, yr	5-km Well: Peak Arrival, Years After Disposal	5-km Well: Peak Concentration, g/L	Columbia River Boundary: Peak Arrival, Years After Disposal	Columbia River Boundary: Peak Rate, g/yr
			200 East				
Cr	3.5×10^{7}	1	2.4×10^{1}	1,200	5.2×10^{-3}	1,500	2.0×10^{5}
Cd	1.4×10^{6}	1	9.4×10^{5}	1,200	1.5×10^{-8}	1,500	1.5
Hg	3.3×10^{5}	1	7.7	1,200	7.0×10^{-5}	1,500	1.1×10^{4}
NO_3^-	3.6×10^{10}	1	8.8×10^{2}	1,200	4.0×10^{-1}	1,500	4.1×10^{7}
NO_x^-	1.8×10^{9}	1	1.0×10^{2}	1,200	1.9×10^{-1}	1,500	1.2×10^{6}
F^-	3.0×10^{8}	1	1.2×10^{6}	1,200	2.5×10^{-6}	1,500	2.6×10^{2}
			200 West				
Cr	6.1×10^{7}	1	3.3×10^{1}	1,300	2.5×10^{-2}	1,400	1.2×10^{6}
Cd	2.4×10^{6}	1	1.3×10^{6}	1,300	5.3×10^{-8}	1,400	1.9
Hg	5.7×10^{5}	1	1.1×10^{1}	1,300	1.4×10^{-4}	1,400	1.2×10^{4}
NO_3^-	6.1×10^{10}	1	1.2×10^{3}	1,300	1.4	1,400	5.1×10^{7}
NO_x^-	3.0×10^{9}	1	1.3×10^{2}	1,300	6.7×10^{-1}	1,400	2.4×10^{7}
F^-	5.0×10^{8}	1	1.6×10^{6}	1,300	9.2×10^{-6}	1,400	3.2×10^{2}

absence, however, of detailed studies of the tank as a source, it was assumed that the vapor-pressure gradient would supply the force necessary to move soil water into the degraded tank structure.

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APPENDIX V

SITE-MONITORING EXPERIENCE

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APPENDIX V

SITE-MONITORING EXPERIENCE

V.1 INTRODUCTION

Since the initial processing of irradiated nuclear fuels at the Hanford Site in the early 1940s, liquid wastes containing low levels of radionuclides have been discharged to the ground, and monitoring has been done to determine disposition and concentration of the radiocontaminants in the ground and groundwater. There have been approximately 200 disposal facilities constructed in the 200 Areas (Graham et al. 1981). The following types of facilities have been utilized for liquid waste disposal at Hanford.

- cribs - liquid dispersal systems, used for disposal of process, condensate and lab wastes
- trenches - unlined excavations, generally used for short periods on a specific retention basis for the disposal of high-salt waste or waste containing complexed radionuclides
- French drains - covered or buried gravel-filled encasements with open bottoms, used for the disposal of small volumes of low-level waste
- reverse wells - buried or covered, encased, drilled holes with the lower end perforated or open, used for the disposal of process waste.

The large volumes of cooling water and steam condensates generated by chemical processing facilities and the evaporator-crystallizers are discharged to surface ponds and ditches. Normally, the radionuclide concentrations in these ponds and ditches remain below concentration guides, but occasionally, nonroutine releases of higher-level wastes do occur (Graham et al. 1981). Ponds are natural or diked surface depressions which allow the liquid effluent to percolate into the underlying sediment. Ditches are unlined excavations used for conveying the low-level liquid waste to the ponds. In several cases, the designation of "ditch" has been given to sites used to dispose of liquids rather than to convey liquids (e.g., 216-S-10 and 216-U-14 ditches).

Over 2,900 wells have been constructed on the Hanford Site from pre-Hanford operations to the present. About 1,100 of these wells were drilled to the groundwater table (McGhan, Mitchell and Argo 1985). The network of wells, constructed mainly in support of the waste disposal activities, provides means for monitoring waste disposal sites both within the vadose zone and below the water table and for monitoring groundwater quality away from the disposal sites. In addition, the wells provide information on geohydrology and aquifer characteristics.

For more than 35 years, a comprehensive program has been in effect for monitoring the movement, distribution and concentration of radiocontaminants (from waste disposal activities) in the unconfined aquifer on the Hanford Site. Groundwater samples are obtained

routinely from wells throughout the Site. During 1984, 339 wells in the Hanford Site network were sampled. In addition, 127 wells in the Separations Area monitoring network located predominantly in the 200 Areas were sampled (Law et al. 1986). Figure V.1 shows the location and distribution of wells currently used in the far-field monitoring program during CY 1984 to assess water quality and measure groundwater levels in the Hanford Site unconfined aquifer. A total of 1,510 well-water samples were taken to provide 4,434 analytical results for evaluating the effects of site operations on the groundwater (Cline, Rieger and Raymond 1985).

The information provided by the well network and the resultant geohydrologic investigations and groundwater monitoring programs have provided unprecedented empirical data on geology, hydrology and subsurface radiocontaminant behavior for the Hanford Site. These data provide an extensive qualitative to semiquantitative understanding of Hanford geohydrology and have supported development of a numerical model, known as the Variable Thickness Transient (VTT) model, of the unconfined aquifer flow system (Kipp et al. 1976; Reisenauer 1979). Originally designed and implemented to model the Hanford Site (Kipp et al. 1976), the VTT code has been updated twice (Reisenauer 1979; Bond, Newbill, and Gutknecht 1981) and applied to a variety of aquifer systems. Standards of code documentation, e.g., NUREG-0856 (Silling 1983), adopted since publication of the series of documents by Reisenauer (1979a,b,c) are not specifically addressed in more recent documentation. However, the code itself is well documented, and its application to the unconfined aquifer underlying the Hanford Site is a matter of record. Attempts to model transport of contaminants within that flow system have met with limited success and then only for conservative constituents[(a)] such as tritium (Ahlstrom et al. 1977).

Iodine-129, because of its long half-life (16 million years) and its biological significance, is recognized as a contaminant of potential concern in the groundwater. An intercontractor working group was formed in 1986 to gather, summarize, and evaluate information on ^{129}I in groundwater (Westinghouse 1987). Findings of this group include the following:

1) Above-background levels of ^{129}I have been measured on site in the confined aquifer system to a depth of 1,500 ft.

2) The amount of quantifiable ^{129}I information is insufficient to draw definite conclusions about its origin or its movement in the confined aquifer.

3) All recent onsite ^{129}I measurements are below the DOE Derived Concentration Guide (DCG) of 500 pCi/L, and all recent offsite measurements are well below the EPA Drinking Water Standard of 1 pCi/L.

4) The concentrations of ^{129}I in well water samples from east of the Columbia River are comparable to surface and groundwater measurements from locations 50 to 200 miles from the Hanford Site, and may be attributed to "rainout/fallout" mechanisms rather than aquifer transport.

(a) i.e., conservative ions, which can move through the geohydrologic system unchanged by chemical processes.

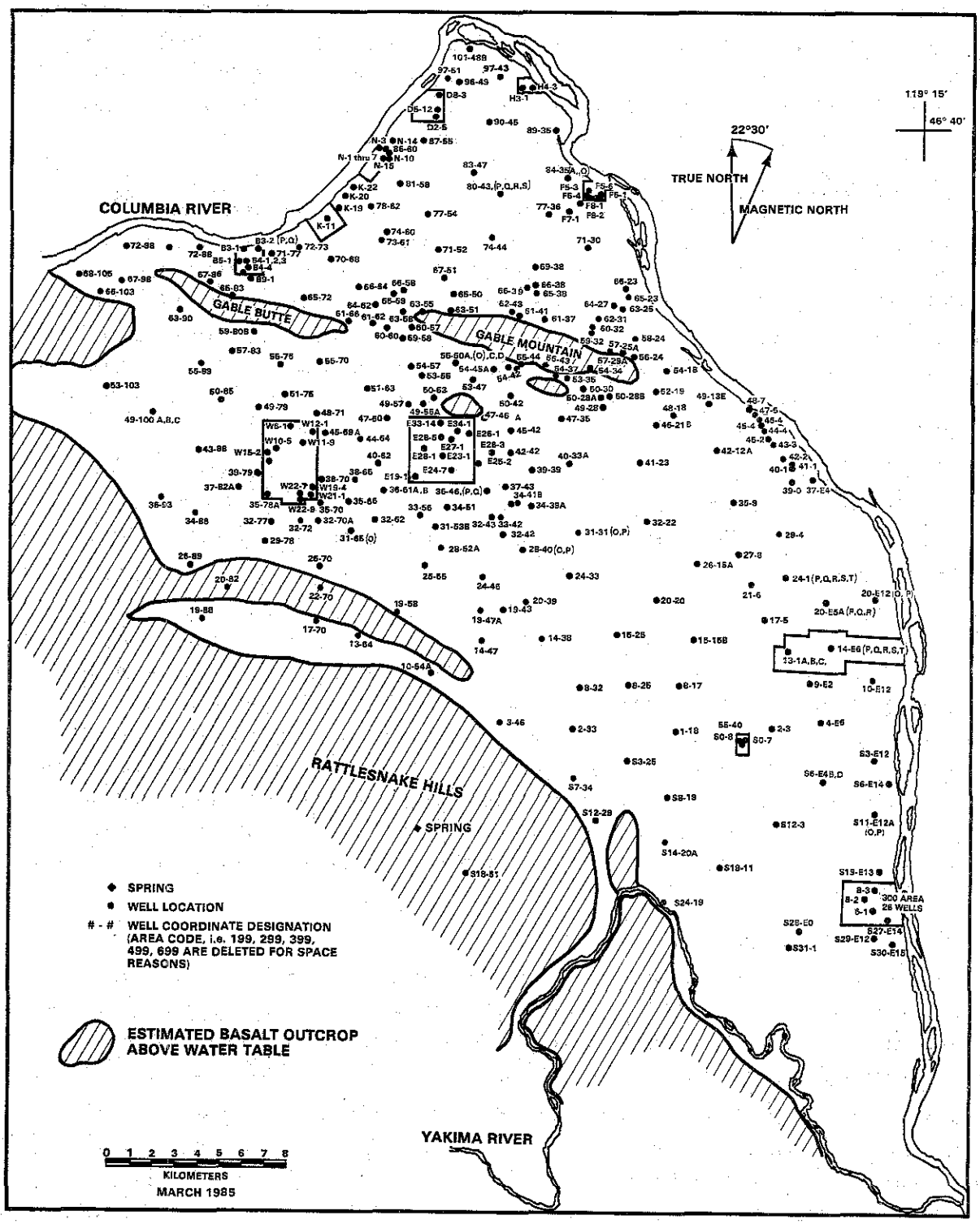

FIGURE V.1. Locations of Sampling Wells CY 1984

Use of the empirical geohydrologic and contaminant data for predicting future groundwater movement and contaminant transport is limited to conditions that relate closely to present and historical hydrologic conditions and observations. Likewise, the numerical models, though more flexible as predictive tools, must be used with care if hydrologic conditions vary greatly from those under which the models were developed.

Under Waste Management Programs at Hanford, selected retired facilities have been characterized to some extent. These characterizations are limited to field measurements of radionuclide distributions in the sediments surrounding the facilities. A review of these contaminant distributions provides insight into the behavior of radionuclides in the Hanford subsurface environment and, therefore, a qualitative check on the model predictions in this document. These data cannot be used to determine if or how much natural recharge through the unsaturated zone has occurred. Because the discharge of radionuclides from waste management operations was not done as a "controlled experiment," the data cannot be interpreted for more than they are worth.

Characterization data for cribs, a trench, a French drain, a reverse well, and a disposal pond and ditch system are summarized below. In addition, data collected on the investigations of a leak in a high-level waste storage tank and of uranium contamination of groundwater near an inactive crib are reviewed.

V.2 CRIBS

Characterization studies have been conducted on four cribs: 216-A-24 (Klepper et al. 1979), 216-Z-12 (Kasper 1981a,b, 1982), 216-Z-1A (Price and Ames 1975; Price et al. 1979; Kasper et al. 1979); and 216-S-1 and S-2 (Haney and Linderoth 1959; Raymond and McGhan 1967; Van Luik and Smith 1982). The results of these investigations are summarized from the above-mentioned references. Uranium contamination of the groundwater underlying the inactive 216-U-1 and 216-U-2 cribs is described briefly, while characterization activities are currently under way. These cribs are described in an effort to provide all available information on the cribs.

216-A-24 Crib

The 216-A-24 crib, built in 1957, is located east of the 200 East Area outside the exclusion fence. Between May 1958, and January 1966, the crib received condensates from the boiling waste storage tanks in the 241-A and 241-AX Tank Farms. As of December 1974, the crib still contained an estimated 385 Ci of ^{137}Cs and 27 Ci of ^{90}Sr (Table V.1).

The structure of the crib is shown in Figure V.2. It consists of four sections, each 350 ft long. Condensates from the tank farm were delivered to the head of the crib and drained into a gravel drainfield through perforations in a 15-in.-dia pipe. The depth of this perforated pipe from finished grade varies from about 15 ft at the upper end of each crib section to about 8 ft at the lower end of each section. The pipe is covered first with gravel and then with a polyethylene sheet. The sheet prevents sand from the overlying backfill material from sifting into the gravel bed.

TABLE V.1. Radioactivity Remaining in the 216-A-24 Crib as of December 31, 1974 (Anderson 1975)

	Remaining Ci
Beta	795
^{90}Sr	27.0
^{106}Ru	0.069
^{137}Cs	385
^{60}Co	0.093

Soil excavations and measurements were made during the characterization of the crib (Klepper et al. 1979). The gravel appeared to retain significant amounts of ^{137}Cs. A gamma scan of a sample of the soil from this layer showed traces of ^{134}Cs and ^{40}K, no significant ^{60}Co, and 0.0259 nCi ^{90}Sr/g. Soil above the gravel layers was not contaminated, although there were detectable levels of ^{137}Cs in the rabbitbrush roots which grew through that soil. Cesium-137 was detectable in the upper cm of soil and in the litter, especially beneath canopies of plants with high levels of ^{137}Cs in their leaves. However, at the 15-cm depth, ^{137}Cs was not detectable in the soil. The characterization document on the 216-A-24 crib contained no data on the horizontal distribution of contaminants or data on the presence of contamination below the gravel layers. Therefore, the behavior of contaminants migrating from this disposal facility cannot be completely characterized.

216-Z-12 Crib

The 216-Z-12 crib is located in the 200 West Area, immediately south of the Z Plant exclusion area. From March 1959 through May 1973, the crib received approximately 2.8×10^8 L of aqueous "low-salt" wastes,(a) derived from the Z Plant complex, containing an estimated plutonium inventory of 25.1 kg. Americium activity was derived from the in-situ decay of ^{241}Pu, not from a separate waste source. No other transuranic elements were discharged to the crib in any significant amount. Before discharge, the solution was collected in holding tanks and neutralized to a pH of 8. The crib was retired in May 1973.

The design of the 216-Z-12 crib is typical of a crib for aqueous waste as described in ERDA-1538 (Energy Research and Development Administration 1975), and is shown in Figure V.3. The crib was constructed by digging a ditch 110 m long and approximately 6.1 m deep, placing a 1.5-m-thick layer of gravel along the bottom, lining the ditch with a plastic sheet, and backfilling to the original grade. A perforated pipe, placed in the gravel layer and running the length of the crib, was designed to distribute the liquid over the bottom of the crib, thus permitting the waste to percolate into the sediments beneath the crib.

(a) Low-salt waste is a dilute (approximately 0.1 M) solution of sodium, fluoride, and nitrate.

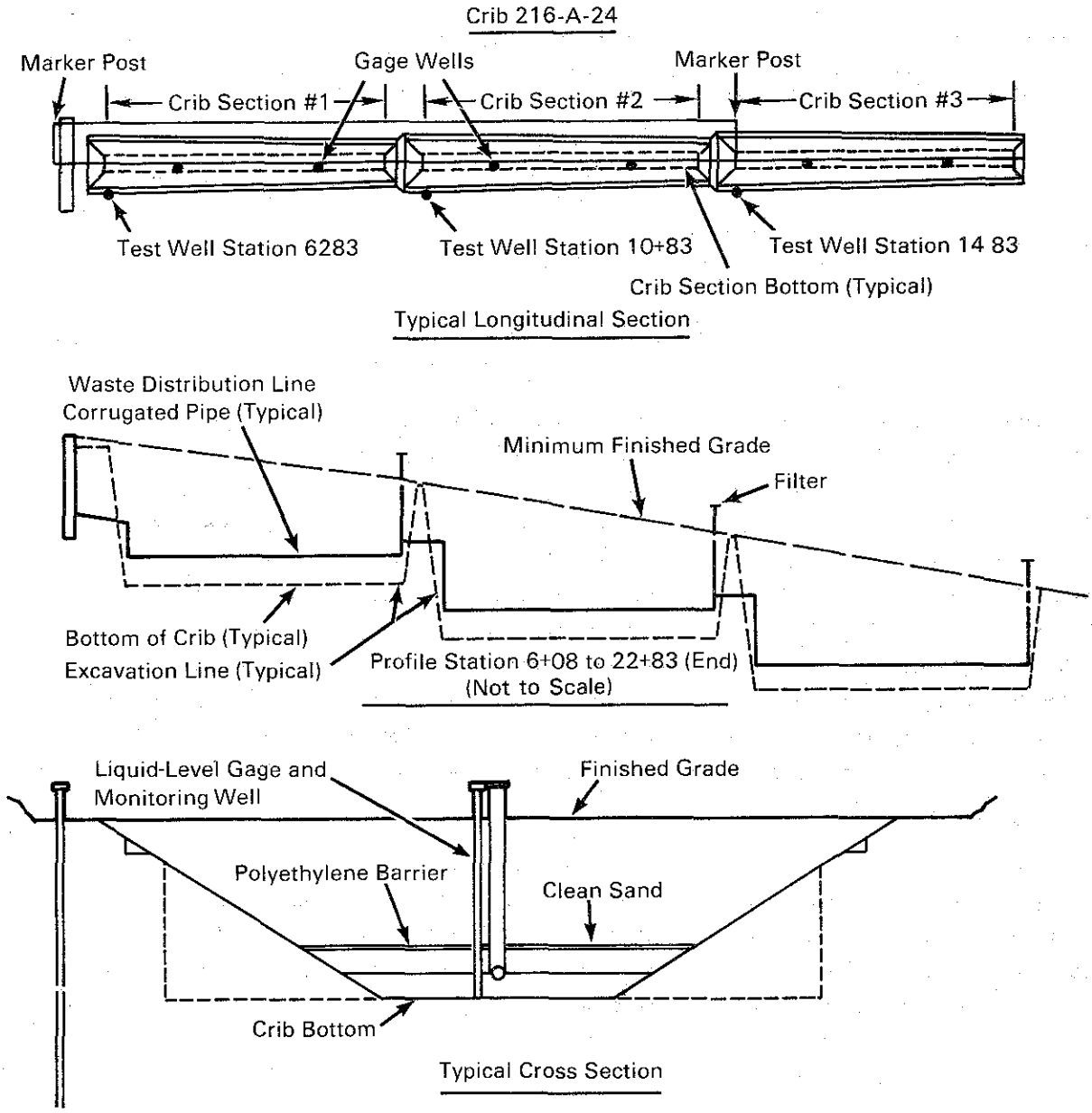

FIGURE V.2. Structural Details of the 216-A-24 Crib

The 216-Z-12 crib was characterized in 1979 (Kasper 1981a,b, 1982). The distribution of plutonium and americium was determined by drilling wells in and around the 216-Z-12 crib and by using specialized techniques and procedures for obtaining samples of radioactively contaminated sediment. Samples from each well were analyzed to determine sediment type, moisture content, and plutonium and americium concentrations. Results of the study showed that the highest concentration of plutonium (approximately 6 x 10^6 pCi/g) occurred in the sediment immediately below the crib bottom. Plutonium concentrations decrease rapidly with distance away from the bottom of the crib. No plutonium activity greater than 1 pCi/g was detected

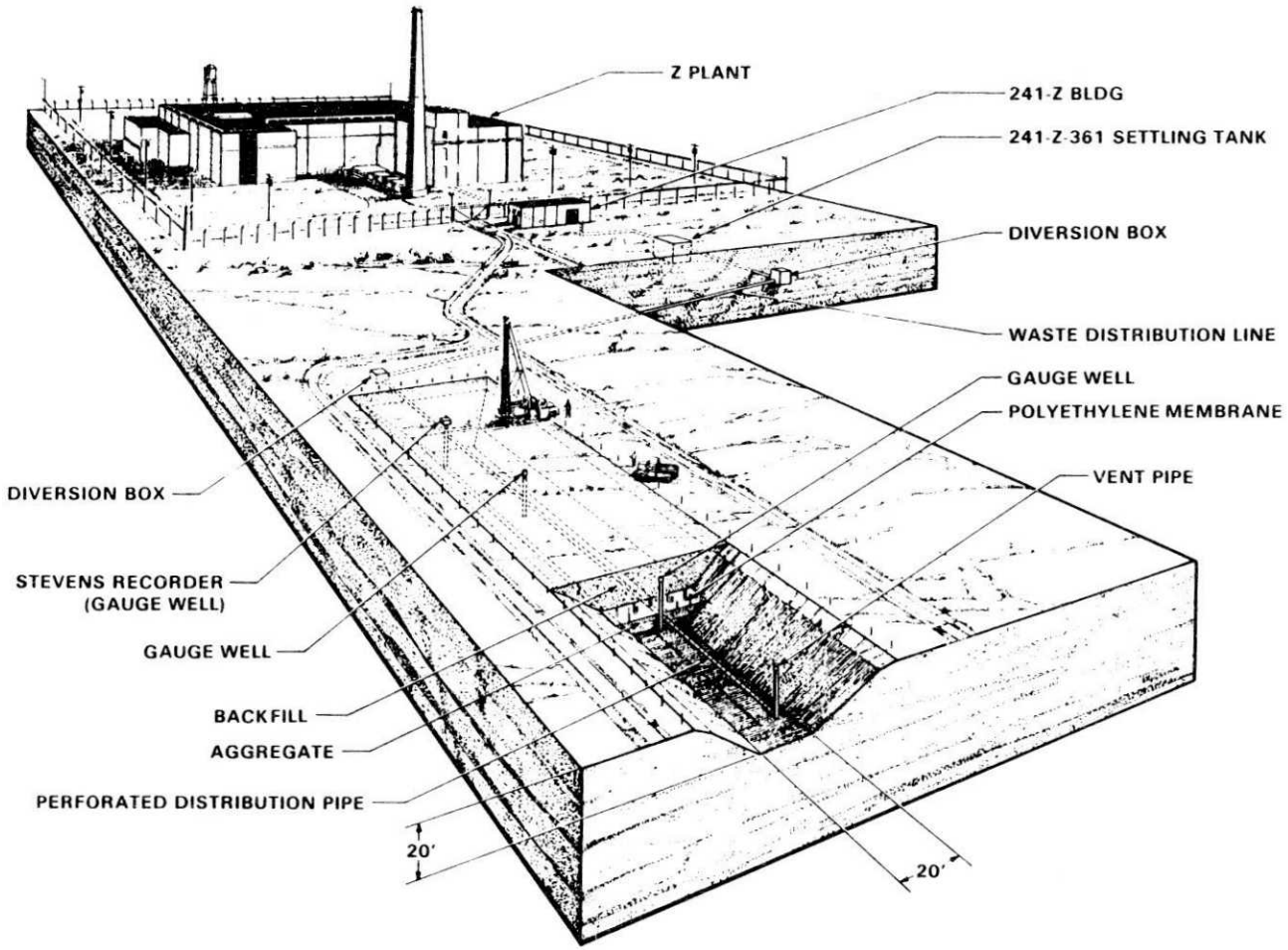

FIGURE V.3. 216-Z-12 Crib Construction Details (Kasper et al. 1981a)

from 12 to 30 m below the crib bottom. However, a low level of plutonium and americium activity was detected from 30 to 36 m below the crib, the maximum depth sampled. The activity was associated with a silt layer at that depth and was probably related to the greater sorption capacity of the silt unit (Figure V.4). Results from groundwater monitoring beneath the 216-Z-12 crib indicate that breakthrough of measurable concentrations of plutonium to the groundwater did not occur.

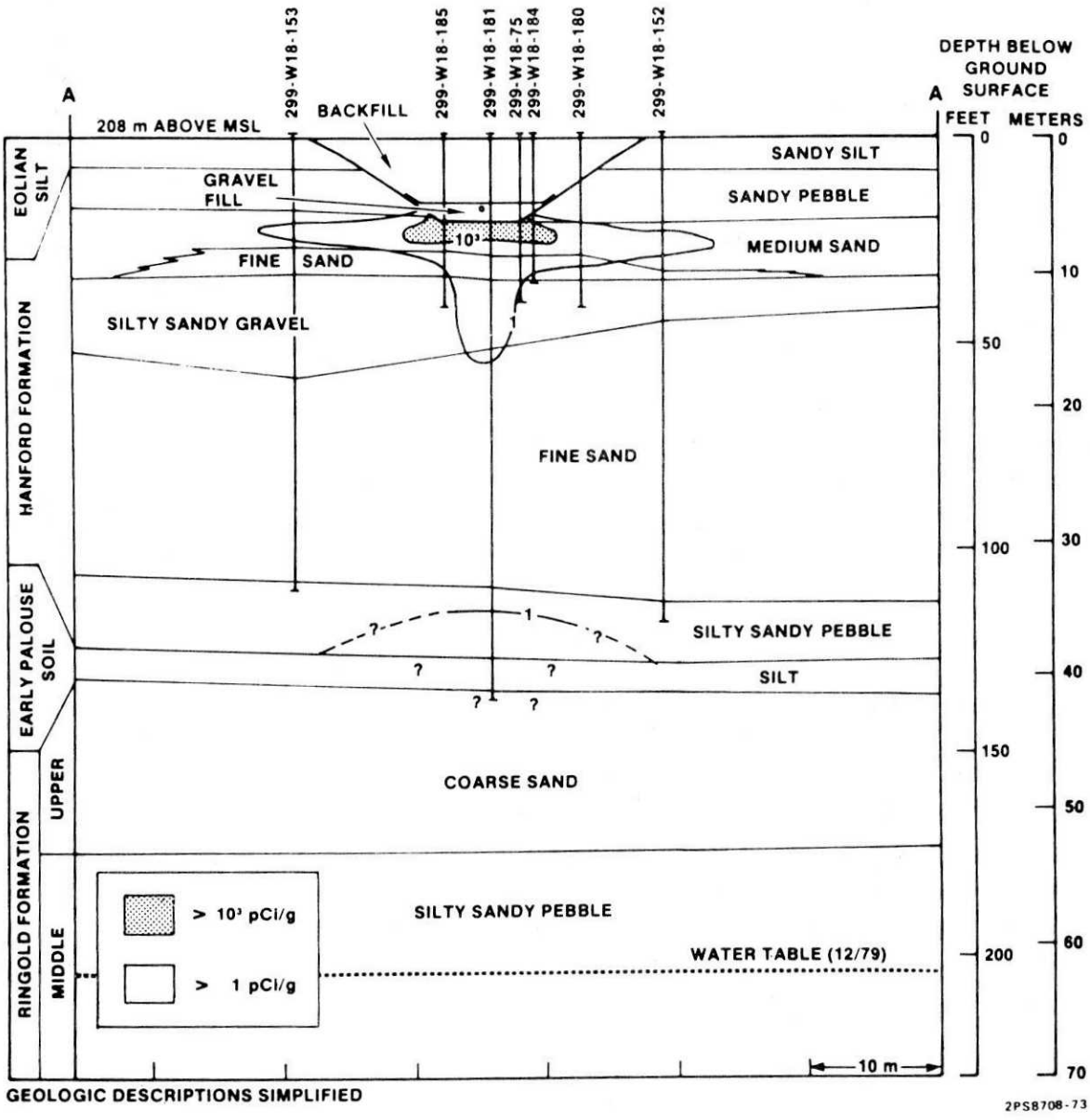

FIGURE V.4. **Distribution of Plutonium Activity Beneath the 216-Z-12 Crib on Cross Section A-A'** (Kasper et al. 1981a)

216-Z-1A Crib

The 216-Z-1A crib, constructed in 1949, is located in the 200 West Area immediately south of the Z Plant exclusion area. The crib was used between 1949 and 1959 to receive the overflow of liquid waste from the 216-Z-1, 216-Z-2, and 216-Z-3 cribs. The waste stream consisted of process waste and analytical and development laboratory waste from Z Plant via the 241-Z-361 settling tank. The use of all four facilities (three cribs and settling tank) was interrupted at the end of this ten-year time period (1949 to 1959). During this time, the 216-Z-1A crib received about 50 g of plutonium. Starting in 1964, waste was routed directly to the 216-Z-1A crib. During the next five years the facility received, from the Plutonium Reclamation Facility located in Z Plant, approximately 6.2×10^6 L of acidic liquid waste containing an estimated cumulative plutonium inventory of 57 kg. Over one-half (30 kg) of this plutonium inventory was added to the crib between June 1964 and May 1966. The acidic waste discharged from this facility was a concentrated solution of aluminum, calcium, magnesium and sodium nitrates. In addition to the aqueous phase, organic liquid was also discharged to the crib. The organics consisted mainly of carbon tetrachloride and tributyl phosphate, with a minor amount of triolein and organic degradation products. The 216-Z-1A crib was permanently retired from service in 1969.

The 216-Z-1A crib was constructed as a rectangular excavation having surface dimensions of approximately 60 by 110 m. The floor of the excavation was covered by a 1.2-m-thick cobble layer, and a herringbone pattern of 20-cm-dia clay pipe was placed on this cobble layer. The 30-m by 79-m rectangular area covered by the piping system was then overlain with 15 cm of cobbles and 1.5 m of sand and gravel. Before reactivation of the 216-Z-1A crib in 1964, a sheet of polyethelene covered by 30 cm of sand and gravel was also added to the facility. This modification was made as a precautionary measure to prevent the upward migration of the liquid waste. In May 1966, the crib was divided into three sections ("a," "b," and "c") and the distribution point was moved from the head of the "a" section to the "b" section. In 1967, the discharge point was moved to the "c" section. Of the total inventory of plutonium, section "a" received approximately 50%, section "b" received approximately 30%, and section "c" received approximately 20%.

During the initial characterization of the 216-Z-1A crib, one well was drilled into the facility (Price and Ames 1975). This test well was located adjacent to the initial point of distribution of the waste. Samples from the test well were characterized geologically, and representative samples were homogenized and proportioned into either 25- or 500-mL containers for nondestructive analysis. Later, in a more detailed characterization, 16 shallow wells were drilled in the unsaturated sediments underlying the facility using specialized, totally contained drilling techniques (Price et al. 1979; Kasper et al. 1979). Samples from each well were analyzed to obtain profiles of both sediment type and plutonium and americium concentrations as a function of depth beneath the facility.

The results of the study show that the highest concentration of $^{239,240}Pu$ (4×10^4 nCi/g of sediment) and ^{241}Am (2.4×10^3 nCi/g) occurs within the first 3 m of sediment beneath the central distribution pipe. The concentration of actinides in sediments generally decreases

with depth beneath the waste distribution system, with the exception of silt-enriched horizons and boundary areas between major sedimentary units. Figure V.5 illustrates the general pattern of waste distribution beneath the central distributor pipe. Detailed vertical distributions of transuranic activity are shown in Figures V.6 and V.7. The maximum vertical penetration of actinide contamination (defined by the 1 x 10^{-2} nCi/g isopleth) is located approximately 30 m below the bottom of the crib, or approximately 30 m above the water table. The estimated lateral extent of contamination is located within a 10-m-wide zone that encompasses the perimeter of the crib, as outlined on the plan view of the facility, also shown in Figure V.5.

The pattern of waste distributed beneath the 216-Z-1A crib is attributed to both physical and chemical mechanisms. Proposed mechanisms include: 1) the filtering of disposed plutonium oxide particles from the waste liquid by sediments located immediately beneath the crib, 2) the effect of unsaturated flow within the sediments, 3) a change in pH produced by silicate hydrolysis reactions between acidic waste liquid and the sediments, and 4) a change in pH produced by neutralization of the acidic waste liquid by calcium carbonate found in the sediments. A change in pH, resulting from either of these last two processes, causes an increase in the sorption and a decrease in the solubility of plutonium.

216-S-1 and 2 Crib

The 216-S-1 and 2 crib was constructed in 1950 and 1951. The crib is located about 430 m northwest of the Redox building in 200 West Area. From 1952 to 1956, the 216-S-1 and 2 crib received waste from the cell drainage collection tank, D-1, and the condensate receiver tank, D-2, located in the Redox building. In January 1955, one of the three original crib monitoring wells was deepened from 45 m to 93 m and the bottom 30 m were perforated. This was done to provide a groundwater monitoring well for the crib. In June 1955, the well was found to contain liquid waste within 15 m of the ground surface. Waste had flowed to the bottom of the well and into the saturated sediments through the perforations in the casing. This indicated that the well casing had failed near the bottom of the crib. Early in August 1955, the well was filled with sand, and within 6 months the crib was removed from service. The radionuclide inventory for the waste streams discharged to the crib is given in Table V.2. The average pH of wastes from D-1 and D-2 was 2.1. Waste was discharged to the crib in batches of about 19,000 L and at an average rate of 10 batches per day.

The design of the 216-S-1 and 2 crib differs from those previously described in that buried wooden boxes were used to distribute the wastes. The bottom of the excavation is approximately 10 m below grade and has bottom dimensions of 12.2 by 27.4 m with 45° side slopes. The bottom 3 m of the crib were filled with screened, crushed stone that was greater than 1.3 cm in diameter. Two open-bottomed, square, wooden crib boxes, 3.7 m long by 2.9 m high, were placed 1.8 m into the gravel layer. The crib boxes were constructed with 15-cm by 20-cm timbers and cross braces. The two crib boxes were connected in series with overflow from the S-1 box flowing into the S-2 box via a pipeline.

The first major study of the 216-S-1 and 2 crib, conducted by Haney and Linderoth (1959), began in 1956 after the crib had been removed from service. The purpose of the study

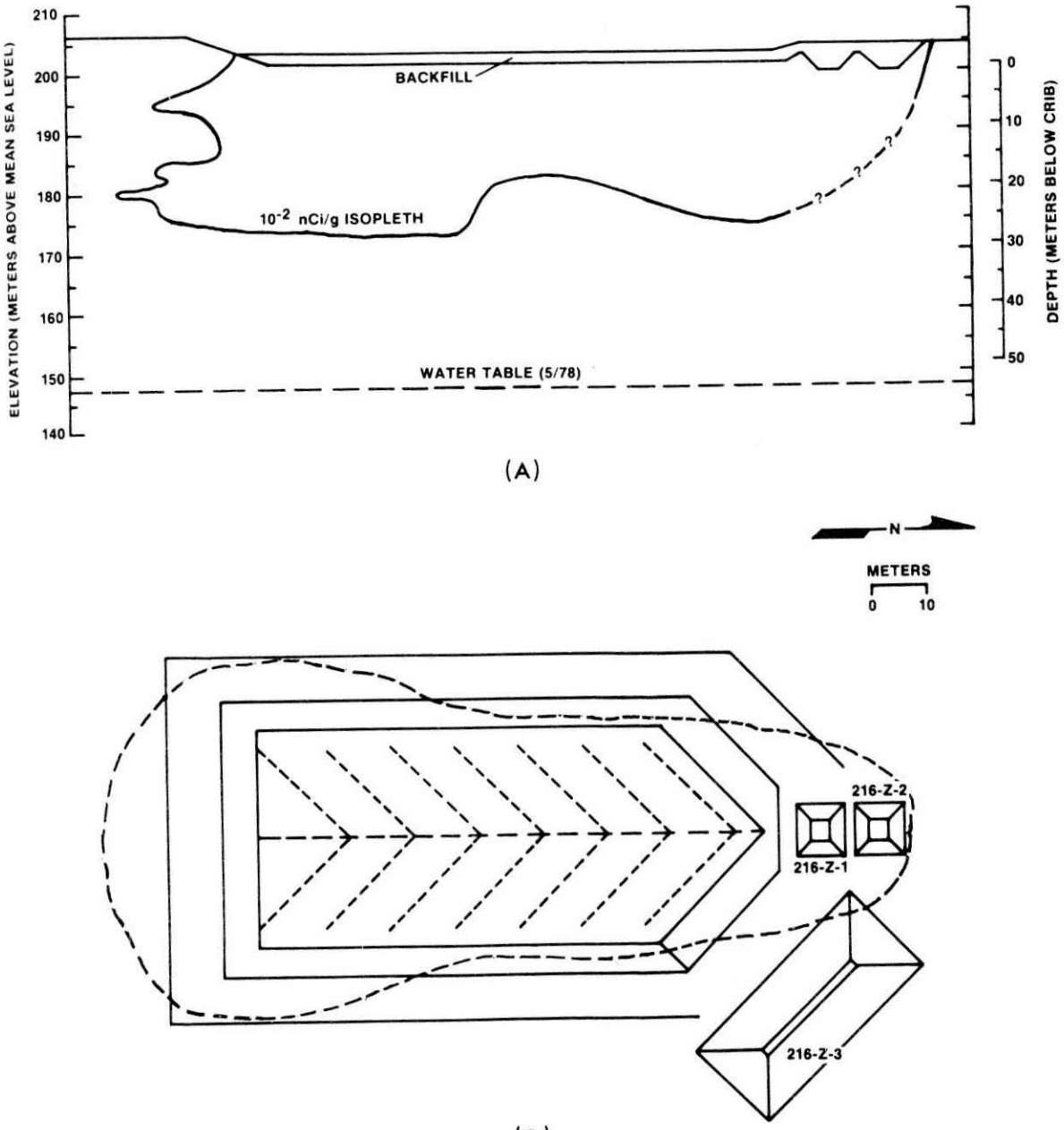

FIGURE V.5. **Graphic Representation of Waste Plume Beneath the 216-Z-1A Crib:** (A) **North-South Cross Section Through Center of Crib** (B) **Plan View of Crib** (Price et al. 1979)

was to determine the spatial distribution of radionuclides in the sediments beneath the crib. The study used ten groundwater monitoring wells consisting of two wells drilled in 1955, two existing wells deepened from 45 m to just more than 90 m, and six new wells. Sediment samples were collected every 0.7 m and analyzed for ^{90}Sr, ^{137}Cs, and total beta activity. Conclusions drawn from this study deal with the distributions of ^{90}Sr and ^{137}Cs beneath the crib. Haney and Linderoth (1959) concluded that ^{137}Cs was confined to the upper

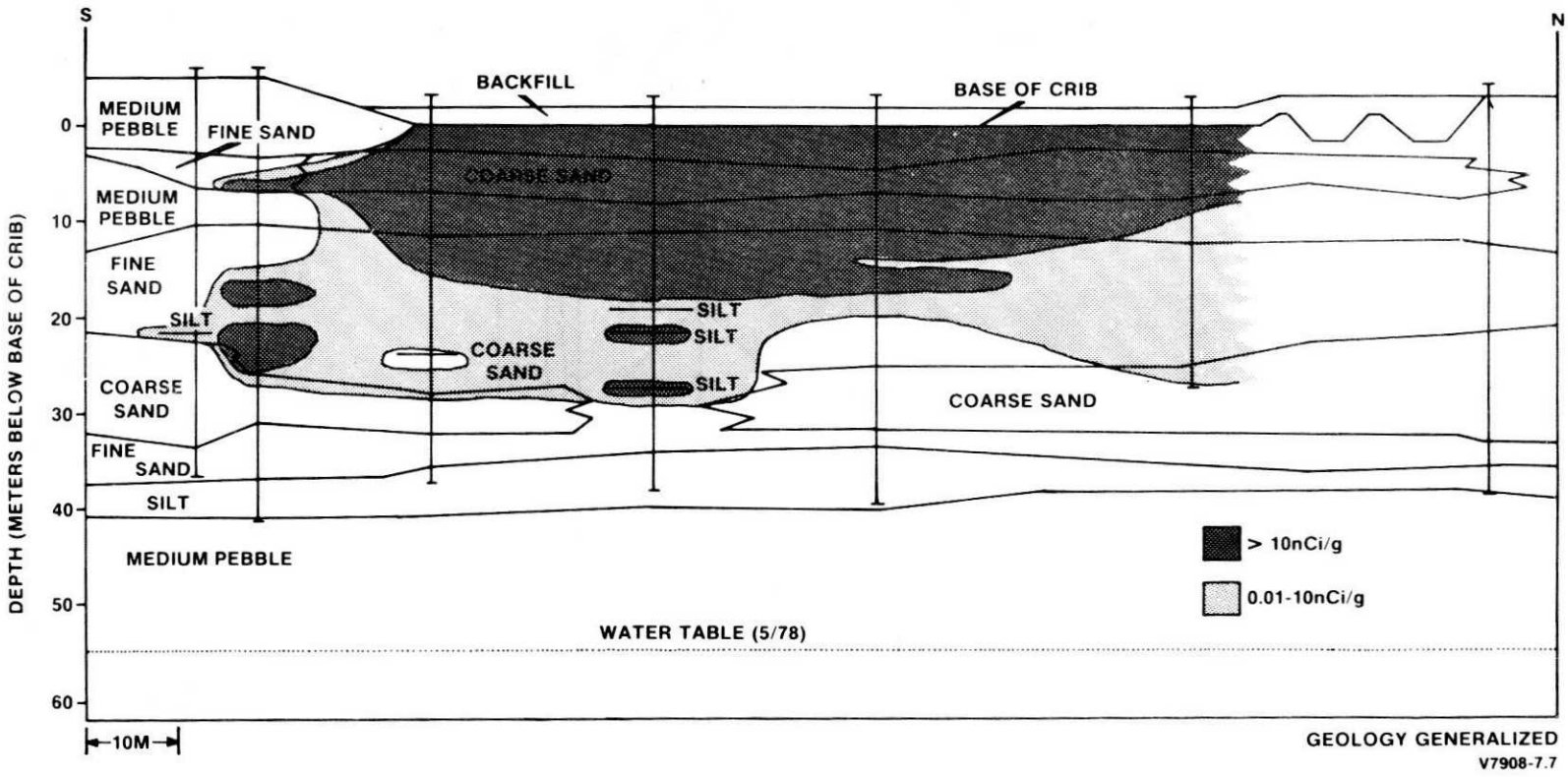

FIGURE V.6. **Total Transuranic Activity Distribution, North-South Cross Section** (216-Z-1A Crib) (Kasper et al. 1979)

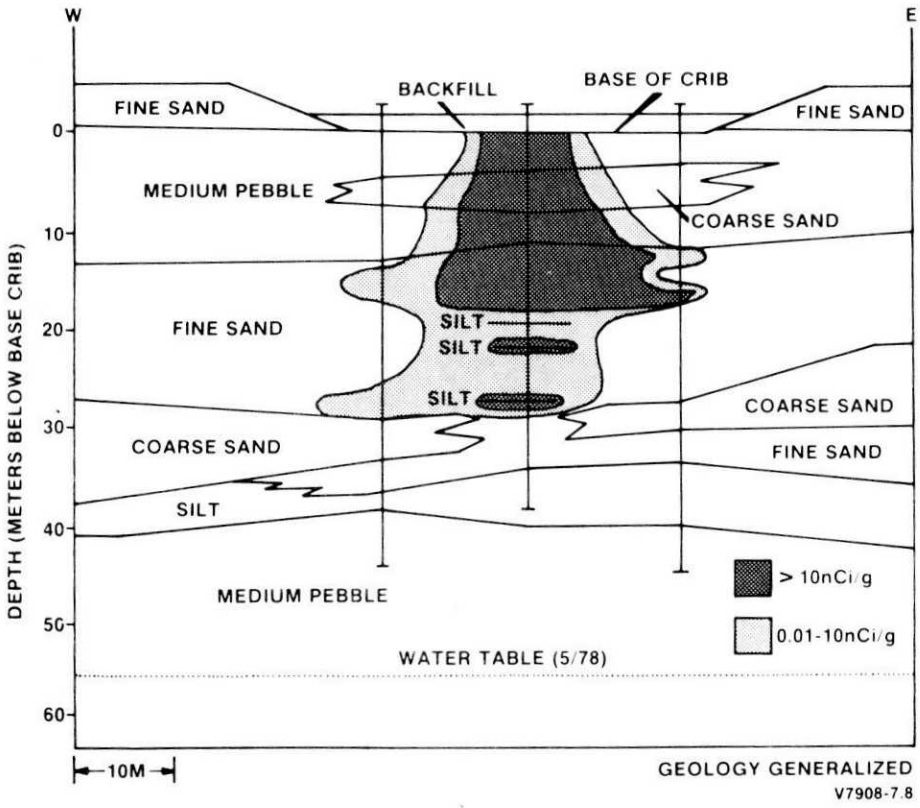

FIGURE V.7. **Total Transuranic Activity Distribution, East-West Cross Section** (216-Z-1A Crib) (Kasper et al. 1979)

strata immediately under the crib site while ^{90}Sr had reached the groundwater encompassing an area of about 10,000 ft^2, which was one-eighth of the area to which the waste had spread before reaching the water table.

Another field study of the 216-S-1 and 2 crib was conducted in 1966 as part of an evaluation of the impact of the proposed Ben Franklin Dam on radionuclides stored in the vadose zone and on Hanford waste management techniques practiced at that time (Raymond and McGhan 1967). Five additional wells were drilled, four of which were located in the crib facility and penetrated the water table. In the 1966 study, it was indicated that some sediments near the water table contained ^{90}Sr up to 1.2×10^{3} $\mu Ci/g$. The average ^{90}Sr concentration in the groundwater beneath the crib in 1966 was 5×10^{-5} $\mu Ci/mL$. The 1966 study concluded that "most of the long-lived isotopes are confined within 100 feet of the ground surface." The distributions of radionuclides determined in the 1956 and 1966 studies are presented in Figure V.8. Subsequent investigations concerning radionuclide sorption from waste discharged to the 216-S-1 and 2 crib conclude that 90% of the ^{137}Cs was adsorbed by the soil while less than 10% of the ^{90}Sr was adsorbed (Rhodes 1956). Rhodes determined that this poor sorption was due to the low pH of the waste solution and the high salt concentrations of the D-1 tank waste. Modifications were made in the waste disposal procedure, and the waste was discharged to a new crib (216-S-7).

TABLE V.2. Radionuclide Inventory of Waste Discharged to the 216-S-1 and -2 Crib[a]

Year	Volume, L	Beta, Ci	^{90}Sr, Ci	^{137}Cs, Ci	^{106}Ru, Ci	^{60}Co, Ci	Pu,g	^{238}U, kg
1952	1.43×10^{7}	5.56×10^{2}	2.00×10^{0}	2.00×10^{0}	2.00×10^{0}	--	8.00×10^{0}	1.50×10^{1}
1953	4.69×10^{7}	4.53×10^{4}	1.81×10^{2}	1.51×10^{2}	1.81×10^{2}	6.00×10^{-1}	4.90×10^{1}	9.30×10^{1}
1954	4.92×10^{7}	3.08×10^{5}	1.23×10^{3}	1.03×10^{3}	1.23×10^{3}	4.10×10^{0}	4.44×10^{2}	8.39×10^{2}
1955	4.96×10^{7}	3.96×10^{5}	1.58×10^{3}	1.32×10^{3}	1.59×10^{3}	5.30×10^{0}	6.97×10^{2}	1.32×10^{3}
1956	2.60×10^{4}	1.16×10^{2}	1.00×10^{0}	--	1.00×10^{1}	--	2.00×10^{0}	4.00×10^{0}
Sum	1.60×10^{8}	7.50×10^{5}	3.00×10^{3}	2.50×10^{3}	3.00×10^{3}	1.00×10^{1}	1.20×10^{3}	2.27×10^{2}
Decay (1/81)	1.60×10^{8}	$<6.03 \times 10^{4}$	1.58×10^{3}	1.37×10^{3}	5.15×10^{-4}	3.24×10^{-1}	1.20×10^{3}	2.27×10^{3}

(a) Hanson et al. 1973.

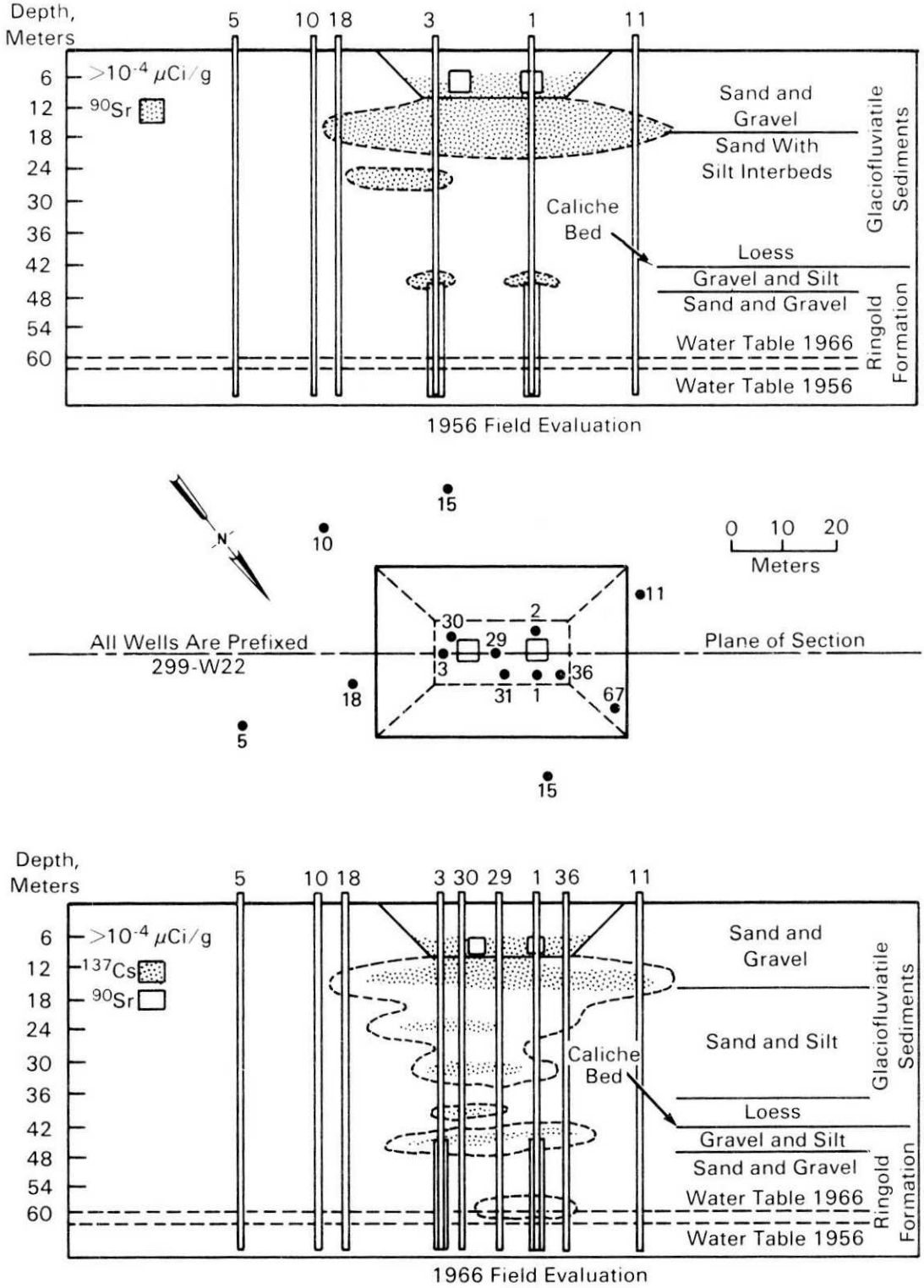

FIGURE V.8. **Results of the 1956 and 1966 216-S-1 and -2 Crib Field Evaluations** (Van Luik and Smith 1982)

Borehole scintillation and gamma spectroscopic profiles of monitoring wells in and around the crib were obtained during the characterization study by Van Luik and Smith (1982). The results of the study confirm findings of previous studies with respect to the location and stability of radionuclides in the crib sediments. They found that most of the ^{137}Cs activity is generally restricted to a 10-m zone beneath the crib bottom (Figure V.9). Cesium-137 migrated deepest beneath the S-2 portion of the crib. Historically, ^{90}Sr was widespread beneath the crib, but its distribution in the unsaturated sediments was not determined in this characterization study because in-situ measurement of ^{90}Sr was not possible.

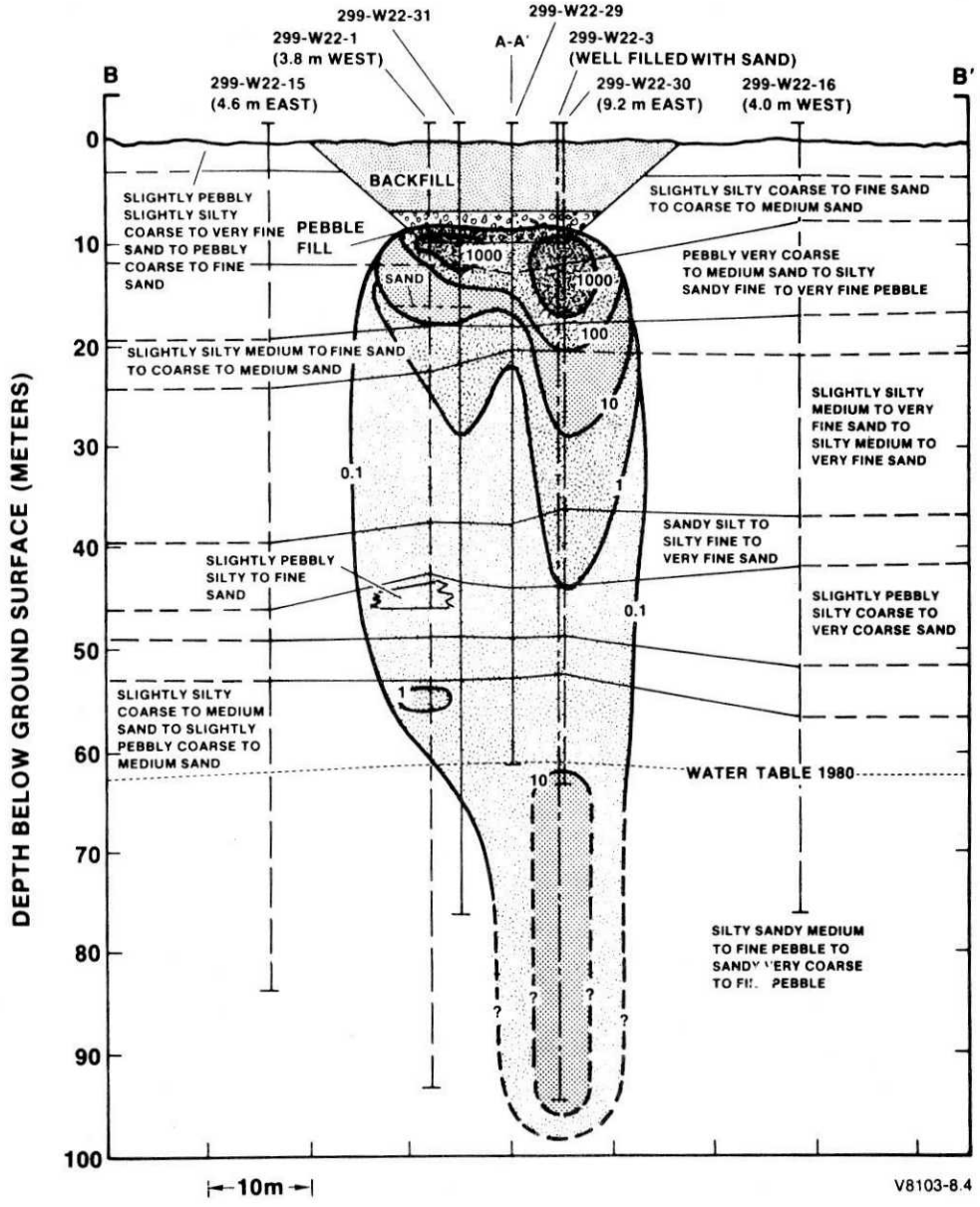

FIGURE V.9. **Cesium-137 Distribution** (nCi/g) **Beneath the 216-S-1 and -2 Crib, B to B'** (Van Luik and Smith 1982)

However, the presence of ^{90}Sr and total beta activity in the saturated sediments beneath the crib were determined by analyzing sediment samples collected when monitoring wells were deepened.

Strontium-90 was detected below the water table in two localized areas beneath the crib. One of these areas is associated with a zone of contamination caused by the casing failure of a groundwater monitoring well within the crib in 1955. A similar cause is suspected, but could not be confirmed, for the other area.

In summary, ^{90}Sr was more mobile than ^{137}Cs in the sediments underlying the 216-S-1 and -2 crib. The poor sorption of ^{90}Sr was attributed to the chemistry of the waste stream. The strontium migrated to the water table, due in part to a failed well casing. Most of the ^{137}Cs activity was generally restricted to a 10-m zone beneath the crib bottom.

216-U-1 and -2 Cribs

The 216-U-1 and -2 cribs, located 800 ft west of U Plant, received wastes from the plant between 1951 and 1967. The cribs were deactivated in 1967. Approximately 4,000 kg of uranium were disposed of to the cribs; however, this radioactive waste is categorized as a low-level waste and is therefore outside the scope of the HDW-EIS.

In January 1985, uranium contamination of the groundwater near the 216-U-1 and -2 cribs was discovered by routine sampling from two monitoring wells. Uranium concentration was well above DOE guidelines. Eight wells surrounding the cribs were sampled subsequently and showed low concentrations or concentrations in agreement with historical results.

Although the 216-U-1 and -2 cribs are currently inactive (i.e., no waste is being discharged to the cribs) it is likely that vertical movement of water from a nearby active crib, 216-U-16, has been diverted by a caliche layer. The water is believed to have moved horizontally to existing wells that provided the pathway for uranium to enter the groundwater near the 216-U-1 and -2 cribs. These wells were ungrouted, and it is probable that water diverted by the caliche layer traveled in the annulus between the well casing and the porous medium in one and possibly two of the wells. The acidic nature of the waste disposed to the 216-U-1 and -2 cribs is a possible contributor to the mobilization of the uranium.

Further investigation and characterization efforts are currently under way to determine the exact source and the extent of the uranium contamination.

While the inventory of uranium in this instance is not included in the HDW-EIS, this recent experience has led to a reexamination of uranium inventories within the scope of the HDW-EIS. Previous studies of uranium migration have employed substantially higher distribution coefficient values than employed in the 216-U-1 and -2 crib release; therefore, the basis of assumptions concerning chemical speciation and sorption characteristics of uranium in EIS waste forms is also being revisited.

V.3 TRENCHES

One Hanford waste-disposal trench, the 216-Z-9 trench, has been characterized (Smith 1973; Price and Ames 1975). The 216-Z-9 trench was mined for plutonium from 1976 through

1978 (Ludowise 1978). The Ludowise document also contains characterization data that are pertinent to this summary.

The 216-Z-9 trench is located 152 m east of the Z-Plant Exclusion Area in the 200 West Area (Ludowise 1978). The trench, completed in 1955, was used to receive liquid wastes from plutonium processing operations (the Recuplex Plutonium Scrap Recovery Facility) in the 234-5 Z Plant between July 1955 and April 1962. The waste solutions were partially neutralized salt wastes (pH approx. 2.5), which at times contained organic materials and undissolved solids. The Recuplex process was a solvent extraction system that recovered plutonium from many different types of scrap or wastes. The Recuplex waste solutions consisted of aluminum, magnesium, calcium, and other metal nitrate salt wastes, degraded solvents (15% tributyl phosphate [TBP] or dibutylbutyl phosphate [DBBP] in carbon tetrachloride), other organics such as those from solvent washing, fabrication oil (a mixture of lard oil and 75% carbon tetrachloride), and other waste materials from hood and equipment flushes.

The waste solutions were collected in three tanks, each having a 950-L capacity. After determining the plutonium content, the waste solution was drained by gravity through a 3.8-cm underground stainless steel pipe to the 216-Z-9 trench. A waste tank was drained about once every 8 hr. During the seven-year life of the trench, the facility received approximately 4×10^6 L of liquid wastes containing approximately 100 kg of Pu. Because of criticality concerns, a 0.07 M solution of cadmium nitrate (a neutron absorber) was sprayed on the soil in the trench. A total of 11 kg of cadmium was used.

The 216-Z-9 trench is an underground excavation with floor dimensions of 9.1 m by 18.3 m and is located 7 m beneath the top of a 23-cm-thick concrete slab (2.7 by 3.7 m) that is supported by six concrete columns. The enclosed trench was provided with two 3.8-cm stainless steel inlet pipes; one served as a spare. Figure V.10 shows a generalized geologic cross section of the undisturbed sediments underlying this facility.

During the initial characterization of the 216-Z-9 trench (Smith 1973), the first 60 cm of sediments underlying the floor of the trench were sampled. The upper few centimeters of the trench revealed the highest concentration of plutonium (20 g of plutonium per liter of sediments). This study indicated that the highest surficial accumulation of plutonium occurred near the center of the trench floor. Subsequent analysis of the sediments collected during this initial characterization revealed that at least two forms of plutonium were present (Ames 1974). The most abundant type was an oxide (up to 10 μm in diameter) that was 60 wt% plutonium oxide. These particles occurred near the top of one core, but extended down nearly to the bottom of a second core (~60 cm). This difference in distribution was thought to be the result of a layer of sludge over the area where the first core was taken that acted as a filtering media to remove and concentrate the plutonium particles. The second form of plutonium occurred in lesser concentrations (less than 0.4 wt% plutonium oxide), but was found throughout the lengths of both cores. This distribution was associated with silicate hydrolysis.

Additional samples from the site were subsequently obtained from one test well drilled to an initial depth of 9 m (Price and Ames 1975). The location of this test well is shown in

Figure V.10. Core samples acquired by drilling this test well were contained within a solid, 6-cm (outside diameter) brass insert that was pre-cut into four 15-cm segments. Contents of the 15-cm inserts, later nondestructively analyzed for actinides, were removed and characterized geologically. Representative portions of these segments were then homogenized and measured into either 25- or 500-mL containers for nondestructive analysis of ^{239}Pu and ^{241}Am. The results of this analysis are listed in Table V.3. In general the actinide concentration, highest just below the bottom of the facility, drops off within the first 2 m of the underlying sediment column. Two types of plutonium were responsible for the observed distribution, the "particulate" and the "nonparticulate."

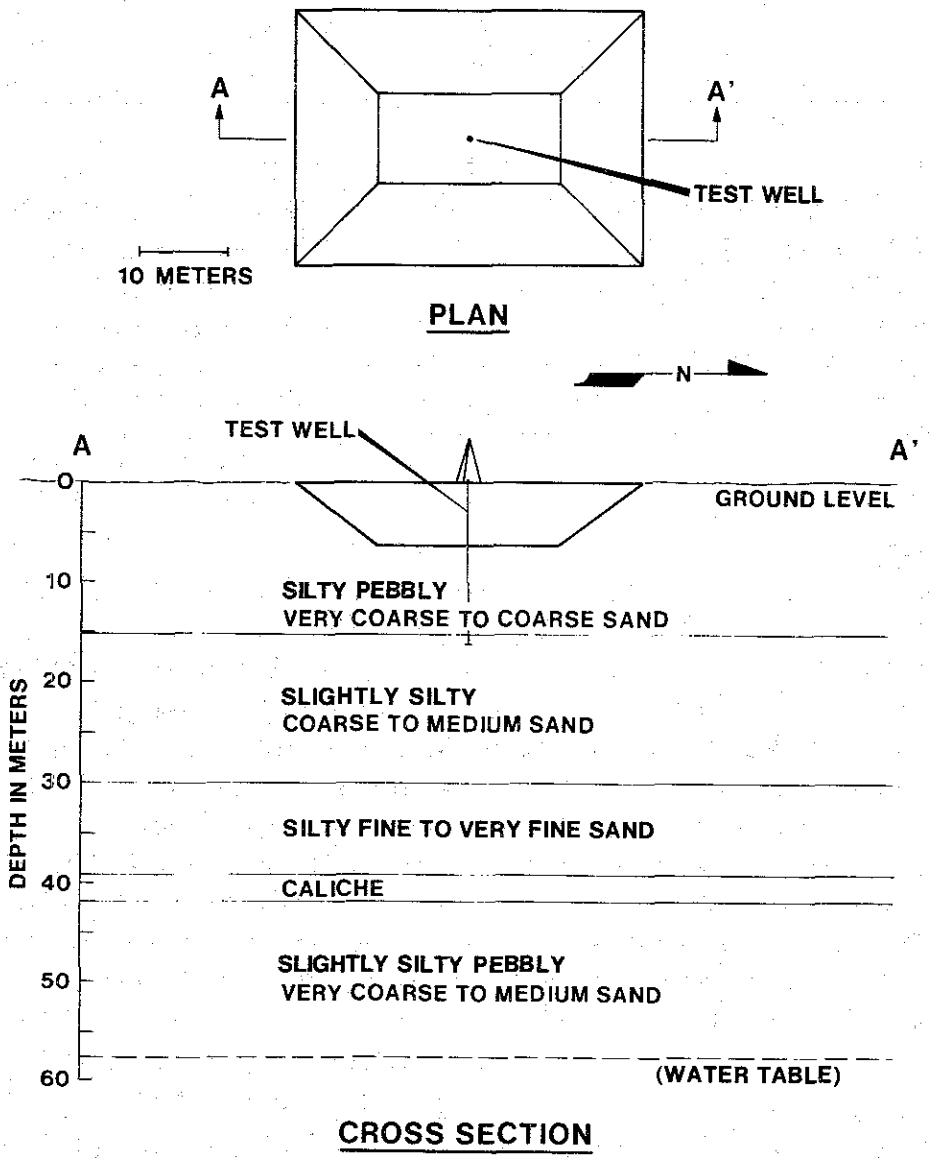

FIGURE V.10. **Construction and Geology of the 216-Z-9 Trench** (Price and Ames 1975)

TABLE V.3. Actinide Concentrations at Selected Depths Below the 216-Z-9 Trenches (determined by gamma energy analysis)

Depth Below Trench Floor	Actinide Concentration, μCi/L of Sediment	
	^{239}Pu	^{241}Am
5 cm	~1 x 10^6	~1 x 10^5
50 cm	~5 x 10^3	~5 x 10^2
2 m	~1 x 10^3	~1 x 10^2
4.5 m	~5 x 10^2	~5 x 10^1
9 m	~1 x 10^1	~1 x 10^1

The "particulate" mode consisted of discrete plutonium particles 2 to 25 μm in diameter. The occurrence of these particles, restricted to the top portions of the sediment column, accounts for the high concentration of Pu/L of sediment observed just below the points of release of the waste liquids. Plutonium detected deeper within the sediment profile was probably contained in the original waste liquids as Pu(IV) in solution. Examination of selected sediment samples revealed that this "nonparticulate" Pu was partially removed by adsorption or precipitation in conjunction with silicate hydrolysis reactions that occurred when the acidic waste solutions came in contact with portions of the sand- to silt-sized rock fragments.

V.4 FRENCH DRAINS

One French drain, 216-Z-8, on the Hanford Site has been characterized (Marratt, Van Luik and Kasper 1985). The 216-Z-8 French drain is located about 40 m west of the Z Plant perimeter fence in 200 West Area. The French drain disposal system, consisting of a 58,500-L-capacity settling tank and French drain (Figure V.11), received liquid waste from the 234-5Z Building from 1955 until 1962. The wastes were discharged in relatively small batches and were routed through a large settling tank called the "silica storage tank." Overflow from the tank went to the French drain. Waste was first discharged to the 216-Z-8 French drain facility in July 1955. Measurements taken of the liquid level in the silica storage tank indicated that a constant level of 2.18 m, the designated overflow level, was attained in October 1957. From October 1957 to April 1962, when the facility was retired, it is estimated that 9,590 L of liquid waste containing an estimated 48.2 g of plutonium overflowed from the silica storage tank to the 216-Z-8 French drain.

A single well was drilled south of and adjacent to the 216-Z-8 French drain. Selected sediment samples collected during the drilling were analyzed for ^{238}Pu, ^{239}Pu, and ^{241}Am. Plutonium and americium activity attributed to the waste discharged to the French drain was encountered in a zone extending approximately 5 m from the bottom of the French drain. Analytical results were used to construct a cross section through the French drain showing an interpretation of the concentration distribution of ^{239}Pu and ^{241}Am. To draw the isopleths,

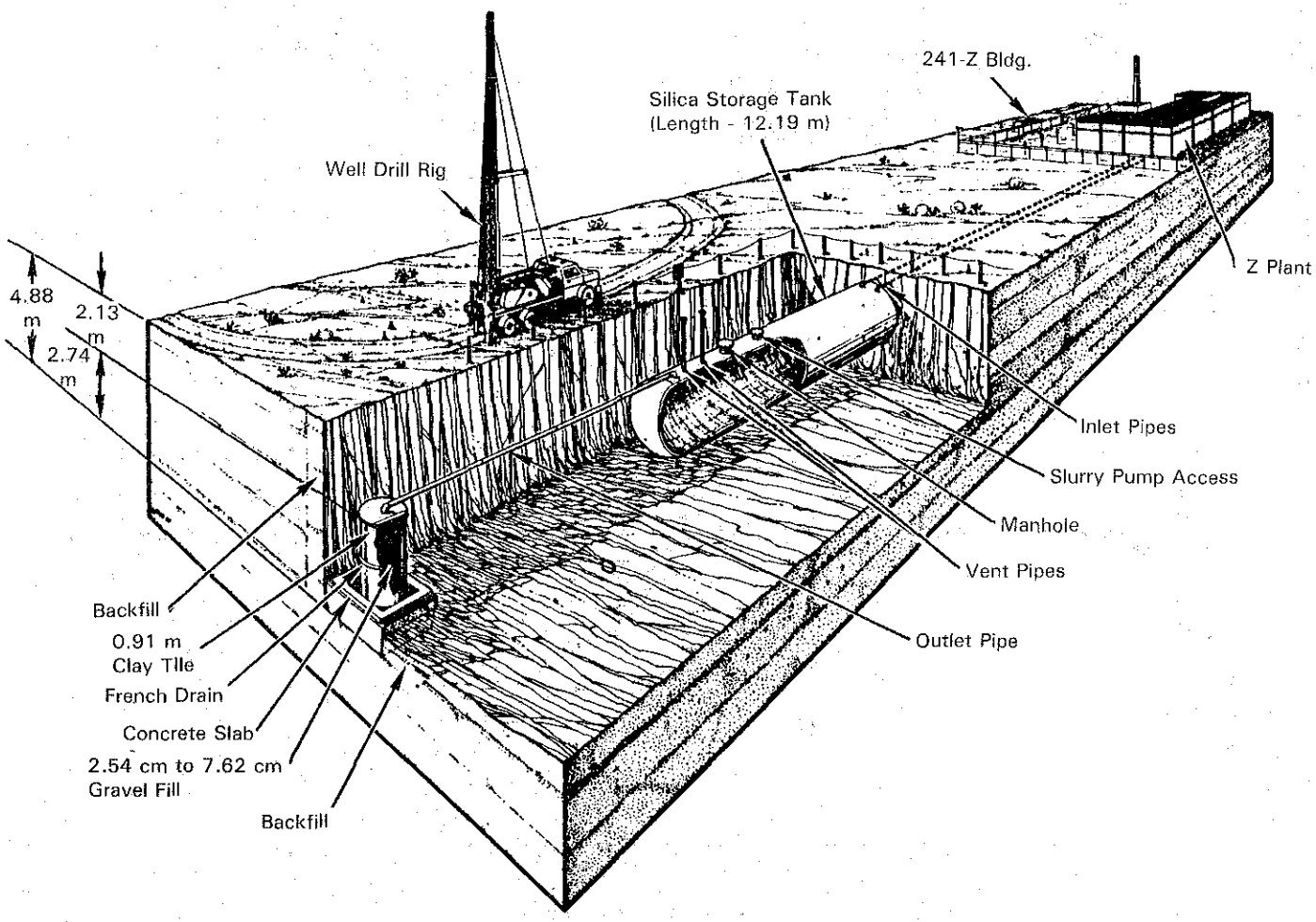

FIGURE V.11. The 216-Z-8 French Drain Facility (Marratt, Van Luik and Kasper 1985)

the concentration of the radionuclides was assumed to be symmetrical away from the French drain, with the activity generally decreasing radially away from the bottom of the drain. The estimated distributions of plutonium and americium are shown in Figures V.12 and V.13, respectively. This interpretation did not take into account variations in distributions due to the layered nature of the sediments.

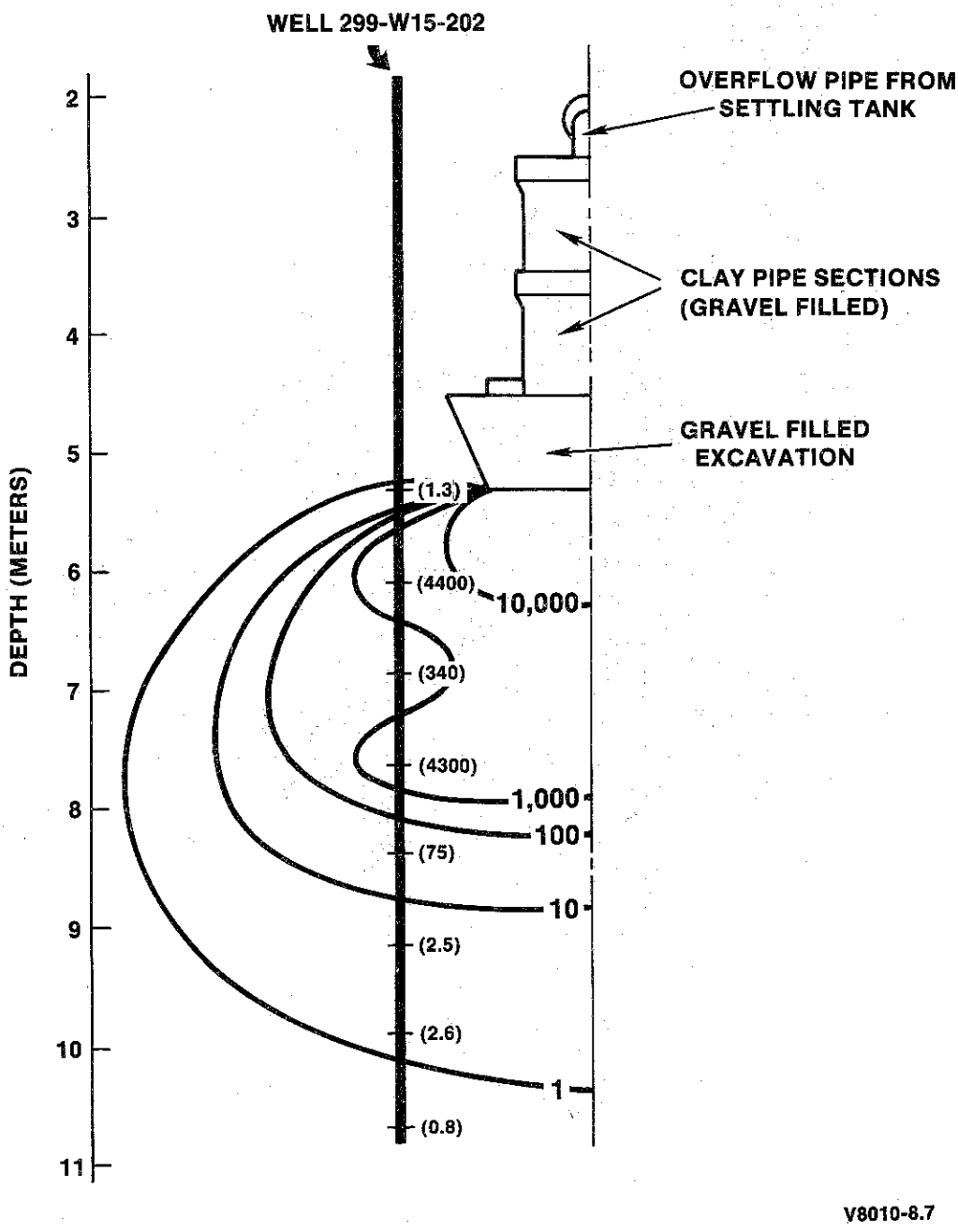

FIGURE V.12. Plutonium-239 Concentrations (in pCi/g) Beneath the 216-Z-8 French Drain (Marratt, Van Luik and Kasper 1985)

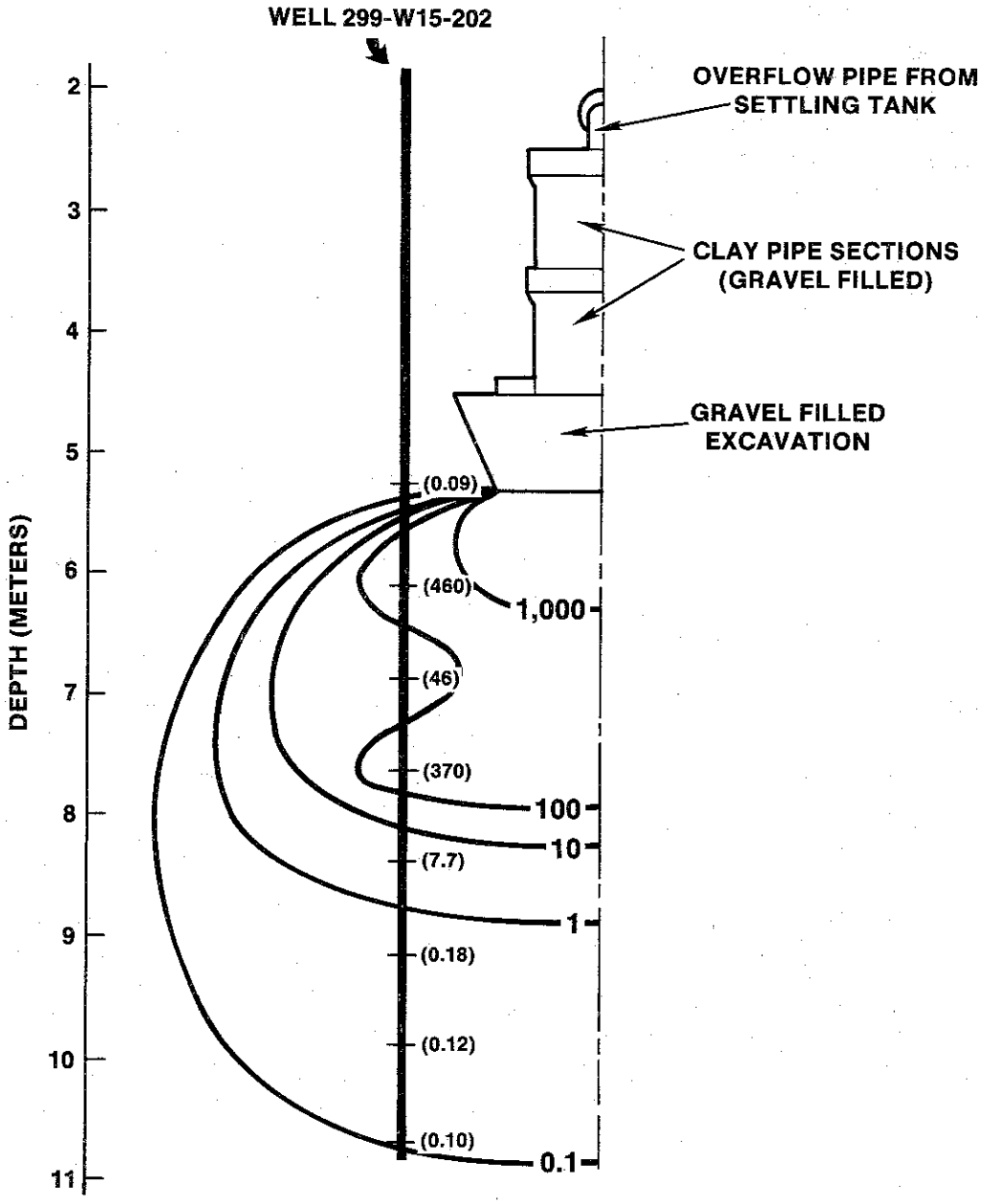

FIGURE V.13. Americium-241 Concentrations (in pCi/g) Beneath the 216-Z-8 French Drain (Marratt, Van Luik and Kasper 1985)

V.5 REVERSE WELLS (Injection Wells)

One reverse well, 216-B-5, has been characterized (Smith 1980, 1981). The 216-B-5 reverse well is located approximately 370 m northeast of the 221-B (B-Plant) building in 200 East Area. Low-salt, alkaline, radioactive liquid wastes from cell washings were discharged to the 216-B-5 reverse well via the 241-B-361 settling tank. The reverse well was used from April 1945 to September 1947. The wastes were discharged to the settling tank and overflowed to the reverse well. The system was designed to remove particulate material from the waste before discharge to the reverse well and thus reduce the chance of plugging the well. The estimated waste inventory discharged to the 241-B-361 settling tank and 216-B-5 reverse well is reported in Table V.4.

TABLE V.4. Estimated Waste Inventory Released to the 241-B-361 Settling Tank and 216-B-5 Reverse Well (Hanson et al. 1973)

	Amount Discharged			Total Amount Discharged	Total Amount Decayed (1979)
	1945	1946	1947		
Volume, L	9.18×10^6	1.22×10^7	9.18×10^6	3.06×10^7	3.06×10^7
Pu, g	1.28×10^3	1.71×10^3	1.28×10^3	4.27×10^3	4.27×10^3
Beta, Ci	1.14×10^3	1.52×10^3	1.14×10^3	3.80×10^3	$<1.39 \times 10^2$
^{90}Sr, Ci	2.27×10^1	3.02×10^1	2.27×10^1	7.56×10^1	3.32×10^1
^{137}Cs, Ci	2.42×10^1	3.23×10^1	2.42×10^1	8.07×10^1	3.73×10^1
^{106}Ru, Ci	4.88×10^1	6.51×10^1	4.88×10^1	1.63×10^2	1.72×10^{-8}

The 216-B-5 reverse well was removed from service in September 1947 when a water sample from a well located 655 m north of the reverse well indicated the presence of alpha contamination in the groundwater. Two days later, the waste that was being discharged to the reverse well was rerouted to other waste disposal facilities. The monitoring well was resampled, and the results of this analysis indicated that the first analysis was incorrect and the groundwater in that area was not contaminated with radionuclides. Analyses of additional samples supported the results of the second water analysis.

A diagram of the 216-B-5 reverse well is shown in Figure V.14. The reverse well was drilled using a telescoping casing technique; 40-cm-dia casing was installed to 4 m, 30-cm-dia casing to 31 m, 25-cm-dia casing to 74 m, and 20-cm-dia casing to 92 m. The 20-cm-dia casing was perforated from the 74-m level to the bottom of the well, providing the means for distributing waste solutions into the surrounding sediments. Waste entered the reverse well at approximately 3.7 m below ground surface. A 1.3-cm-dia pipe (gageline) extended from the ground surface to within 15 m from the bottom of the well for the purpose of liquid-level measurements. The gageline served as a warning system to indicate that the reverse well was filling with liquid waste.

Drilling logs from other wells drilled near the reverse well indicated that the water table at the 216-B-5 reverse well was approximately 90 m, which indicated that the reverse well penetrated the water table and radioactive liquid wastes were discharged directly into the saturated sediments below the water table. These findings provided the impetus for a full-scale groundwater contamination investigation of the 216-B-5 reverse well from 1947 to 1950 (Brown and Ruppert 1948, 1950).

The major objectives of the study were to determine the spatial distribution of radionuclide contamination in the groundwater and to predict the direction that contamination would migrate if it moved at all. Eleven wells were drilled from November 1947 to May

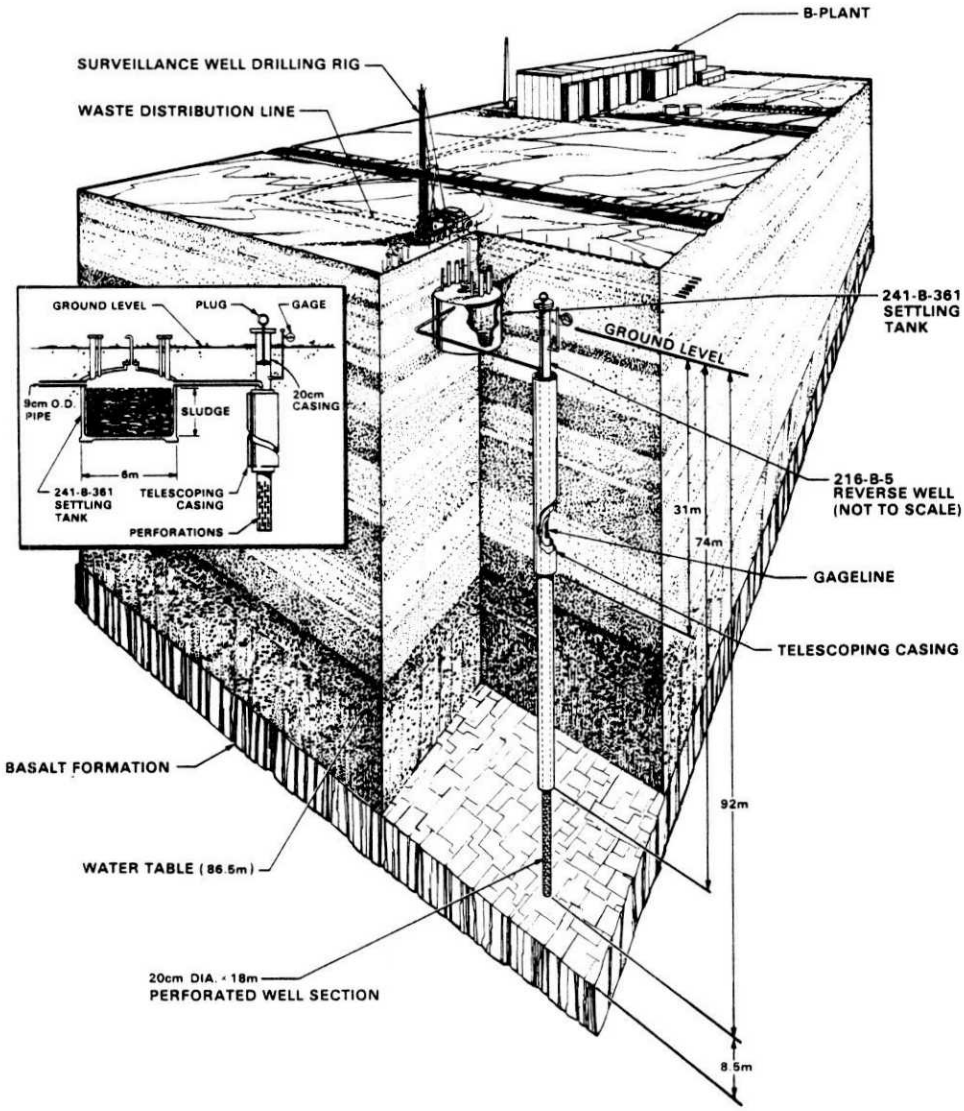

FIGURE V.14. **216-B-5 Reverse Well Disposal System** (Smith 1981)

1948. The wells were drilled 9 m into the saturated zone below the water table. Sediment and ground-water samples were collected at the time of drilling and were analyzed for alpha and total beta-gamma contamination.

No radioactive contaminants were detected in any of the sediment samples collected from the 11 wells, but analyses of groundwater samples indicated the presence of beta-gamma and alpha activity in the groundwater. Groundwater contamination plumes as functions of time for total fission product activity (beta-gamma) and total alpha activity from November 1947 to July 1949 are shown in Figure V.15. The total fission product radionuclides were thought to contain short-lived isotopes, thus accounting for the decrease in size of the fission product contamination plume with time. Uranium was thought to be the predominant alpha-emitting contaminant.

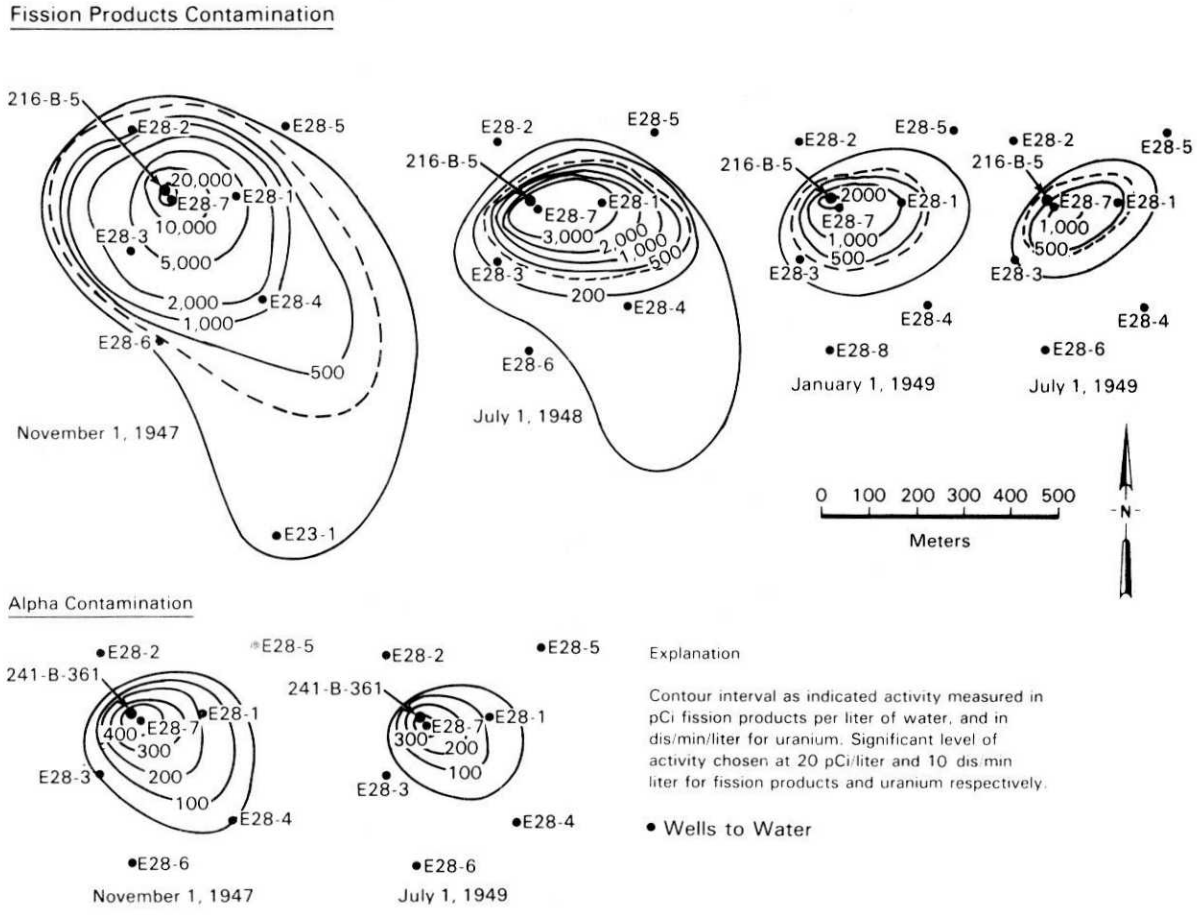

FIGURE V.15. Radionuclide Distributions in the 216-B-5 Reverse Well
(Brown and Ruppert 1950)

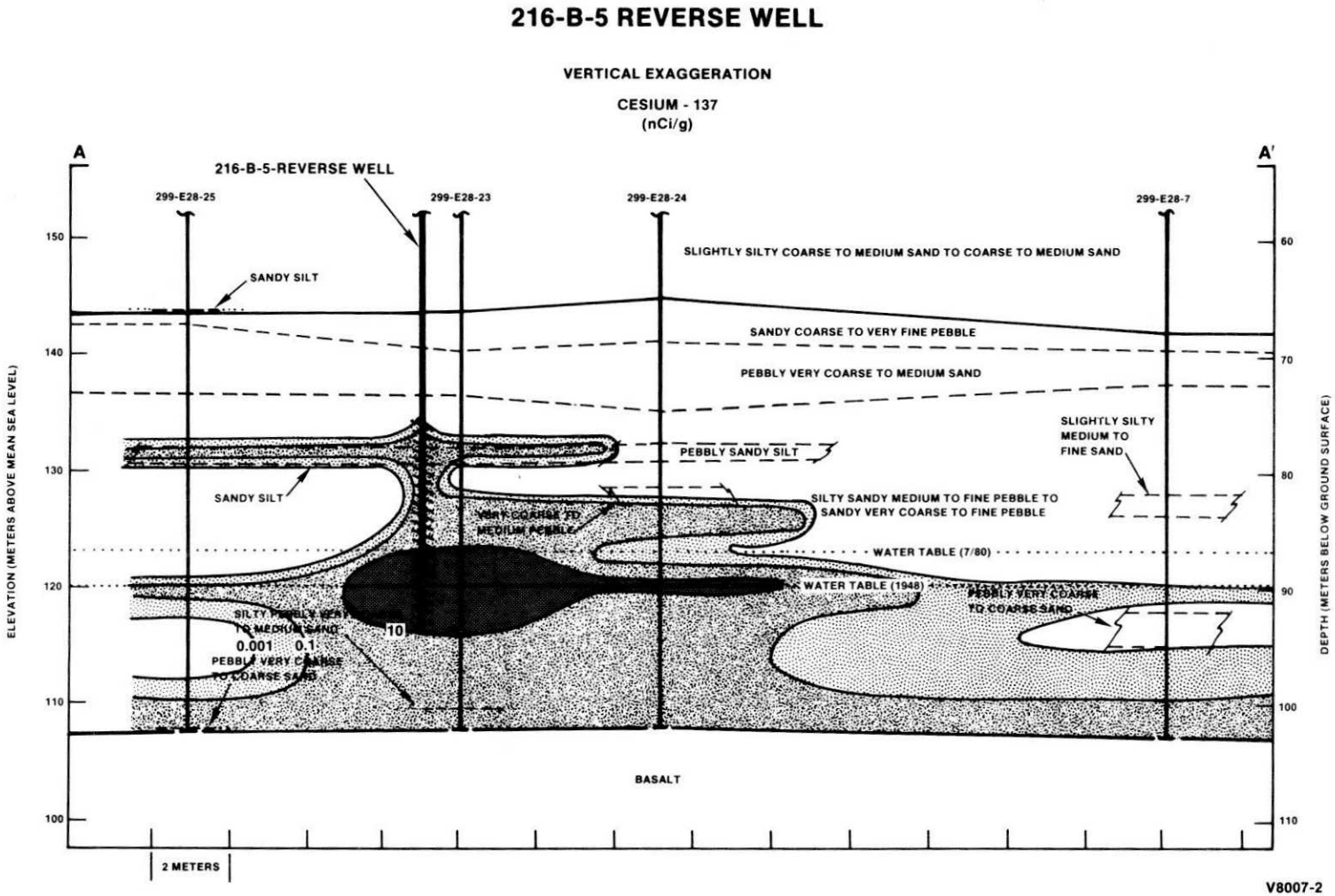

FIGURE V.16. Cesium-137 Distribution (Smith 1981)

A subsequent characterization study of the 216-B-5 reverse well was conducted to determine the distribution of radionuclides sorbed on the sediments (Smith 1980, 1981). Five wells were drilled, and one well was deepened as part of this study. At the time of drilling, sediment samples were collected throughout the entire length of each well. These samples were then analyzed and used to develop geologic cross sections, moisture profiles, and radionuclide distributions.

The distribution of ^{137}Cs is presented in Figure V.16. The distribution was influenced by the silt layer 78 m below ground surface and by the 1948 water table at approximately 90 m. The highest ^{137}Cs concentration, 51.3 nCi/g, was detected in well 299-E28-23 at 86.6 m. The 0.1-nCi/g isopleth indicates that ^{137}Cs may have accumulated on the basalt surface (at the bottom of the unconfined aquifer) and spread laterally along this boundary. This trend is indicated in both the upgradient and downgradient directions.

The $^{239,240}Pu$ distribution is presented in Figure V.17. The plutonium distribution also shows evidence of the influence of the 1948 water table and the direction of groundwater flow. The highest level of plutonium detected, 191 nCi/g, was located at a depth of 98.5 m in well 299-E28-23. This was the approximate depth to the water table in 1948. Plutonium contamination above 10 nCi/g was limited to a distance less than 6 m from the reverse well.

Figure V.18 shows the distribution of ^{90}Sr. This distribution is similar to the other distributions in that it also shows the influence of the 1948 water table and direction of groundwater flow. The limited distribution of ^{90}Sr compared to ^{137}Cs was partially attributed to settling of ^{90}Sr in the 241-B-361 settling tank. Therefore, a larger portion of the ^{137}Cs inventory overflowed to the reverse well than the ^{90}Sr inventory.

In summary, although plutonium was introduced directly to the aquifer, little migration has been observed. The ^{90}Sr and ^{137}Cs are more widespread due to their increased mobility. However, the zone of contamination around the 216-B-5 reverse well appears to be stable, with no apparent further migration of radionuclides.

V.6 DISPOSAL PONDS

The 216-U-10 (U) Pond and associated ditches (U-Pond system) were characterized in 1979 and 1980 to determine the distribution of radionuclides beneath and adjacent to the disposal system (Last 1983). The U-Pond disposal system (Figure V.19) was constructed in 1943 to receive large volumes of very low-level contaminated waste water from 200 West Area facilities. The 216-U-10 Pond and 216-Z-19 ditch were retired and stabilized by early 1984. The large volumes of low-level waste water and occasional isolated releases of considerably higher-level, nonroutine discharges have resulted in the accumulation of transuranic, fission product and activation product inventories. A total of 1.3×10^{11} L of liquid had been discharged to the system through 1982, with a radionuclide inventory estimated to include 8.2 kg plutonium, 1.5×10^{3} kg uranium, 15.3 Ci ^{137}Cs, and 22.6 Ci ^{90}Sr. The large number of discharge sources and the operational service dates of the U-Pond system components complicated attempts to derive total inventories for the individual U-Pond components.

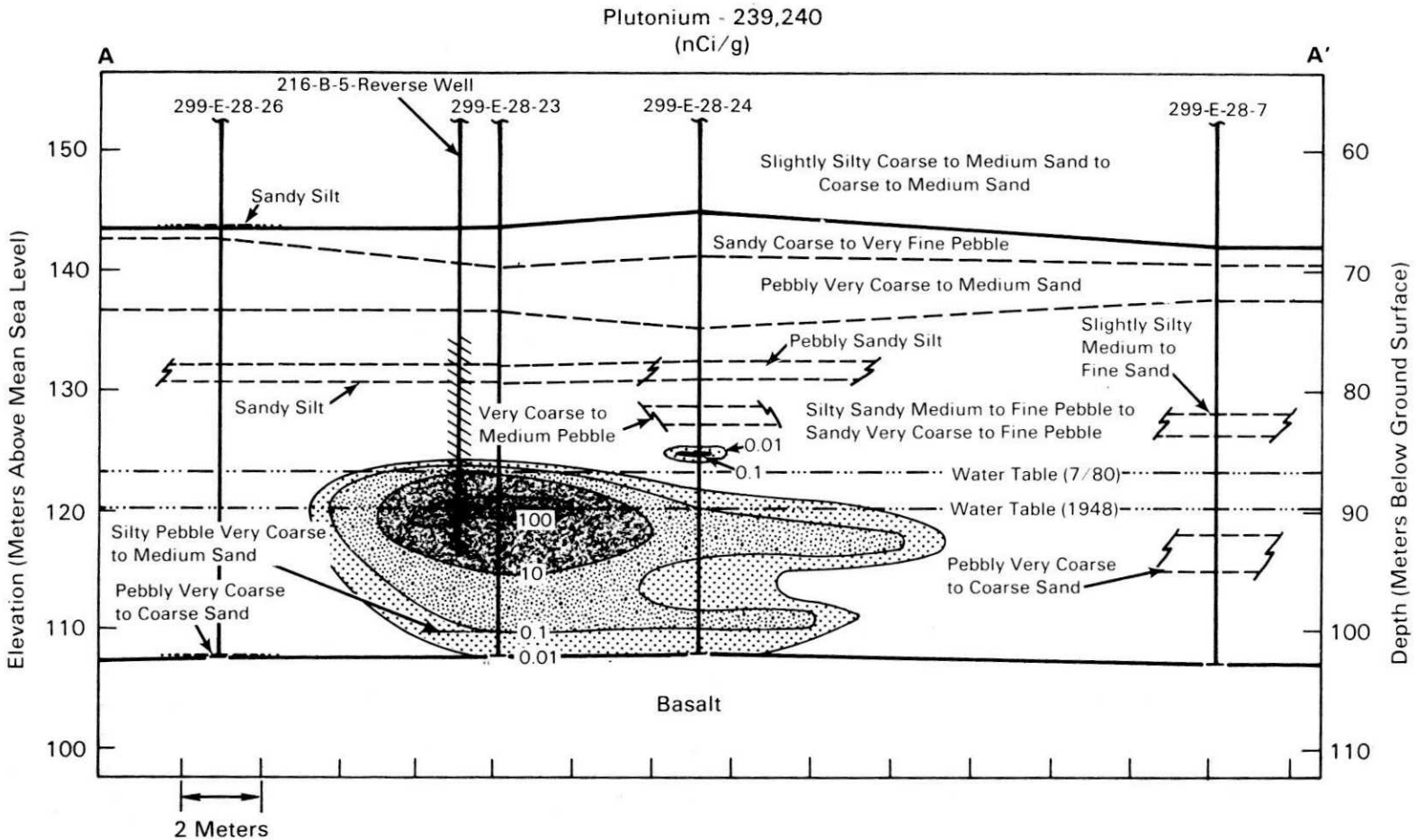

FIGURE V.17. Plutonium-239-240 Distribution (Smith 1981)
(216-B-5 Reverse Well)

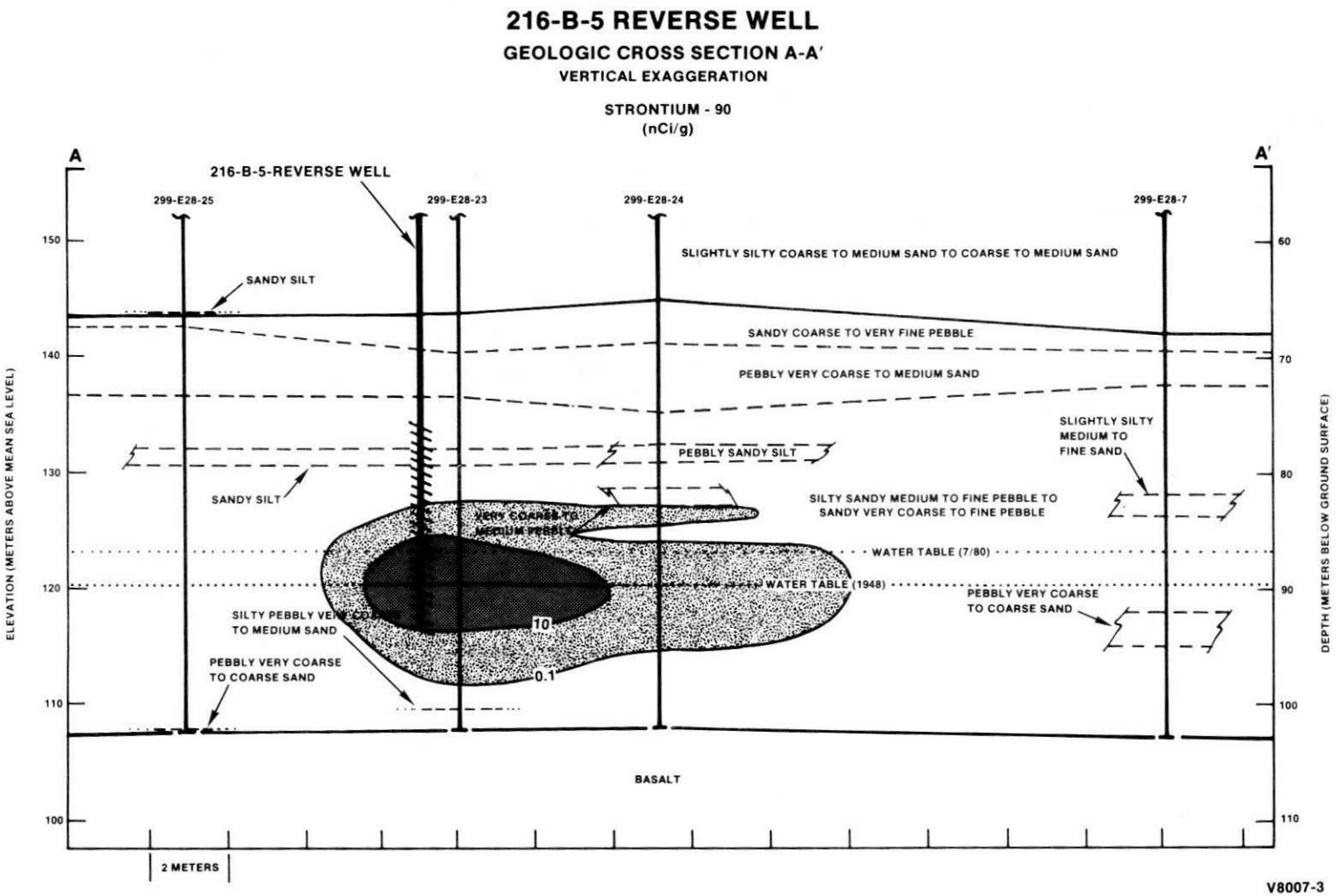

FIGURE V.18. **Strontium-90 Distribution** (Smith 1981)

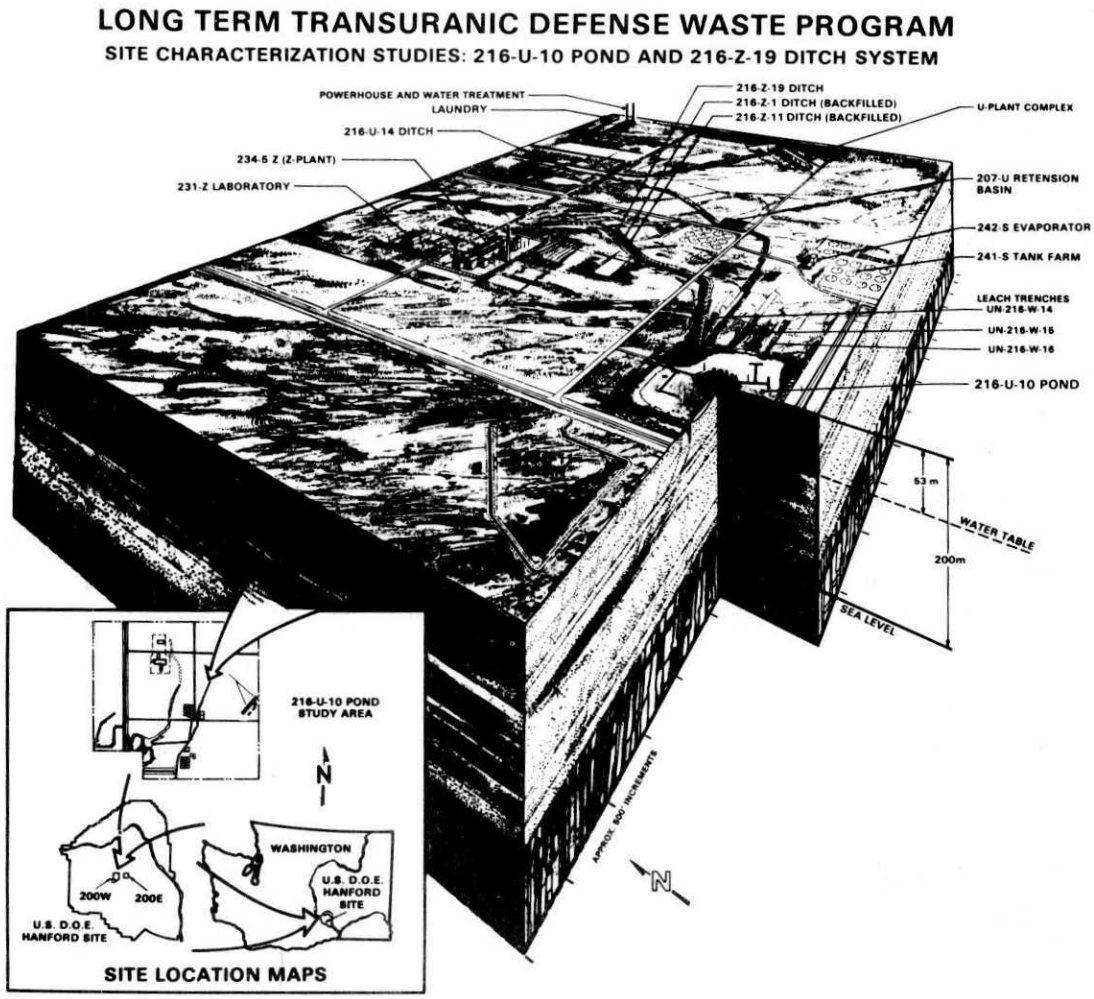

FIGURE V.19. Location of the U-Pond Disposal System and its Various Components

The discharges of principal interest in the Last study were to the 216-Z-19 ditch and its predecessors, the 216-Z-1 and Z-11 ditches. Of a total 8.2 kg plutonium released to the U-Pond system, all but negligible amounts were released to these ditches. A comparison of the annual plutonium discharges and the service dates of the Z ditches indicates that the 216-Z-1 ditch received 138.5 g, the 216-Z-11 ditch received 8,074.7 g, and the 216-Z-19 ditch received 143.0 g.

Over the last 40 years, the U-Pond system has undergone numerous physical modifications. The majority of the modifications resulted from changes in discharge sources and waste volumes released to the U-Pond system. These discharge sources include the Plutonium Processing and Reclamation Facilities (231-Z and 234-5Z), laundry and mask-cleaning facilities (2724-W and 2723-W), uranium recovery facilities (221-U and 224-U), a powerhouse and water treatment plant (284-W), and an evaporator-crystallizer plant (242-S).

Surface samples and near-surface core samples (30 cm) were collected throughout the U-Pond system. Over 700 surface and near-surface samples were taken. Two monitoring wells were drilled to a depth of approximately 25 m; another monitoring well was drilled near U Pond to a depth of 75 m for groundwater monitoring purposes; and seventeen shallow wells (approximately 4 m) were drilled. From these wells, 322 subsurface samples were collected. These field samples were analyzed in the laboratory for gamma-emitting radionuclides, plutonium, americium, ^{90}Sr, uranium, moisture content, and texture. Neutron well logging and in-situ gamma-energy analyses were also conducted.

The vertical distribution of cesium was known best around the perimeter of U Pond. In the delta area, near-surface core samples indicated that ^{137}Cs contamination was generally concentrated in the top 18 cm of soil. Cesium-137 concentrations less than 400 pCi/g were observed to a depth of 1.5 m, with much lower concentrations extending to 30 m. The ^{90}Sr concentrations were slightly higher in some of these deeper samples.

Plutonium and americium were found to be concentrated in the 216-Z-19 ditch (and its predecessors), although variable concentrations of these isotopes were observed in the pond. The plutonium was concentrated in the top 50 cm of the ditches, where concentrations were as high as 100,000 pCi/g. Detectable $^{239,240}Pu$ was found to a depth of 14 m beneath the Z ditches.

In summary, the strontium and cesium have migrated deeper in the soil profile than has plutonium. Strontium and cesium were found at depths of 30 m, whereas plutonium was detected at a maximum depth of 14 m.

V.7 241-T-106 TANK LEAK

In June 1973, the 241-T-106 tank, located in the 200 West Area, was confirmed as leaking. Approximately 4.35×10^5 L of liquid containing 40,000 Ci of ^{137}Cs, 14,000 Ci of ^{90}Sr, 6 Ci of plutonium and americium, and 297,000 Ci of various fission products (with half-lives less than five years) were released to the sediments surrounding the tank.

Subsequent to the leak, studies were conducted to monitor and assess the potential for migration of the contaminants (ARHCO Staff 1973; Routson et al. 1979; Brown et al. 1979).

The 2.02×10^6-L-capacity 241-T-106 tank is one of 12 identical steel-lined tanks constructed in 1943 and 1944 in the T tank farm. The 241-T-106 tank was the first one used for liquid storage in 1944. A drawing of the 241-T-106 tank showing important structural details is given in Figure V.20. The 241-T-106 tank is approximately 23 m in dia and 10 m high. The top of the tank is approximately 2 m below the surface of the ground, and the bottom of the tank is 49.4 m above the water table.

For the initial characterization of the leak, 16 drywells were drilled (ARHCO Staff 1973). The initial evaluation was based on the in-well total-gamma profiles and laboratory gamma-energy analysis (GEA) of sediment samples from various depths of these drywells. In the original 1973 assessment, radioactivity was found at a maximum depth of 27 m, which is 35 m above the water table. The assessment of the movement of radionuclides was based on

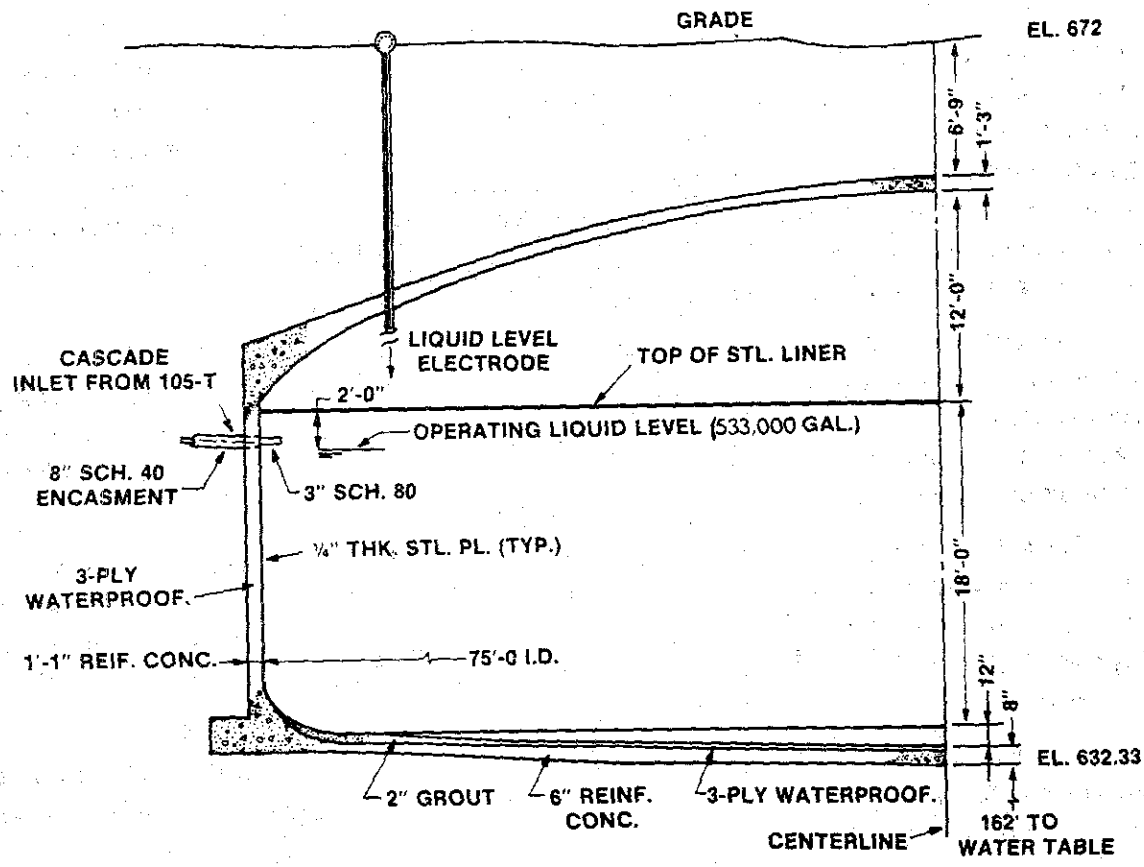

FIGURE V.20. Structural Details of 241-T-106 Tank (Routson et al. 1979)

plan and section views of the concentration distributions of ^{106}Ru, ^{144}Ce and ^{137}Cs. These three radionuclides were chosen for evaluation because they span much of the radionuclide mobility range exhibited in the 241-T-106 tank leak system. A composite of the plan and section views of the 1973 (shortly after the leak) 1-μCi/L concentration isopleths for ^{106}Ru and ^{137}Cs is provided in Figure V.21. Contamination in the vicinity of the 241-T-103 tank resulted from a failed grout seal in a spare fill entry line (ARHCO Staff 1973).

Following the 1973 investigation, 47 additional drywells were drilled around the 241-T-106 tank (Routson et al. 1979). Plan and section views of the 1-μCi/L concentration isopleths for ^{106}Ru and ^{137}Cs were constructed for November 1977 and May 1978 (Figures V.22 and V.23) and compared with those constructed using 1973 data. It was concluded that the volume of soil enclosed by the 1978 ^{106}Ru 1-μCi/L isopleth was only slightly greater than that enclosed by the 1973 isopleth. Routson et al. (1979) concluded that essentially all detectable ^{106}Ru movement occurred between 1973 and 1974. In 1978, ^{106}Ru concentrations above 1 μCi/L were found at a maximum depth of 33 m or 29 m above the water table. For ^{137}Cs, the volume of sediment enclosed by the 1978 ^{137}Cs 1-μCi/L isopleth was greater than that enclosed by the 1973 isopleth. As with the ^{106}Ru, a large portion of the ^{137}Cs movement was thought to have occurred during 1973 and 1974. Plutonium and americium were measured around the tank using a foil activation technique. Low levels of plutonium were detectable

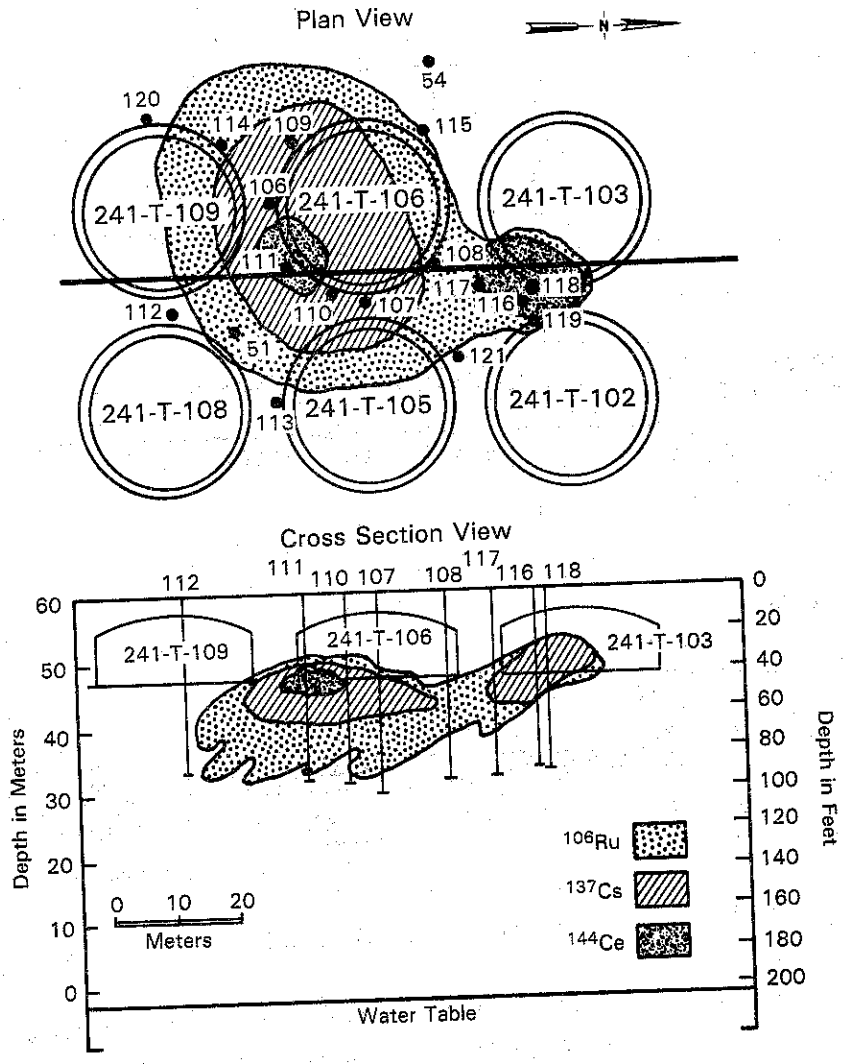

FIGURE V.21. Composite Drawing of Plan and Section Views of 0.1-μCi/L Concentrations of ^{144}Ce, ^{137}Cs and ^{106}Ru in 1973 (Routson et al. 1979)

near the bottom of the 241-T-106 tank and in the wells nearest the leak. The maximum plutonium concentration was found at the 9.2-m depth of one well adjacent to the tank.

V.8 SUMMARY AND CONCLUSIONS

From field observations of the distribution of contaminants in the sediments surrounding waste-management facilities at Hanford, a number of general conclusions can be drawn. The migration of radionuclides is greatly influenced by the local stratigraphy. That is, the layering of sediments with differing hydraulic properties and geochemical properties affects the horizontal and vertical movement of radionuclides. The chemistry of the waste, and the geochemical interactions of the waste and the sediments, is also a principal factor influencing the distribution of contaminants, as observed at the 216-Z-1A crib. Geochemical factors become more important for the higher-water-flux cases associated with crib discharges

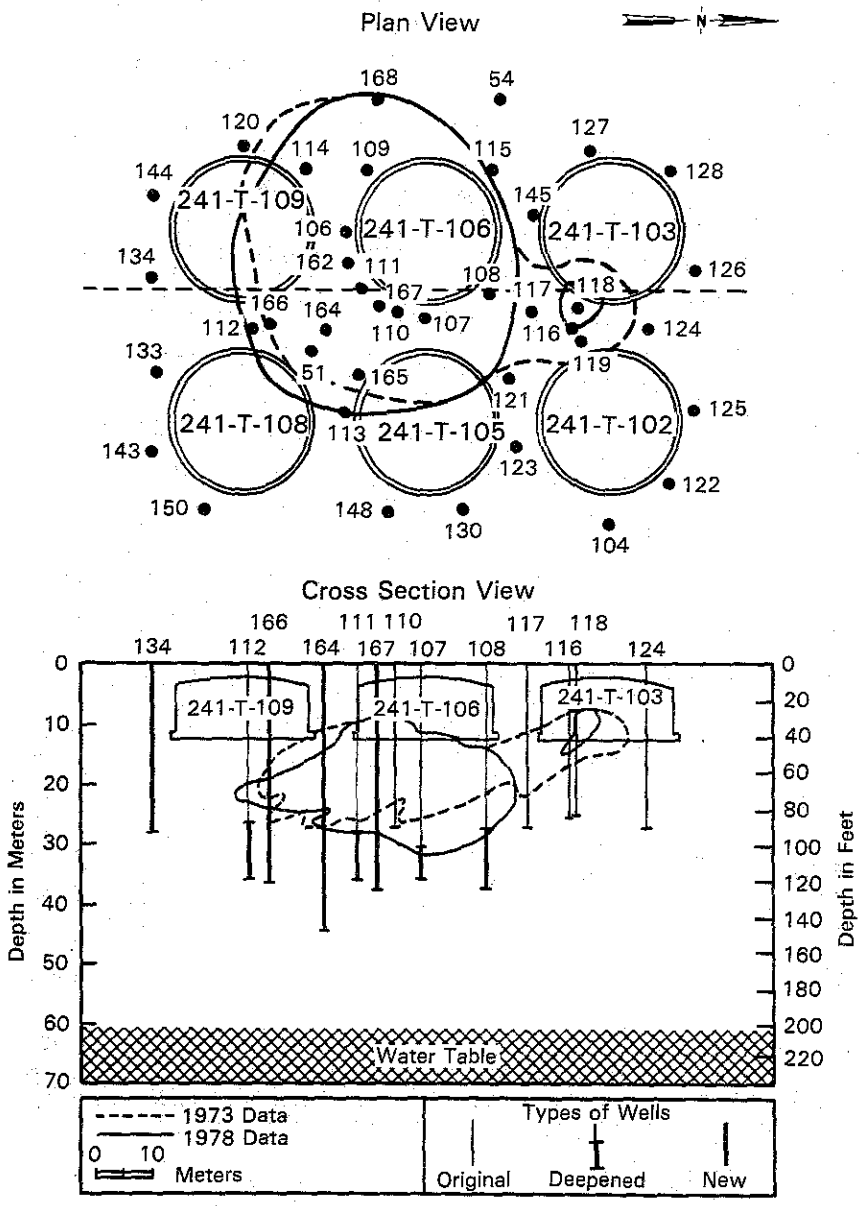

FIGURE V.22. **Plan and Cross-Section View Through a Portion of 241-T Tank Farm with 1-μCi/L ^{106}Ru Isopleth Distribution Pattern** (Routson et al. 1979)

and tank leaks. Also, the manner in which the radionuclides were originally dispersed influences the observed pattern of contamination. Lastly, the contaminants were added to the subsurface at Hanford in relatively large volumes. The initial redistribution of water (and radionuclides) in the unsaturated zone as the system re-equilibrates seems to control the observed distribution of contaminants (as in the 241-T-106 tank leak). Subsequent movement

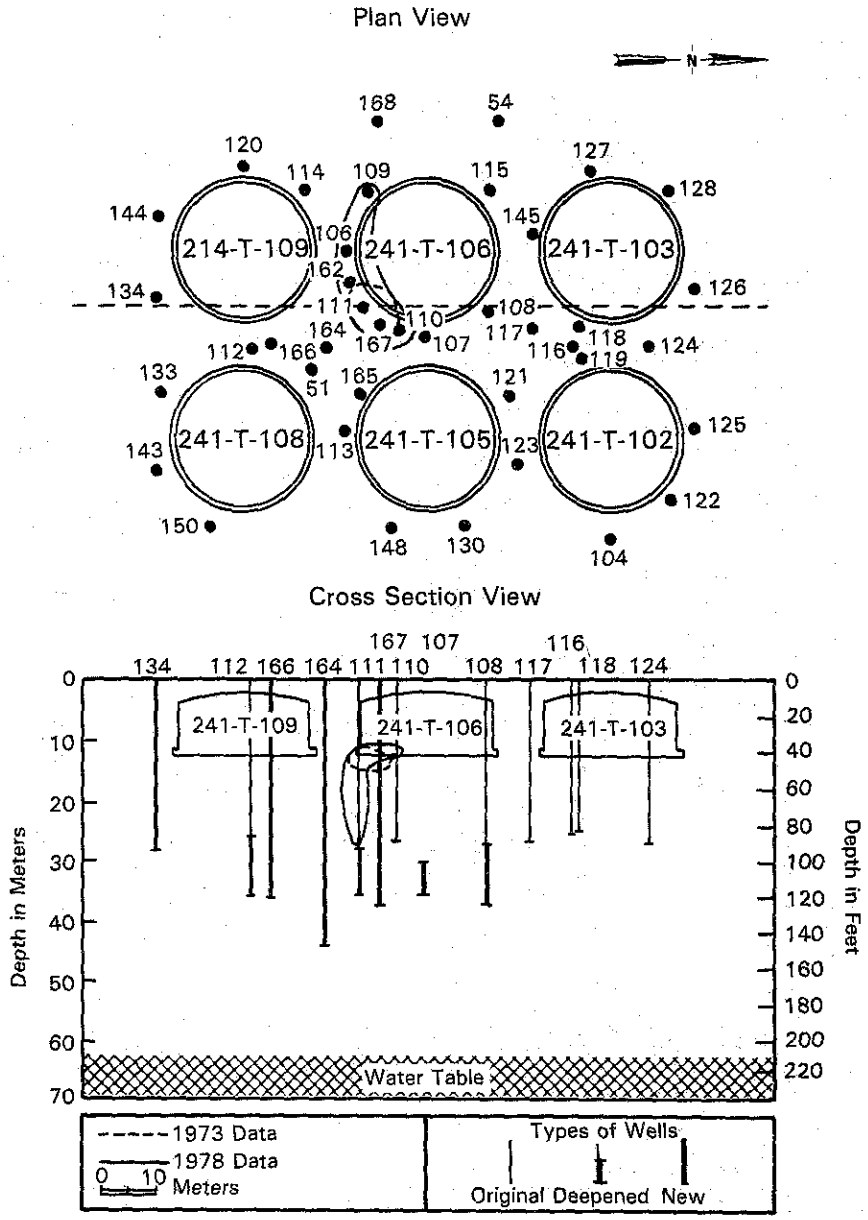

FIGURE V.23. **Plan and Cross-Section View Through a Portion of 241-T Tank Farm with 1-μCi/L ^{137}Cs Isopleth Distribution Pattern** (Routson et al. 1979)

of long-lived radionuclides in the Hanford subsurface appears to be limited. Plutonium appears to be adsorbed or precipitated closer to the source than either strontium or cesium. Strontium appears to be more mobile than cesium, particularly in acidic waste streams (as in the 216-S-1 and 2 crib).

The conclusions that can be drawn from empirical observations of crib discharges and tank leaks are necessarily general. Sampling the distribution of radionuclides via soil analysis alone and subsequent monitoring of the unconfined aquifer do not provide adequate

information from which to differentiate the various controlling physical and chemical mechanisms. Although useful in a confirmatory sense, such limited field data should not be relied upon for the development of predictive models.

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