8.3.3 SEAL PROGRAM

8.3.3.1 Overview

Section 8.3.3 presents the performance allocation tables for the seals for shafts, ramps, and boreholes.

8.3.3.2 Performance Allocation Tables for Seal Characteristics

This section addresses compliance with the design criteria in 10 CFR Part 60 that relate to sealing, specifically 60.134(a) and (b), 60.112, 60.113(a), and 60.142(a), (b), (c), and (d). Sealing components are identified in Table 8.3.3.2-1, together with their associated functions, processes, material properties, performance measures, and tentative goals. Sealing-related repository design constraints and goals are identified in Table 8.3.3.2-2. The site data needed to support resolution of the sealing issue are identified in Tables 8.3.3.2-3 and 8.3.3.2-4.

9303150163-Part 8

Table 8.3.3.2-1. Sealing components and associated functions, processes, material properties, performance measures, and goals (page 1 of 4)

Step A	Step B		Step C		Step D		
Sealing component	Function	Process	Material properties	Performance measure		Tentative design goal[a]	Needed confidence
			SHAFT AND RAMP SEALING COMPONENTS				
1. Anchor-to-bedrock plug/seal	Reduce amount of water that could potentially reach the waste disposal rooms	Water entering the upper portion of the shaft or ramp	Permeability	Quantity of water	1A.	Limit surface waters entering shaft to 1,700 m^3/yr from 0 to 500 yr and 23,000 m^3/yr at the end of the sealing period	High
	Reduce the potential for human intrusion into the repository	Penetrability through sealing components	To be determined through design tradeoff studies	Physical presence	1B.	Deter human entry	Medium
2. General fill	Reduce the amount of water that could potentially reach the waste disposal rooms	Infiltration of surface and subsurface waters reaching the base of the shafts	Permeability of fill	Quantity of water	2A.	Restrict flow	Low
	Reduce the air flow up through shafts	Air flow up through the shaft due to convective air movement	Air permeability of fill	Percentage of gaseous radionuclides preferentially exiting shafts	2B.	Restrict gaseous releases through shaft to 1% of Environmental Protection Agency allowable release limits to accessible environment	Low
	Reduce the potential for human intrusion into the repository	Penetrability through sealing components	To be determined through design trade-off studies	Physical presence	2C.	Deter human entry	Medium
3. Station plugs	Reduce the amount of water that could potentially reach the waste disposal rooms	Water passage from the base of shaft to the waste emplacement drifts	Permeability	Quantity of water	3A.	Limit surface and subsurface waters entering the underground facility to 1,000 m^3 per yr from 0 to 500 yr and 14,000 m^3 per yr at end of the sealing period	High
4. Unsaturated Topopah Spring Member (TSw2) at base of shafts	Encourage drainage from base of shafts	Flow through the bulk rock, at base of shaft, both lined and unlined cases	Bulk rock hydraulic conductivity	Drainage capacity	4A.	Ensure uninhibited flow from the base of exploratory shaft 1 (ES-1) and the men and material (MM) shaft	High

Table 8.3.3.2-1. Sealing components and associated functions, processes, material properties, performance measures, and goals (page 2 of 4)

Step A	Step B		Step C		Step D		
Sealing component	Function	Process	Material properties	Performance measure		Tentative design goal[a]	Needed confidence
			UNDERGROUND FACILITY SEALING COMPONENTS				
5. Single dam or bulkhead[b] in emplacement drifts	Retain and drain water entering emplacement drifts where water entry occurs	Lateral migration of water in drifts	Permeability	Quantity of water	5A.	Retain a portion of the ground-water inflow near source by providing adequate storage volume and drainage capacity and limit flow through dam to 47 m^3/yr from 0 to 300 yr and 220 m^3/yr to the end of the sealing period (500 yr)	Medium
Single dam or bulkhead in perimeter and main drifts	Retain and drain water entering nonemplacement drifts	Lateral migration of water in drifts	Permeability	Quantity of water	5B.	Promote drainage through drift floor upgradient from dam by limiting leakage through the dam or bulkhead to 10% of the drainage capacity of the drift floor upgradient from the dam, i.e., <200 m^3/yr	High
6. Double bulkheads[b] in emplacement drifts (no settlement)	Retain and drain water entering emplacement drifts where water entry occurs	Lateral migration of water in drifts	Permeability	Quantity of water	6A.	Retain inflow between two bulkheads by providing adequate storage volume and drainage capacity and limit flow through bulkhead to 24 m^3/yr per bulkhead from 0 to 300 yr and 110 m^3/yr per bulkhead at the end of the sealing period (500 yr)	Low
			UNDERGROUND FACILITY SEALING COMPONENTS				
Double bulkheads[b] in emplacement drifts (settlement)	Retain and drain water entering emplacement drifts where water entry occurs	Lateral migration of water in drifts	Permeability	Quantity of water	6B.	Retain a portion of the inflow near source by providing adequate capacity and limit flow through bulkhead to 24 m^3/yr per bulkhead from 0 to 300 yr and 110 m^3/yr per bulkhead at the end of the sealing period (500 yr)	Low

Table 8.3.3.2-1. Sealing components and associated functions, processes, material properties, performance measures, and goals (page 3 of 4)

Step A	Step B		Step C		Step D	
Sealing component	Function	Process	Material properties	Performance measure	Tentative design goal[a]	Needed confidence
			UNDERGROUND FACILITY SEALING COMPONENTS (continued)			
7. Backfilled sump[b]	Retain and drain water entering drifts	Drainage through bulk rock in floor of drift	Bulk permeability of rock at floor of drift	Quantity of water	7A. Retain ground-water inflow near source by providing ≥5 m^3 temporary storage capacity ≥100 m^3/yr	Low
8. Backfilled channel[b]	Divert water away from waste emplacement areas	Drainage through channel fill	Permeability of channel fill	Quantity of water	8A. Channel ground water away from waste packages at rates sufficient to handle inflow	Low
9. Plug in horizontal emplacement boreholes[c]	Reduce the amount of water entering horizontal emplacement boreholes	Infiltration through fault system	Permeability	Quantity of water	9A. Limit flow past plug to 12 m^3/yr from 0 to 300 yr and 56 m^3/yr to the end of sealing period	Low
10. Drift backfill	Reduce the potential for subsidence	Failure of rock mass above drifts		Amount of fill	10A. Backfill to within 0.5 m of roof	Low
	Reduce the potential of human intrusion into the repository	Penetrability through sealing components	To be determined through design tradeoff studies	Physical presence	10B. Deter human entry	Low
			EXPLORATORY BOREHOLE SEALING COMPONENTS			
11. Exploratory borehole seal						
11A. Upper borehole seal	Reduce the amount of water that could potentially reach the waste disposal rooms	Infiltration of surface and subsurface waters reaching the repository horizon	Permeability of fill	Quantity of water	11A. Restrict flow	Low
	Reduce the air flow up through borehole	Air flow up through the boreholes due to convective air movement	Air permeability of fill	Percentage of gaseous radionuclides preferentially exiting boreholes	11B. Restrict gaseous releases through shaft to 1% of Environmental Protection Agency allowable release limits to accessible environment	Low

Table 8.3.3.2-1. Sealing components and associated functions, processes, material properties, performance measures, and goals (page 4 of 4)

Step A	Step B		Step C		Step D	
Sealing component	Function	Process	Material properties	Performance measure	Tentative design goal[a]	Needed confidence
			EXPLORATORY BOREHOLE SEALING COMPONENTS (continued)			
11B. Lower borehole seal (including Calico Hills)[d]	Reduce the potential for water transported radionuclides to be preferentially transported through boreholes	Preferential groundwater flow through the repository, Calico Hills unit and the saturated zone	Equivalent hydraulic conductivity of the borehole system	Percentage of flow	11C. Control the potential for vertical flow through boreholes to 1% or less of the potential for vertical flow through the entire rock mass	Low

[a]As used here a design goal applies to a specific sealing component and a performance goal applies to sealing subsystems such as the underground facility subsystem. Tentative performance goals for the sealing subsystems are given in Table 8.3.3.2-5.

[b]Specific sealing components will be selected as part of the design process.

[c]Probably will not be used because it is most likely that no waste would be emplaced in boreholes with water inflow.

[d]Borehole system includes the borehole seals, the interface zone, and the modified permeability zone surrounding the borehole sealing. Boreholes are categorized for sealing purposes in Table 8.3.3.2-1a.

Table 8.3.3.2-1a. Exploratory borehole categories for sealing[a,b,c]

Category A						
Within repository limits	Distance from edge of repository: 1 km	2 km	3 km	4 km	5 km	Category B
USW H-5	UE-25a#4	UE-25WT#4	UE-25WT#5	UE-25WT#14	UE-25WT#15	USW H-3
USW G-4	UE-25a#5	USW WT-1	UE-25c#1		UE-25WT#13	USW G-3
UE-25a#6[d]	UE-25a#7		UE-25p#1			USW UZ-1
USW H-4	UE-25b#1					USW G-1
USW WT-2	UE-25a#1					USW H-1

[a]Category A boreholes represent potential pathways to the accessible environment. Category B boreholes are not believed to be potential pathways to the accessible environment but because of their proximity to the repository boundary are currently planned to be sealed.

[b]Shallow boreholes that do not require sealing for repository purposes will be backfilled or sealed as required by other regulations.

[c]The zone of influence, and hence those additional holes that may need to be sealed, will be further analyzed based on data gathered during site characterization.

[d]This borehole does not penetrate the repository horizon.

Table 8.3.3.2-2. General design constraints passed to Issue 1.11, configuration of underground facilities (postclosure), for major repository features from sealing program (page 1 of 3)

Step A	Step B		Step C	Step D	
Major repository feature	Function	Process	Performance measure	Tentative design goal	Needed confidence
12. Shafts and ramps	Provide entry into repository	Water flow in shafts and ramps	Location of surface entry	12A. Place portals of shaft and ramps outside of flood-prone areas	High
		Water flow in shafts and ramps	Number of entry points into the repository	12B. Restrict the number of shafts and ramps	High
13. Shafts	Provide entry into repository	Retain capability for permanent seal installation	Ease of liner removal	13A. Ensure shaft liner can be removed, especially at the base of the shaft	High
		Limit potential for preferential pathway	Depth of shaft	13B. No shafts should penetrate into the Calico Hills unit. Penetration by exploratory shaft 1 (ES-1) is being evaluated	High
		Encourage shaft inflow drainage at base of shaft	Water storage capacity at base of shaft	13C. 150 m^3 (backfilled assuming porosity of 0.3)	High
		Limit potential for preferential pathway	Effective thickness of the zeolitic portion of the Calico Hills unit between the lowest portion of the exploratory studies facility (ESF) and the ground-water table	13D. The thickness between the bottom of ES-1 or any ESF drifting and the ground-water table should be greater than the minimun thickness of the Calico Hills unit above the water table anywhere within the repository boundary	High

Table 8.3.3.2-2. General design constraints passed to Issue 1.11, configuration of underground facilities (postclosure), for major repository features from sealing program (page 2 of 3)

Step A	Step B		Step C	Step D	
Major repository feature	Function	Process	Performance measure	Tentative design goal	Needed confidence
14. Underground drifting	Provide access to waste disposal areas	Potential water flow in underground facility	Drift grade	14A. Establish drainage pattern from emplacement drifts to non-emplacement drifts	High
			Drift grade in vicinity of ES-1, ES-2, and men and material (MM) shafts	14B. Establish drift grade so that the drifts associated with the ESF, the waste emplacement support shops, and the development support shops drain toward the ES-1 or MM shafts	High
			Drift grade	14C. Establish grades access and emplacement drifts so that no drainage occurs into ES-1 and MM shaft	High
			Water storage capacity in low point of repository	14D. Provide 10,000 m^3 of water storage capability before any water enters the waste emplacement drifts (assume drifts are backfilled with backfill having porosity of 0.3)	High

Table 8.3.3.2-2. General design constraints passed to Issue 1.11, configuration of underground facilities (postclosure), for major repository features from sealing program (page 3 of 3)

Step A	Step B		Step C	Step D		
Major repository feature	Function	Process	Performance measure		Tentative design goal	Needed confidence
14. Underground drifting (continued)			Ease of restoring drift floors to enhance drainage	14E.	Ensure the compacted tuff on drift floors in selected areas can be removed and the floor reconditioned to enhance drainage	High
15. Underground facility	Prevent complication of seals installation	Standoff from exploratory boreholes	Ease in sealing exploratory boreholes within the repository boundary	15A.	Drifting should be at least 15 m from exploratory boreholes	High
16. Shafts and underground facility	Prevent complication of seal evaluation and emplacement	Limit chemical alteration in seal environment	Ease of emplacing a grout curtain in selected locations where seals are currently proposed	16A.	No grouting should take place at these locations during the construction period	High
		Limit blast-induced permeability changes	Ease of restoring the modified permeability zone in selected locations where drift seals are proposed	16B.	Reduce the potential for fracturing rock in selected seal locations by exercising as much control as possible and practical, while excavating the shaft, ramps or drifts in these locations	High

[a]As used here, a design goal applies to a specific sealing component and a performance goal applies to sealing subsystems such as the shafts and ramps subsystem and the underground facility subsystem. Tentative performance goals for the sealing subsystem are given in Table 8.3.3.2-5.

Table 8.3.3.2-3. Hydrologic-related site parameters needed to support resolution of Issue 1.12 (seal characteristics) (page 1 of 3)

Related design goal[a]	Performance or design parameters	Modifiers[b]	Tentative parameter goal	Needed confidence	Current confidence	Expected parameter values	SCP section providing data
1A, 2A, 3A, 11A, 11B	Saturated hydraulic conductivity of alluvium	Within 75 m of shaft and borehole locations	1×10^{-5} to 1×10^{2} cm/s	Medium	Low	1×10^{-2} to 1×10^{-3} cm/s	8.3.1.2.2
1A, 2A, 3A, 11A, 11B	Saturated bulk rock hydraulic conductivity of Tiva Canyon Member		1×10^{-5} to 1×10^{-2} cm/s	Medium	Low	1.2×10^{-3} cm/s	8.3.1.2.2
1A, 2A, 3A, 11A	Morphology of bedrock surface	In order of priority: downgradient and about 160 m from shaft and borehole locations	Determine contours to within ±3 m	Medium	Low	Contours accurate to 3 m	8.3.1.14.2
1A, 2A, 3A, 11A, 11B	Thickness of alluvium	Within 75 m of shaft and borehole locations	Determine thickness to within ±10%	Medium	Low	0 to 10 m	8.3.1.14.2
1A, 2A, 3A, 11A	Quantity of water due to surface flooding events 100- and 500-yr flood & probable maximum flood including area of inundation and debris load of flows	Determine parameter at shaft, ramp and borehole locations	Inundation maps with elevation of inundated area to within ±2 m	Medium	Low	(see Figure 6-8)	8.3.1.16.1
			Estimates of debris quantity and category	Low	Low	Not available	8.3.1.16.1
			Determine topography of drainage area using 2 m contours	Medium	Medium	Contours to 2 m	8.3.1.14.1

Table 8.3.3.2-3. Hydrologic-related site parameters needed to support resolution of Issue 1.12 (seal characteristics) (page 2 of 3)

Related design goal[a]	Performance or design parameters	Modifiers[b]	Tentative parameter goal	Needed confidence	Current confidence	Expected parameter values	SCP section providing data
1A, 2A, 3A, 11A	Continuous saturation profile of alluvium to bedrock-alluvium interface	At shaft and borehole locations	±10% of natural saturation every meter	Medium	Low	To be determined	8.3.1.2.2 8.3.1.14.2
1A, 2A, 3A, 11A	Gradation of alluvium	At shaft locations predominantly within 15 m from shaft and borehole locations	Determination through standard sieving analyses	Not applicable	Low	Soils classified as GP to GM as per ASTM D-2487-83[c]	8.3.1.2.2 8.3.1.14.2
1A, 2A, 3A	Extent and hydraulic conductivity of the modified permeability zone (MPZ)	MPZ in TCw and TSw2	Less than or equal to 60 times the undisturbed, rock mass hydraulic conductivity (saturated), averaged over one radius from the wall of the shaft	Medium	Low	1 to 20 times undisturbed, rock mass hydraulic conductivity	8.3.1.2.2
1A, 2A, 3A, 11A, 11B	Unsaturated hydraulic, matrix properties	TSw2, especially in vicinity of shafts	1×10^{-8} to 1×10^{-15} m/s	Medium	Low	1×10^{-8} to 1×10^{-15} m/s	8.3.1.2.2
5A, 5B, 6A, 6B, 7A, 8A	Drainage capacity	TSw2 at selected drift floor locations at repository horizon	Saturated, bulk rock hydraulic conductivity $K_{SAT}d > 1 \times 10^{-5}$ cm/s	High	Low	1.2×10^{-3} cm/s	8.3.1.2.2

Table 8.3.3.2-3. Hydrologic-related site parameters needed to support resolution of Issue 1.12 (seal characteristics) (page 3 of 3)

Related design goal[a]	Performance or design parameters	Modifiers[b]	Tentative parameter goal	Needed confidence	Current confidence	Expected parameter values	SCP section providing data
4A	Drainage capacity	TSw2 at base of shafts	Saturated, bulk rock hydraulic conductivity $K_{SAT} > 1 \times 10^{-5}$ cm/s	High	Low	1.2×10^{-3} cm/s	8.3.1.2.2
4A, 11C	Saturated, bulk rock hydraulic conductivity	CHn1 at base of ES-1 and in boreholes	Saturated, bulk rock hydraulic conductivity $K_{SAT} > 1 \times 10^{-5}$ cm/s	Low	Low	2.4×10^{-4} cm/s	8.3.1.2.2
4A	Magnitude of water entering shafts	At ES-1, ES-2, MM and EE shafts	<150 m^3/yr per shaft considering anticipated processes	Low	Low	0-100 m^3/yr	8.3.1.2.2
1A, 2A, 3A	Erosion potential	At ES-1, ES-2, MM and EE shafts	<1 m per 1,000 yr preferential erosion at shaft entry points	Low	Low	<40 cm per 1,000 yr preferential erosion at shaft entry points	8.3.1.16.1 8.3.1.6.2 8.3.1.6.1

[a]Design goals identified here are from Table 8.3.3.2-1.

[b]Thermal/mechanical units used in the modifier column are as follows: TSw2 = Topopah Spring, welded (repository horizon); TCw = Tiva Canyon, welded; CHn1 = Calico Hills, nonwelded. Other abbreviations are as follows: ES-1 and -2 = exploratory shafts 1 and 2; MM = man and material shaft, EE = emplacement area exhaust shaft.

[c]GP = poorly graded gravel; GM = silty gravel.

[d]K_{SAT} = saturated hydraulic conductivity.

Table 8.3.3.2-4. Miscellaneous information needed to support resolution of Issue 1.12 (page 1 of 4)

Related design goal[a]	Performance or design parameters	Modifiers[b]	Tentative parameter goal	Needed confidence	Current confidence	Expected parameter values	SCP section providing data
1A, 2A, 3A, 10A, 11A	Compressive strength of rock mass	TCw at shaft and ramp locations	No more restrictive than for Issue 1.11	Medium	Low	See Table 6-12	8.3.1.4.2 8.3.1.15.2
		TSw2	No more restrictive than for Issue 1.11	Medium	Low	See Table 6-12	8.3.1.4.2
		CHn1	No more restrictive than for Issue 1.11	Medium	Low	See Table 6-12	8.3.1.15.2
1A, 2A, 3A, 10A, 11A	In situ stresses	In TCw, TSw2, and CHn1	Vertical stress accurate to ±1 MPa Horizontal stress accurate to ±2 MPa	Low	Low	4 to 10 MPa vertical Horizontal to vertical ratio 0.3 to 1.0	8.3.1.15.2 8.3.1.15.2
1A, 2A, 3A, 5A, 5B, 6A, 6B, 7A, 11A	Seismic response spectra	At shaft and ramp location (surface and repository horizon) At selected location in underground facility In Calico Hills unit for boreholes within boundary of the underground facility	To be determined through design studies	High	Low	Acceleration <0.65g	8.3.1.8.2

Table 8.3.3.2-4. Miscellaneous information needed to support resolution of Issue 1.12 (page 2 of 4)

Related design goal[a]	Performance or design parameters	Modifiers[b]	Tentative parameter goal	Needed confidence	Current confidence	Expected parameter values	SCP section providing data
1A	Meteorological environment						
	Temperature variations at ground surface	At ground surface At shaft and ramp entry points	To be determined by laboratory testing and activities	To be determined by laboratory and design activities	Low	-14 to 114°F	8.3.1.12.1
	pH of rainfall	At shaft and ramp location	>4.5	Medium	Low	pH >6	8.3.1.12.1
1A	Chemistry of alluvium	At end upgradient from shaft location					
	Dissolved sulphates SO^{2-}	At end upgradient from shaft location	<0.10% soluble SO^{2-} in soils or surface water <150 ppm dissolved SO^{2-}	Low	Low	<15 mg/L (see Table 3-3)	8.3.1.14
	pH of alluvium	At end upgradient from shaft location	>4.5	Medium	Low	>7 (see Table 3-3)	8.3.1.14
1A, 3A, 5A, 5B, 6A, 6B, 7A, 11	Geochemistry	TCw, TSw2, CHnlv, CHnlz	No more restrictive than for Issue 1.1	Medium	Low	See Section 4.1.1	8.3.1.3.2

Table 8.3.3.2-4. Miscellaneous information needed to support resolution of Issue 1.12 (page 3 of 4)

Related design goal[a]	Performance or design parameters	Modifiers[b]	Tentative parameter goal	Needed confidence	Current confidence	Expected parameter values	SCP section providing data
1A, 3A, 5A, 5B, 6A, 6B, 7A, 10A, 11A	Maximum temperature at seal locations	Upper portion of shaft	<90°C	High	Low	<90°C	8.3.2.2.6
		At repository horizon around shaft	To be determined through design tradeoff studies	TBD[c]	TBD	<115°C	8.3.2.2.6
		At selected drift locations in repository horizon	To be determined through design tradeoff studies	TBD	Low	<150°C	8.3.2.2.6
		Calico Hills unit in boreholes below the repository	<90°C	High	Low	<90°C	8.3.2.2.6
3A, 5A, 5B, 6A, 6B, 7A, 9A, 11A	Thermal expansion, heat capacity, and thermal conductivity of seal emplacement environment	TSw2 CHnl	To be determined through design trade-off studies	Medium	Low	See Table 6-16	8.3.1.4.2 8.3.1.14.2
2A, 2B	Shaft and ramp fill properties						
	Saturated hydraulic conductivity		1×10^{-2} cm/s	High	Low	1×10^{-2} to 1×10^{-6} cm/s	8.3.3.2.2 8.3.3.2.4
	Gradational analyses, angle of internal friction, compressibility		To be determined through design trade-off studies	High	Low	Not applicable	8.3.3.2.2 8.3.3.2.4

Table 8.3.3.2-4. Miscellaneous information needed to support resolution of Issue 1.12 (page 4 of 4)

Related design goal[a]	Performance or design parameters	Modifiers[b]	Tentative parameter goal	Needed confidence	Current confidence	Expected parameter values	SCP section providing data
1A, 3A, 5A, 5B, 6A, 6B, 7A, 8A, 10A	Fracture characteristics	TCw TSw2 CHnl at base of ES-1 PTn	<20 fractures/m <40 fractures/m <5 fractures/m <10 fractures/m	High High High High	Low Low Low Low	<20 fractures/m <40 fractures/m <5 fractures/m <10 fractures/m	8.3.1.2.2, 8.3.1.4.1, 8.3.1.15.1
5A, 5B, 6A, 6B, 7A, 8A, 10A	Chemistry of waters (if any) in fault including sediment content		Elemental concentration similar to those contained in Table 4-6	Medium	Low	See Table 4-6	8.3.1.3.1
5A, 5B, 6A, 6B, 7A, 8	Grade of emplacement drifts and drift dimensions	In repository	1-10%	Not applicable	High	1-10%	8.3.2.5.8, 8.3.2.2.7
11A, 11B, 11C	Casing location and condition for exploratory boreholes	All boreholes in categories A & B[c]	Location of casing to ±5 m. Conditions determined by logging and drilling records	High	Medium	See Fernandez and Freshley (1984)	8.3.3.2.4
11A, 11B, 11C	Unit contacts in exploratory boreholes	All boreholes in categories A & B[c]	Contact location ±5 m	High	Low	Not applicable	8.3.3.2.4

[a]Design goals identified are from Tables 8.3.3.2-1 through 8.3.3.2-3.

[b]Thermal/mechanical units used in the modifier column are as follows: TCw = Tiva Canyon welded; TSw2 = Topopah Spring welded (repository horizon); CHnlv = Calico Hills nonwelded, vitric; CHnlz = Calico Hills nonwelded, zeolitic; PTn = Paintbrush nonwelded.

[c]TBD = to be determined.

[d]Category A boreholes represent potential pathways to the accessible environment. Category B boreholes are not potential pathways to the accessible environment but because of their proximity to the repository boundary are currently planned to be sealed. These boreholes are identified in Table 8.3.3.2-1a.

8.3.4 WASTE PACKAGE PROGRAM

8.3.4.1 Overview

Section 8.3.4 presents the performance allocation tables that request site data for postclosure waste package design

8.3.4.2 Performance Allocation Tables for Waste Package Postclosure Characteristics

This section addresses compliance with the postclosure design criteria of 10 CFR 60.135(a). The performance allocation rests upon the identification of the waste package model hierarchy and inputs required for the models (Table 8.3.4.2-1). The confidence needed in the model input and the SCP section providing the site parameter values are documented in this table. Table 8.3.4.2-2 identifies the system elements and corresponding performance measures, goals and needed confidence in the goals for Issue 1.10. Performance parameters, and goals and needed confidence for the performance measures are provided in Table 8.3.4.2-3.

Because one objective of the waste package program is to characterize the near-field waste package environment, Table 8.3.4.2-4 is presented as a characterization-type allocation table. The issues requesting values for a set of near-field performance parameters are identified, together with corresponding characterization parameters as defined in the waste package program. For each characterization parameter, a test basis was developed; the test basis is generally presented as the maximum experimental uncertainty for measurements of the indicated parameter. Finally, a reference is provided to the SCP section responsible for delivering the values for the characterization parameters.

Table 8.3.4.2-1. Model hierarchy and model inputs for Issue 1.10 (waste package characteristics--postclosure)

Model	Model input	Needed confidence	SCP section[a]
Near-field flow and transport	For Topopah Spring Tuff at repository horizon (TSw2)[b]:		
	Hydraulic conductivity of matrix for liquid phase	High	8.3.1.2.2
	Porosity of matrix	High	8.3.1.2.2
	Water retention curves	High	8.3.1.2.2
	Relative permeability curves	High	8.3.1.2.2, 8.3.4.2.4
	Knudsen diffusion coefficients	Medium	8.3.1.2.2
	Fracture permeabilities	High	8.3.1.2.2
	Fracture orientation	Medium	8.3.1.2.2
	Fracture porosity	High	8.3.1.2.2
	Fracture spacing	Medium	8.3.1.2.2
	Heat output of packages	High	8.3.4.2.2
	Thermal conductivity of matrix	High	8.3.1.15.1
	Heat capacity of matrix	High	8.3.1.15.1
	Bulk density of matrix	High	8.3.1.15.1
	Radionuclide releases from container	High	8.3.5.10.4
	Effective sorption coefficients for radionuclides released from package	High	8.3.1.3.4
	Effective solubilities of radionuclides in vadose pore water	Medium	8.3.1.3.5
	Diffusion coefficients for radionuclides in rock matrix	High	8 3.1.3.6
	Dispersivity for radionuclides in rock matrix	Medium	8.3.1.3.6
	Distribution of recharge rates through repository horizon in time and space	High	8.3.1.2.2
Waste package environment	Mineralogy and chemistry of pre- and postemplacement environment	High	8.3.4.2.4.1
	Near-field hydrology	High	8.3.4.2.4.2
	Thermal and mechanical properties of the postemplacement waste package environment	High	8.3.4.2.4.3

Table 8.3.4.2-1. Model hierarchy and model inputs for Issue 1.10 (waste package characteristics--postclosure) (continued)

Model	Model input	Needed confidence	SCP section[a]
Mineralogy and chemistry	Mineralogy and water quality		
	Rock-water interaction at elevated temperature	High	8.3.4.2.4.1.1
	Repository material-induced changes in water chemistry	High	8.3.4.2.4.1.2
	Vadose water composition	High	8.3.4.2.4.1.3
	Dissolution-precipitation effects on water chemistry	Medium	8.3.4.2.4.1.4
	Radiation-induced changes in water chemistry	High	8.3.4.2.4.1.5
	Corrosion-induced changes in water chemistry	Medium	8.3.4.2.4.1.6
Near-field hydrology	Water quantity	High	8.3.4.2.4.2
	Single-phase fluid flow	High	8.3.4.2.4.2.1
	Two-phase fluid flow	High	8.3.4.2.4.2.2
Thermal and mechanical properties	Thermal loading	High	8.3.4.2.4.3
	Near-field temperature distribution	High	8.3.4.2.4.3.1
	Borehole stability	High	8.3.4.2.4.3
	Near-field mechanical properties	High	8.3.4.2.4.3.2
Borehole stability	Fracture orientation and density		
	Average spacing within each borehole	High	8.3.4.2.4.3.2
	Set identification	High	8.3.4.2.4.3.2
	Distribution of orientation	High	8.3.4.2.4.3.2
	Average dip of set	High	8.3.4.2.4.3.2
	Average azimuth of set	High	8.3.4.2.4.3.2
	Fracture stiffness		
	Aperture	Medium	8.3.4.2.4.3.2
	Normal stress	High	8.3.4.2.4.3.2
	Shear stress	High	8.3.4.2.4.3.2
	Joint roughness coefficient	Medium	8.3.4.2.4.3.2

Table 8.3.4.2-1. Model hierarchy and model inputs for Issue 1.10 (waste package characteristics--postclosure) (continued)

Model	Model input	Needed confidence	SCP section[a]
Borehole stability (continued)	Fracture shear strength		
	Joint roughness coefficient	High	8.3.4.2.4.3.2
	Joint compressive strength	Medium	8.3.4.2.4.3.2
	Residual friction angle	High	8.3.4.2.4.3.2
	Emplacement geometry		
stability (continued)	Hole orientation	High	8.3.4.2.4.3.2
	Hole dimensions	Medium	8.3.4.2.4.3.2
	Thermal properties of rock		
	Coefficient of linear expansion	Medium	8.3.4.2.4.3.2
	Rock temperature	Medium	8.3.4.2.4.3.2
	Mechanical and thermal stress loading		
	Poisson's ratio	Medium	8.3.4.2.4.3.2
	Unit weight	Medium	8.3.4.2.4.3.2
	Principal stress magnitude	Medium	8.3.4.2.4.3.2
	Joint roughness	High	8.3.4.2.4.3.2
	Principal stress orientations	Medium	8.3.4.2.4.3.2
	Mineral alteration		
	Coefficient of thermal expansion	Medium	8.3.4.2.4.3.2
	Modal abundance of water-rock interaction products	Medium	8.3.4.2.4.1.1

[a]The SCP section references for the near-field flow and transport model refer to discussions on the information need level; specific activities for these input parameters are described in the information need discussions.

[b]TSw2 = welded Topopah Spring Member.

Table 8.3.4.2-2. Performance measures and goals for Issue 1.10 (waste package characteristics--postclosure)

System element	Performance measure	Tentative goal	Needed confidence
Engineered environment	Quantity of liquid water that can contact the container	See Issue 1.4 (Table 8.3.5.9-1 Section 8.3.5.9)	
	Quality of liquid water than can contact the container	See Issue 1.4 (Table 8.3.5.9-1 Section 8.3.5.9)	
	Rock-induced load on waste package	Container will not fail when subjected to design basis loads	High
	Temperature vs. time in waste package environment	See Issue 1.11 (Table 8.3.2.2-4, Section 8.3.2.2)	
	Tectonic processes	<0.5% of containers breached	High
Waste package	Select waste package material to contribute to containment	See Issue 1.4 (Table 8.3.5.9-4, Section 8.3.5.9)	
	Constrain waste-handling operations so as not to degrade isolation and containment performance of the waste package	See Section 8.3.2.5	

Table 8.3.4.2-3. Performance parameters and goals for Issue 1.10 (waste package characteristics--postclosure)

Performance measure	Performance parameter	Tentative goal	Needed confidence	Expected parameter value	Current confidence
Rock-induced load on waste package	Load on waste package	<1,000 kg/pkg for 1,000 yr <3,000 kg/pkg between 1,000 and 10,000 yr	High	TBD[a]	
Tectonic processes	Breaching of containers by tectonic processes	<0.5% containers breached	High	See Section 8.3.1.8	

[a]TBD = to be determined.

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 1 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5)	Water quality	Vadose water		8.3.4.2.4.1.3
		pH	±1 (1)	
		F^-, Cl^-	±1 mg/L (1)	
		PO_4^{3-}	±1 mg/L (1)	
		NO_3^-, SO_4^{2-}	±5 mg/L (1)	
		CO_3^{2-}, HCO_3^-	±30 mg/L (1)	
		Anions not specified	±1 mg/L (1)	
		Cations present at <6 mg/L	±1 mg/L (1)	
		Cations present at 6 to 40 mg/L	±5 mg/L (1)	
		Cations present at >40 mg/L	±20 mg/L (1)	
		Rock-water interaction		8.3.4.2.4.1.1
		pH	±1 (1)	
		F^-, Cl^-	±1 mg/L (1)	
		PO_4^{3-}	±1 mg/L (1)	

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 2 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Water quality (continued)	Rock-water interaction (continued)		
		NO_3^-, SO_4^{2-}	±5 mg/L (1)	
		CO_3^{2-}, HCO_3^-	±30 mg/L (1)	
		Anions not specified	±1 mg/L (1)	
		Cations present at <6 mg/L	±1 mg/L (1)	
		Cations present at 6 to 40 mg/L	±5 mg/L (1)	
		Cations present at >40 mg/L	±20 mg/L (1)	
		Temperature	±5°C	
		Composition of solid reactants and products	±10 wt% of elemental abundance for those elements that comprise more than 5 wt% of minerals analyzable on the electron microprobe	
		Reactant surface area	±20% for BET[b] surface area measurements	

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 3 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Water quality (continued)	Rock-water interaction (continued)		
		Modal abundance of solid reactants and products	±20% for optically identifiable phases	
		Dissolution and precipitation		8.3.4.2.4.1.4
		pH	±0.5 (1)	
		Mineral composition	±10 wt% of elemental abundance for those elements that comprise more than 5 wt% of minerals analyzable on the electron microprobe	
		Composition of product fluid	±10% for those elements that constitute more than 10% (atomic) of the mineral phase	
		Mineral structural state	±20% for the degree of disorder in the crystal lattice	

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 4 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Water quality (continued)	Repository materials effect on water chemistry		8.3.4.2.4.1.2
		pH	±1 (1)	
		F^-, Cl^-	±1 mg/L (1)	
		PO_4^{3-}	±1 mg/L (1)	
		NO_3^-, SO_4^{2-}	±5 mg/L (1)	
		CO_3^{2-}, HCO_3^-	±30 mg/L (1)	
		Anions not specified	±1 mg/L (1)	
		Cations present at <6 mg/L	±1 mg/L (1)	
		Cations present at 6 to 40 mg/L	±5 mg/L (1)	
		Cations present at >40 mg/L	±20 mg/L (1)	
		Temperature	±5°C	

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 5 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Water quality (continued)	Repository materials effect on water chemistry (continued)		
		Composition of solid reactants and products	±10 wt% of elemental abundance for those elements that comprise more than 5 wt% minerals analyzable on the electron microprobe	
		Reactant surface area	±20% for BET surface area measurements	
		Modal abundance of solid reactants and products	±20% for optically identifiable phases	
		Radiation effects		8.3.4.2.4.1.5
		Temperature	±5°C	
		Radiation dose rate	0-100 krad/h	
		Degree of water saturation in experiment atmosphere	±20%	

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 6 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Water quality (continued)	Radiation effects (continued)		
		Nature of solid materials	Chemicals and structural characterization of material sufficient to allow fluid and gas composition to be experimentally reproduced to within ±20%	
		pH	±1(1)	
		F^-, Cl^-	±1 mg/L (1)	
		PO_4^{3-}	±1 mg/L (1)	
		NO_3^-, SO_4^{2-}	±5 mg/L (1)	
		CO_3^{2-}, HCO_3^-	±30 mg/L (1)	
		Anions not specified	±1 mg/L (1)	
		Cations present at <6 mg/L	±1 mg/L (1)	
		Cations present at 6 to 40 mg/L	±5 mg/L (1)	

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 7 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Water quality (continued)	Radiation effects (continued)		
		Cations present at >40 mg/L	±20 mg/L (l)	
		Formate ions	±30% (l)	
		Oxalate ions	±30% (l)	
		HNO_3	±20% (l)	
		Nitrite: nitrate ratio	±30% (l)	
		CO_2	±20% (g)	
		O_2	±20% (g)	
		NO_x	±20% (g)	
		N_2	±20% (g)	
		NH_3	±30% (g)	
		Corrosion products		8.3.4.2.4.1.6
		Temperature	±5°C	

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 8 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Water quality (continued)	Corrosion products (continued)		
		Composition and mineralogy of corrosion products	Chemical and structural material characterization sufficient to allow fluid and gas composition parameters to be experimentally reproduced to within ±20%	
		Degree of water saturation in experiment atmosphere	±20%	
		pH	±1 (1)	
		F^-, Cl^-	±1 mg/L (1)	
		PO_4^{3-}	±1 mg/L (1)	
		NO_3^-, SO_4^{2-}	±5 mg/L (1)	
		CO_3^{2-}, HCO_3^-	±30 mg/L (1)	
		Anions not specified	±1 mg/L (1)	

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 9 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Water quality (continued)	Corrosion products (continued)		
		Cations present at <6 mg/L	±1 mg/L (1)	
		Cations present at 6 to 40 mg/L	±5 mg/L (1)	
		Cations present at >40 mg/L	±20 mg/L (1)	
	Water quantity	Single-phase fluid		8.3.4.2.4.2.1
		Nature of fluid phase	Liquid or gas	
		Number of rehydration and dehydration cycles	Number of cycles must be sufficient to attain steady state permeability	
		Temperature	±5°C	
		Relative permeability	±20%	
		Fracture permeability	±20%	
		Degree of saturation	±50%	

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 10 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Water quantity (continued)	Single-phase fluid (continued)		8.3.4.2.4.2.1
		Resistivity	±15%	
		Magnitude of thermal gradient	±20%	
		Two-phase fluid flow		8.3.4.2.4.2.2
		Number of rehydration and dehydration cycles	Number of cycles must be sufficient to attain steady state permeability	
		Temperature	±5°C	
		Relative permeability	±20%	
		Fracture permeability	±20%	
		Degree of saturation	±50%	
		Resistivity	±15%	
		Magnitude of thermal gradient	±20%	
		Gas: liquid ratio	±20%	

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 11 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Thermal loading	Near-field temperature distribution		8.3.4.2.4.4.3
		Thermal properties (initial temperature, heat capacity, thermal conductivity) for TSw2 as identified in Section 8.3.2.2 (Issue 1.11, configuration of underground facilities (postclosure))	See Table 8.3.2.2-5	8.3.2.2
		Package emplacement geometry	TBD[c] by repository design	8.3.2.2.6
		Package spacing	TBD by repository design	8.3.2.2.6
		Heat output of waste packages	TBD by package design, Issue 2.6	8.3.5.10.1
	Rock-induced loading	Near-field stress distribution and rock displacements		8.3.4.2.4.3.1

Table 8.3.4.2-4. Input parameters for characterization models for Issue 1.10 (waste package characteristics--postclosure) (page 12 of 12)

Issue	Performance parameter	Characterization parameter	Test basis[a]	SCP section
Containment (Issue 1.4) and Release rate (Issue 1.5) (continued)	Rock-induced loading (continued)	Near-field stress distribution and rock displacements (continued)		
		Mechanical properties (Young's modulus, Poisson's ratio, compressive strength, etc.) for TSw2 as identified in Section 8.3.2.2 (Issue 1.11)	See Table 8.3.2.2-5	8.3.2.2
		Fracture (joint) characteristics (shear and normal stiffness, orientation, frequency, etc) for TSw2 as identified in Section 8.3.2.2 (Issue 1.11)	See Table 8.3.2.2-5	8.3.2.2

[a]Unless otherwise stated, the specified percentages and plus-and-minus values are characterization goals that indicate the maximum experimental uncertainty for measurements of the indicated parameter. (l) indicates species in the liquid phase, (g) indicates species in the gas phase.

[b]BET = Brunauer-Emmett-Teller.

[c]TBD = to be determined.

8.3.5.2 Performance Allocation Tables for Waste Retrievability

Issue 2.4 addresses compliance with the performance objective to maintain the waste retrieval option as specified in 10 CFR 60.111 (b). The performance allocation for this issue rests upon a review of the current design and analyses, and the identification of the retrievability-related functions that must be performed. These functions are:

1. Provide access to the emplacement boreholes.
2. Provide access to the waste packages.
3. Remove waste package from the emplacement boreholes.
4. Transport and deliver the waste packages to the surface facilities.

For each of the four functions, the system elements and processes that relate to performing the functions were identified and are provided in Tables 8.3.5.2-2 through 8.3.5.2-5. The performance measures corresponding to the processes, and the goals and needed confidence in meeting the goals are also provided in the tables.

To avoid repetition and duplication in the lists of data needs, the requests for both site and design information to address the retrievability requirement was handled by definition of "input items". "Input items" are information requests resulting from various design requirements that have been aggregated under a single requirement, which plays the role of the monitor. Table 8.3.5.2-6 provides the retrieval-related input items that are to be provided through activities described in SCP Section 8.3.2.5 (Issue 4.4), which plays the monitor role for the repository design activities. Retrieval-related design or performance goals (design criteria) are presented in Tables 8.3.5.2-7 for normal conditions and Table 8.3.5.2-8 for potential abnormal retrieval conditions.

Table 8.3.5.2-2. Performance measures, goals, and needed confidence for processes or activities involved in providing access to the emplacement borehole for retrieval (retrieval function 1) (page 1 of 2)

Process or activity	Performance measures	Tentative goals[a]	Needed confidence
Design and construct the accesses and drifts to be usable throughout the retrievability period for normal and credible abnormal conditions	Time during which the drifts and accesses will remain usable	Time ≥84 yr	High
Develop rock support concepts that ensure maintainability	Amount of spall	Spall averages less than 3 tons per 1,000 ft of drift per year	High
	Opening displacement	Opening displacement <6 in.	High
	Frequency of maintenance	Frequency of needed maintenance in underground openings >5 yr average	Low
Develop backfill removal concepts (if needed)	Time and level of effort for backfill removal	None--the current design basis allows for backfilling during repository closure (i.e, after the period of retrievability)	NA[b]
Monitor drifts and accesses to determine maintenance needs	Localized rock and rock support displacement	Monitor displacements >1 in.	High

Table 8.3.5.2-2. Performance measures, goals, and needed confidence for processes or activities involved in providing access to the emplacement borehole for retrieval (retrieval function 1) (page 2 of 2)

Process or activity	Performance measures	Tentative goals[a]	Needed confidence
Design for a specific temperature and air quality environment within the accesses and drifts	Drift temperature	Temperature less than 50°C (for 50 yr - emplacement drift (H)[c] or access drift (V)[c])	Low
	Air quality	Air quality standards met (work areas)	High
Verify environment for maintenance and retrieval operations	Air quality	Air quality measurements adequate for retrieval operations to meet standards	High
Modify environment (as necessary)	Time required to modify the environment for retrieval	Air quality standards met within 8 weeks (unprotected)	Medium

[a]These goals are integrated with goals from other issues in the discussion of Issue 4.4, preclosure design and technical feasibility (Section 8.3.2.5, Tables 8.3.2.5-1 through 12). Site characterization related design or performance parameters, their goals, and their confidences are also established in the Issue 4.4 discussions.

[b]NA = not applicable for SCP.

[c]H = horizontal emplacement; V = vertical emplacement.

Table 8.3.5.2-3. Performance measures, goals, and needed confidence for processes or activities involved in providing access to the waste packages for retrieval (retrieval function 2) (page 1 of 2)

Process or activity	Performance measures	Tentative goals[a]	Needed confidence
Design waste emplacement envelope to allow access to the waste package throughout the retrievability period for normal and credible abnormal conditions	Borehole usability		
	Rockfall	Average rockfall <250 lb per foot of borehole	Medium
	Displacement of borehole wall	Rock displacement <2 in.	Medium
	Borehole liner lifetime	Liner lifetime ≥84 yr	High
	Borehole liner displacement	Liner displacement <2 in. (V)[b]	High
		Liner displacement <3 in. (H)[b]	High
	Borehole liner curvature radius	Liner curvature radius >110 ft (H)	Medium
Assess the condition of the emplacement envelope and waste package prior to removal (as required)	Borehole liner displacement	Detect displacement >0.5 in.	Medium

Table 8.3.5.2-3. Performance measures, goals, and needed confidence for processes or activities involved in providing access to the waste packages for retrieval (retrieval function 2) (page 2 of 2)

Process or activity	Performance measures	Tentative goals[a]	Needed confidence
Perform corrective actions (as required)	Time required to perform corrective actions	Average time <1 month per drift (normal conditions)	Medium
		Timely manner considering site-specific credible abnormal conditions. For planning purposes, time <1 yr is assumed for each event.	Medium

[a]These goals are integrated with goals from other issues in the discussion of Issue 4.4, preclosure design and technical feasibility (Section 8.3.2.5, Tables 8.3.2.5-1 through 12). Site characterization related design or performance parameters, their goals, and their confidences are also established in the Issue 4.4 discussions.

[b]V = vertical emplacement; H = horizontal emplacement.

Table 8.3.5.2-4. Performance measures, goals, and needed confidence for processes or activities involved in removing waste packages from emplacement boreholes (retrieval function 3) (page 1 of 2)

Process or activity	Performance measures	Tentative goals[a]	Needed confidence
Design the waste package and transporter with the option to remove the waste for normal and credible abnormal conditions	Radiation protection	Worker dose less than allowable dose (see Issue 2.7 for specific goals and needed parameters)	High
	Time required to perform waste removal	Average time for removal less than twice the time for emplacement	Medium
	Removal latch and pull strength	These performance measures do not require site data and will be addressed in the repository design plan	NA[b]
	Structural strength of the waste package or dolly	These performance measures do not require site data and will be addressed in the repository design plan	NA
Verify conditions of equipment and waste package	Waste package structural failure detection	These performance measures do not require site data and will be addressed in the repository design plan	NA
	Removal equipment performance	These performance measures do not require site data and will be addressed in the repository design plan	NA

Table 8.3.5.2-4. Performance measures, goals, and needed confidence for processes or activities involved in removing waste packages from emplacement boreholes (retrieval function 3) (page 2 of 2)

Process or activity	Performance measures	Tentative goals[a]	Needed confidence
Verify operator training	Operator competency certification	These performance measures do not require site data and will be addressed in the repository design plan	NA

[a]These goals are integrated with goals from other issues in the discussion of Issue 4.4, preclosure design and technical feasibility (Section 8.3.2.5, Tables 8.3.2.5-1 through 12). Site characterization related design or performance parameters, their goals, and their confidences are also established in the Issue 4.4 discussions.

[b]NA = not applicable for SCP.

Table 8.3.5.2-5. Performance measures, goals, and needed confidence for processes or activities involved in transporting and delivering the waste to the surface facilities (retrieval function 4)[a] (page 1 of 2)

Process or activity	Performance measures	Tentative goals[b]	Needed confidence
Design the transporter with the ability to transport the waste to the surface for normal and credible abnormal conditions	Transporter design characteristics (braking ability, maximum speed, cornering ability, radiation protection)	Transporter must be able to operate with anticipated rockfall in accesses and drifts	High
	Time required to transport the waste to the surface	These performance measures do not require site data and will be discussed in the repository design plan	NA[c]
Design the surface waste-handling building and the transporter with the ability to unload waste at the surface facilities for normal and credible abnormal conditions	Time required to unload waste	These performance measures do not require site data and will be discussed in the repository design plan	NA
	Radiation protection	These performance measures do not require site data and will be discussed in the repository design plan	NA
	Transporter unloading capability	These performance measures do not require site data and will be discussed in the repository design plan	NA
Assess the ability to transport the waste to the surface facilities	Transporter drive system performance	These performance measures do not require site data and will be discussed in the repository design plan	NA

Table 8.3.5.2-5. Performance measures, goals, and needed confidence for processes or activities involved in transporting and delivering the waste to the surface facilities (retrieval function 4)[a] (page 2 of 2)

Process or activity	Performance measures	Tentative goals[b]	Needed confidence
Assess the ability to transport the waste to the surface facility (continued)	Operator competency certification	These performance measures do not require site data and will be discussed in the repository design plan	NA
Assess the ability to unload the waste at the waste-handling building	Transporter unloading system	These performance measures do not require site data and will be discussed in the repository design plan	NA
	Surface facility unloading system performance	These performance measures do not require site data and will be discussed in the repository design plan	NA
	Operator competency certification waste to the surface	These performance measures do not require site data and will be discussed in the repository design plan	NA

[a]Requirements for access and drift usability for transporter operation are included under function 1 (Table 8.3.5.2-1).

[b]These goals are integrated with goals from other issues in the discussion of Issue 4.4, preclosure design and technical feasibility (Section 8.3.2.5, Tables 8.3.2.5-1 through 12). Site characterization related design or performance parameters, their goals, and their confidences are also established in the Issue 4.4 discussions.

[c]NA = not applicable for SCP.

Table 8.3.5.2-6. Retrieval-related input items (to be provided by Issue 4.4)

Information need	Input item
2.4.2	Drift and access design and supporting evidence
	Rock support system design and supporting analyses
2.4.2	Monitoring system (rock movement) and support analyses
	Drift and access maintenance program concepts and supporting evidence
	Ventilation system design and supporting analyses (for retrieval operations)
	Basis for ensuring air quality in operational areas and evaluating air quality in nonoperational areas
2.4.3	Waste emplacement envelope design and supporting analyses
	Waste emplacement envelope assessment
	Corrective actions (waste emplacement envelope)
2.4.4	Waste package removal system design and supporting analyses
	Concepts for borehole preparation for waste removal and supporting evidence
	Demonstrations of borehole preparation for waste removal and supporting evidence
2.4.5	Transporter design concepts and supporting analyses
	Unloading equipment design (surface facility) and supporting analyses
	Demonstrations for waste transport
	Demonstrations for waste unloading at the surface
2.4.6	Reference operations plans
	Basis for establishing the use of reasonably available technology for retrieval-related equipment
	Reference design and supporting analyses

Table 8.3.5.2-7. Retrieval-related design or performance goals (design criteria)

Information need	Design or performance goal
2.4.2	The access and drifts will remain usable for at least 84 yr
	The average amount of spall in the drifts will be less than 3 tons per 1,000 ft of drift per year
	The rock displacement in the drifts will be less than 6 in.
	The monitoring system will detect rock displacements within the drifts that exceed 1 in.
	The frequency of maintenance within the underground openings will be greater than 5 yr
	For the vertical emplacement concept, the temperature within the access drifts will not exceed 50°C for 50 yr after waste emplacement
	For the horizontal emplacement concept, the temperature within the emplacement drifts will not exceed 50°C for 50 yr after waste emplacement
	For operational areas, all applicable air quality standards will be met
	The time required to modify the environment within closed drifts for unprotected workers will not exceed 8 wk
2.4.3	Rockfall within the emplacement boreholes will average less than 250 lb per foot of borehole
	Displacement of the borehole wall will be less than 2 in.
	The liner lifetime will be at least 84 yr
	The maximum liner deflection is 2 in. (5 cm) for the vertical emplacement concept and 3 in. (7.6 cm) for the horizontal concept
	For the horizontal emplacement concept, the minimum radius of curvature for the liner is 110 ft (33.5 m)

Table 8.3.5.2-7. Retrieval-related design or performance goals (design criteria) (continued)

Information need	Design or performance goal
2.4.4	The time required per container for waste removal will not exceed twice the amount of time required for emplacement of a waste container
	Worker dose rate during removal operations will not exceed the allowable rate established in Issue 2.7, repository radiological design criteria (preclosure)
	The ability to perform borehole preparation tasks will be demonstrated
	The ability to remove the waste containers under normal and credible abnormal conditions will be demonstrated
2.4.5	None related to site characterization
2.4.6	The design basis for the actual retrieval period is 34 yr
	The ability to perform the retrieval operations using reasonably available technology is required

Table 8.3.5.2-8. Potential abnormal conditions for retrieval

Information need	Potential abnormal condition
2.4.2	Rockfall within the ramp due to a seismic event, faulting, variability in rock strength, a maintenance error, or corrosion-induced rockbolt failure
	Rockfall within a drift due to faulting, variability in rock strength, a maintenance error, corrosion-induced rockbolt failure, or human error resulting in excessive thermal loading
	Rockfall within a shaft due to faulting or variability in rock strength
	A ventilation system malfunction due to a seismic event, an equipment fabrication error, or a maintenance error
	Loss of offsite power due to a seismic event
2.4.3	Rockfall in the emplacement borehole (vertical only) due to a seismic event, faulting, variability in rock strength, or excessive thermal loading resulting from human error
	Axial movement of the waste container (horizontal only) due to a seismic event
	Waste container tilt (vertical only) due to a seismic event
	Shield plug jam due to a seismic event, or a fabrication error
	Excessive liner deflection (horizontal only) due to faulting, a fabrication error, or excessive corrosion resulting from radiolysis
	A collar malfunction due to a fabrication or maintenance error
	An auxiliary equipment malfunction due to a fabrication or maintenance error
2.4.4	A cask-collar bind due to a seismic event
	A dolly failure during removal (horizontal only) due to a fabrication error or excessive corrosion resulting from radiolysis
	A waste container pintle failure (vertical only) due to excessive corrosion resulting from radiolysis

Table 8.3.5.2-8. Potential abnormal conditions for retrieval (continued)

Information need	Potential abnormal condition
	A malfunction of the transporter removal equipment due to a maintenance error
	Unspecified failures due to operator error including errors during alignment and waste removal
2.4.5	A transporter malfunction during transport or unloading due to a maintenance error
	A transporter collision with the ramp, a drift, auxiliary equipment, or another transporter due to human error
	Unspecified malfunctions due to operator error, including errors during alignment and waste unloading operations

8.3.5.3 Performance Allocation Tables for Public Radiological Exposures - Normal Conditions

This issue addresses radiation exposure to the general public from the normal operation, closure, and decommissioning of the repository. The regulatory basis for this issue is derived from 10 CFR 60.111, 40 CFR 191, Subpart A, and 10 CFR Part 20.

The performance allocation for this issue specifies the system elements, the functions and processes or activities related to those elements, and the corresponding performance measures with tentative goals and estimates of needed confidence in meeting the goals (Table 8.3.5.3-1). Performance parameters corresponding to the performance measures, together with associated goals, expected values and estimates of current and needed confidence are provided in Table 8.3.5.3-2. A reference to the SCP section providing the parameter is also provided.

Table 8.3.5.3-1. Functions, performance measures, and performance goals for Issue 2.1 (public radiological exposures--normal conditions)

System element	Function	Process or activity	Performance measure	Tentative goal	Needed confidence
Surface	Provide remoteness from highly populated areas and members of the public	Locate repository in a low population area	Population density	A. Population densities less than or equal to those required by the qualifying conditions of 10 CFR Part 960	High
	Provide dispersion and transport of routine radioactive releases to the unrestricted area through water pathways, crops, and animals	Analyze dilution, transportation, bioaccumulation of radionuclides in rivers, streams, and food stuffs	Radionuclides concentrations in environmental media and individual doses	B. Dose limits of 40 CFR Part 191, Subpart A and 10 CFR Part 20 as applied to the contribution from radionuclides in food chain pathways	High
	Provide transport, dispersion, and diffusion of routine airborne radioactive effluents to the unrestricted area	Analyze atmospheric transport by wind and convection, including dispersion and diffusion	Radionuclides concentrations in environmental media and individual doses	C. Composite dose limits required by 40 CFR Part 191, Subpart A and 10 CFR Part 20	High
Repository	Provide containment of potential sources of radiation to the unrestricted area	Limit releases of routine gaseous, particulate, and liquid radioactive effluents	Radionuclides concentrations in environmental media and individual doses	D. Composite dose limits required by 40 CFR Part 191, Subpart A and 10 CFR Part 20 as applied to routine releases from the repository	High
Offsite installations	Verify that there are no nuclear (uranium) fuel cycle facilities that need to be considered in assessing the public dose	Locate and analyze nearby nuclear (uranium) fuel cycle facilities	Number of nuclear (uranium) fuel cycle facilities requiring consideration in assessing the public dose	E. No nuclear (uranium) fuel cycle facilities requiring consideration in assessing the public dose	High

Table 8.3.5.3-2. Parameters required for Issue 2.1 (public radiological exposures--normal conditions) (page 1 of 4)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
A	Distances from highly populated areas	140 km radius	≥5 km	High	About 130 km	Medium	8.3.1.12, (b)
A	Population located in adjacent 1-mile by 1-mile area	Nye and Clark counties	<1,000 persons	High	No permanent population	Medium	(b)
A	Population density of the region	Nye and Clark counties	Low population density	High	Section 3.6.2 in environmental assessment (DOE, 1986b)	Medium	(b)
B	Bioaccumulation of radionuclides in terrestrial flora	80 km radius	(c)	Medium	1×10^{-28} to 1×10^{-14} Ci/kg (see footnote d)	Medium	(b)
B	Bioaccumulation of radionuclides in terrestrial fauna	80 km radius	(c)	Medium	1×10^{-25} to 1×10^{-15} Ci/kg (see footnote e)	Medium	(b)
B	Types of crops raised	80 km radius	(c)	Medium	(f)	Medium	(b)
B	Amounts of crops raised	80 km radius	(c)	Medium	1×10^{4} to 1×10^{7} kg/yr (see footnote g)	Medium	(b)
B	Types of crops consumed	80 km radius	(c)	Medium	(h)	Medium	(b)
B	Amounts of crops consumed	80 km radius	(c)	Medium	1×10^{4} to 1×10^{5} kg/yr	Medium	(b)
B	Types of animals raised	80 km radius	(c)	Medium	(i)	Medium	(b)

Table 8.3.5.3-2. Parameters required for Issue 2.1 (public radiological exposures--normal conditions) (page 2 of 4)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
B	Number of animals raised	80 km radius	(c)	Medium	1×10^1 to 1×10^5 kg/yr	Medium	(b)
B	Types of animals consumed	80 km radius	(c)	Medium	(j)	Medium	(b)
B	Amounts of meat consumed	80 km radius	(c)	Medium	1×10^4 to 1×10^6 kg/yr	Medium	(b)
B	Animal consumption of forage	80 km radius	(c)	Medium	1×10^1 to 1×10^4 kg/yr	Medium	(b)
B	Forage storage time	80 km radius	Goal is values given in Reg. Guide 1.109 (NRC, 1977a)	Medium	Data not available	Data not available	(b)
B	Grazing yield and period	80 km radius	(c)	Medium	75 to 100% of the year	High	(b)
B	Radius of crop and animal area	80 km radius	(c)	Medium	50 km to bulk of cropland and farms (W to SW)	High	(b)
B	Volumetric flow of surface water to water bodies	80 km radius	Little or no surface runoff	Medium	Section 3.3.1 in environmental assessment (DOE, 1986b)	Medium	(b)
B	Population served by local drinking water	80 km radius	(c)	Medium	1×10^2 to 1×10^4	Medium	(b)
B	Volumetric flow of local drinking water	80 km radius	(c)	Low	Section 3.3.1 in environmental assessment (DOE, 1986b)	Medium	(b)

Table 8.3.5.3-2. Parameters required for Issue 2.1 (public radiological exposures--normal conditions) (page 3 of 4)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
B	Recreational uses of water bodies	80 km radius	Very little recreational use of water	High	(k)	(k)	(b)
C,E	Wind speeds	80 km radius	(c)	High	Figures 5-3 to 5-7, and Tables 5-6 and 5-7	Medium	8.3.1.12
C,E	Wind direction	80 km radius	(c)	High	Figures 5-3 to 5-7, and Tables 5-6 and 5-7	Medium	8.3.1.12
C,E	Atmospheric stability	80 km radius	(c)	Medium (See foot-note 1)	Table 5-11	Medium	8.3.1.12
C,E	Mixing layer depth	80 km radius	(c)	Medium	(m)	Medium	8.3.1.12
C,E	Average ambient temperature	80 km radius	(c)	Medium	Tables 5-2 and 5-3	Medium	8.3.1.12
C,E	Atmospheric moisture	80 km radius	(c)	Medium	Tables 5-2 and 5-5	Medium	8.3.1.12
C,E	Precipitation: type, amount, intensity, etc.	80 km radius	(c)	Medium	Tables 5-2 and 5-4	Medium	8.3.1.12
C,E	Barometric pressure	80 km radius	(c)	Medium	Table 5-2	Medium	8.3.1.12
C,E	Size and distance of topographic features from release points	80 km radius	Topographic features beneficial to dispersion	Medium	See U.S Geological Survey (USGS) topographic maps	High	Literature

Table 8.3.5.3-2. Parameters required for Issue 2.1 (public radiological exposures--normal conditions) (page 4 of 4)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
D	Radon emanation rate from tuff	(TSw2 unit)[n]	(c)	High	0.48 pCi/m²-s	Low	8.3.1.15
D	Reference repository design and supporting analyses	No additional site characterization data needed--see footnote o.					
E	Location of nearby uranium fuel cycle facilities	80 km radius	No nearby nuclear fuel cycle facilities	High	No nearby nuclear fuel cycle facilities	Medium	8.3.1.13
E	Doses from nearby uranium fuel cycle facilities	80 km radius	Doses less than 40 CFR 191 limits	High	Doses less than 40 CFR 191 limits	Medium	8.3.1.13

[a]The letters in this column key the performance parameters in this table to the tentative performance goals in Table 8.3.5.3-1.
[b]Collection of these data is part of the environmental program planned activities and is addressed in the Radiological Monitoring Plan discussed in Section 8.3.1.13.
[c]Tentative goal is to have further measurements of this parameter verify the range of expected values listed here.
[d]This range covers all flora for which data are now available; specific values are flora and radionuclide specific.
[e]This range covers all fauna for which data are now available; specific values are fauna and radionuclide specific.
[f]Wheat/grains, corn, apples, potatoes, alfalfa, alfalfa seed, hay, silage, peppers, melons, berries, pecans, leafy vegetables, and honey.
[g]Specific values depend on available crops, crop areas, and crop densities.
[h]Includes all crops listed footnote f except alfalfa, hay, and silage.
[i]Beef cattle, dairy cattle, goats, hogs, sheep, and poultry.
[j]All of those in footnote i plus quail, freshwater fish, ducks, geese, rabbit, deer.
[k]Very limited use of Crystal Reservoir; swimming pool data not yet available.
[l]Medium confidence requirements are intended to indicate that these parameters need to be site-specific.
[m]See Quiring (1968).
[n]TSw2 unit is the nonlithophysal Topopah Spring unit (repository horizon).
[o]For communicating the design information needed to evaluate worker radiological safety under normal conditions, the input items from Issue 4.4 (obtained through Issue 2.7) are collectively listed as a parameter.

8.3.5.4 Performance Allocation Tables for Worker Radiological Exposures - Normal Conditions

This performance issue addresses requirement for the repository to be designed, constructed, operated, closed and decommissioned while ensuring the radiological safety of workers under normal conditions. The regulatory basis for this issue comes from 10 CFR 60.111 and 10 CFR Part 20.

The performance allocation for this issue specifies the system elements, the functions and processes or activities related to those elements, and the corresponding performance measures with tentative goals and estimates of needed confidence in meeting the goals (Table 8.3.5.4-1). Performance parameters corresponding to the performance measures, together with associated goals, expected values and estimates of current and needed confidence are provided in Table 8.3.5.4-2. A reference to the SCP section providing the parameter is also provided.

Table 8.3.5.4-1. Functions, performance measures, and performance goals for Issue 2.2 (worker radiological safety--normal conditions) (page 1 of 2)

System element	Function	Process or activity	Performance measure	Tentative goal	Needed confidence
Surface	Provide transport, dispersion, and diffusion of routine airborne radioactive effluents within site boundaries	Analyze atmospheric transport and dispersion characteristics within the site boundaries	Transport characteristics of atmosphere within site boundaries	A. Adequate atmospheric transport characteristics to assist in meeting dose limits	High
		Analyze worker doses from outdoor airborne radionuclides within site boundaries	Doses resulting from airborne radionuclide concentrations around repository facilities	B. Total doses below limits of 10 CFR Part 20 and ALARA[a]	High
Subsurface	Provide assurance that doses to workers underground are not excessive	Analyze shielding of workers from direct radiation using properties of the host rock	Effective attenuation of direct radiation by host rock	C. Significant attenuation of direct radiation using host rock properties	High
		Analyze the natural radiation released in the underground facilities	Release rates and concentrations of naturally occurring radionuclides	D. Natural radiation levels low enough to pose no significant health hazard to the workers	High
		Analyze radiation levels from miscellaneous sources of radiation such as calibration and testing sources	Direct radiation and contamination levels from miscellaneous sources	E. Insignificant levels of direct radiation and contamination from miscellaneous sources	High
Repository	Provide containment of radiation and limit radiation doses to repository workers	Analyze direct radiation levels in all areas of the repository	Direct radiation levels in all areas of the repository	F. Levels low enough to keep doses to workers below limits of 10 CFR Part 20 and ALARA	High

Table 8.3.5.4-1. Functions, performance measures, and performance goals for Issue 2.2 (worker radiological safety--normal conditions) (page 2 of 2)

System element	Function	Process or activity	Performance measure	Tentative goal	Needed confidence
Repository (continued)	Provide containment of radiation and limit radiation doses to repository workers (continued)	Analyze high-level waste containment and handling operations	Doses due to worker occupancy in direct radiation areas	G. Total doses below limits of 10 CFR Part 20 and ALARA	High
		Analyze site-generated waste containment, handling, and treatment operations	Doses due to worker occupancy in direct radiation areas	H. Total doses below limits of 10 CFR Part 20 and ALARA	High
		Analyze radiation levels from miscellaneous sources of radiation such as calibration and testing sources	Direct radiation and contamination levels from miscellaneous sources	I. Insignificant levels of direct radiation and contamination from miscellaneous sources	High
		Analyze shielding provided by structures, containments, equipment, and waste packages	Effective attenuation of direct radiation levels	J. Significant attenuation of direct radiation from all sources	High
		Analyze ventilation and filtration of repository airstreams	Contamination and airborne radionuclide concentrations in repository airstreams	K. Total doses below limits of 10 CFR Part 20 and ALARA	High

[a]ALARA - as low as reasonably achievable.

Table 8.3.5.4-2. Parameters required for Issue 2.2 (worker radiological safety--normal conditions) (page 1 of 2)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value(s)	Current confidence	SCP section providing parameters
A,B	Wind speeds	Site area	(b)	High	Figures 5-3 to 5-7, and Tables 5-6 and 5-7	Medium	8.3.1.12
A,B	Wind direction	Site area	(b)	High	Figures 5-3 to 5-7, and Tables 5-6 and 5-7	Medium	8.3.1.12
A,B	Atmospheric stability	Site area	(b)	Medium[c]	Table 5-11	Medium	8.3.1.12
A,B	Mixing layer depth	Site area	(b)	Medium	(d)	Medium	8.3.1.12
A,B	Average ambient temperature	Site area	(b)	Medium	Tables 5-2 and 5-3	Medium	8.3.1.12
A,B	Atmospheric moisture	Site area	(b)	Medium	Tables 5-2 and 5-5	Medium	8.3.1.12
A,B	Precipitation type, amount, intensity, etc.	Site area	(b)	Medium	Tables 5-2 and 5-4	Medium	8.3.1.12
A,B	Barometric pressure	Site area	(b)	Medium	Table 5-2	Medium	8.3.1.12
A,B	Dust particle size distributions	Site area	1 to 10 micron, normal	High	Data not available	Data not available	(e)
A,B	Size and distance of topographic features from release points	Site area	Topographic features beneficial to dispersion	Medium	See U.S Geological Survey topographic maps	High	Literature
B	Routine releases	(f)	(f)	(f)	(f)	(f)	(f)
B	Surface facilities layout	(f)	(f)	(f)	(f)	(f)	(f)

Table 8.3.5.4-2. Parameters required for Issue 2.2 (worker radiological safety--normal conditions) (page 2 of 2)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value(s)	Current confidence	SCP section providing parameters
C	Elemental composition of host rock	TSw2 unit[g]	Normal composition for tuffs	High	Normal composition for tuffs	Medium	8.3.1.3
C	Bulk density of host rock	TSw2 unit	(b)	High	2.26 to 2.33 g/cc	Medium	8.3.1.15
C	Water content of host rock	TSw2 unit	(b)	High	65% saturation	Medium	8.3.1.16
D	Radon emanation rate from tuff	TSw2 unit	(b)	High	0.48 pCi/m^2-s	Low	8.3.1.15[e]
E,F,G,H,I,J,K	Reference repository design, operating plan, and supporting analyses	No additional site characterization data needed--see footnote f					

[a]The letters in this column key the performance parameters in this table to the tentative goals in Table 8.3.5.4-1.
[b]Tentative goal is to have further measurements of this parameter verify the range of expected values listed here.
[c]Medium confidence requirements are intended to indicate that these parameters need to be site specific.
[d]See Quiring (1968).
[e]Collection of these data is part of the environmental program planned activities and is addressed in the Radiological Monitoring Plan discussed in Section 8.3.1.13.
[f]For purposes of communicating the design information needed to evaluate worker radiological safety under normal conditions, the input items from Issue 4.4 (obtained through Issue 2.7) are collectively listed as a parameter.
[g]TSw2 unit is the nonlithophysal Topopah Spring unit (repository horizon).

8.3.5.5 Performance Allocation Tables for Accidental Radiological Releases

Issue 2.3 addresses the requirement for the repository to be designed, constructed, operated, closed and decommissioned while ensuring that credible accidents will not result in projected radiological exposures of the general public or workers that are in excess of applicable limiting values.

The performance allocation for this issue specifies the system elements, the functions and processes or activities related to those elements, and the corresponding performance measures with tentative goals and estimates of needed confidence in meeting the goals (Table 8.3.5.5-1). Performance parameters corresponding to the performance measures, together with associated goals, expected values and estimates of current and needed confidence are provided in Table 8.3.5.5-2. A reference to the SCP section providing the parameter is also provided.

Table 8.3.5.5-1. Functions, performance measures, and performance goals for Issue 2.3 (accidental radiological releases) (page 1 of 2)

System element	Function	Process or activity	Performance measure	Tentative goal	Needed confidence
Site	Provide location that assists in limiting potential radiation exposure to the public and essential workers from accidents	Analyze remoteness of repository location	Population density of region	A. Resolution of Issue 2.5 (higher level findings--preclosure radiological safety)	High
		Analyze probabilities and consequences of accidents caused by natural or site-related phenomena[a]	Consequences of credible site-related accidents	B. Radiation doses well below applicable limiting values	High
		Analyze short-term public and essential worker radiation exposure mitigation features of the site	Quick-acting dispersion and transport characteristics of the site	C. Adequate short-term transport characteristics to assist in limiting doses	High
		Analyze long-term public and essential worker radiation exposure mitigation features of the site	Long-term dispersion, diffusion, and bioaccummulation characteristics of the site	D. Adequate long-term transport characteristics to assist in limiting doses	High
Repository	Provide prevention, containment, and mitigation of accident consequences and limit radiation exposures to essential workers and public	Analyze probabilities and consequences of design-related accidents	Consequences of credible design-related initiating events	E. Radiation doses well below applicable limiting values	High
		Analyze design for vulnerability to effects of natural, site-related, and design-related accidents	Sensitivity of repository design to possible accidents	F. Repository designed to provide desirable responses to possible accidents	High

Table 8.3.5.5-1. Functions, performance measures, and performance goals for Issue 2.3 (accidental radiological releases) (page 2 of 2)

System element	Function	Process or activity	Performance measure	Tentative goal	Needed confidence
Repository (continued)		Analyze design for effectiveness of preventive features	Effectiveness of preventive design features	G. Near total prevention of accidents and consequences	High
		Analyze design for effectiveness of mitigative features	Effectiveness of mitigative design features	H. Mitigation of accident consequences to well below applicable limiting values	High
Offsite installations	Provide assurance that repository and essential workers are safe from effects of offsite accidents	Analyze vulnerability of repository and essential workers to effects of offsite accidents	Consequences of credible offsite accidents that could affect the repository and the essential workers	I. Radiation doses well below applicable limiting values	High

*Short-term radiation exposures will be evaluated to assess compliance with applicable accident dose limits. Long-term radiation exposures will be used to assess risk from credible accidents.

Table 8.3.5.5-2. Parameters required for Issue 2.3 (accidental radiological releases) (page 1 of 5)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
A	Population density of region	Nye and Clark counties	Low population density	High	Section 3.6.2 in Environmental Assessment (DOE, 1986[b])	Medium	8.3.1.10
B	Frequency and magnitudes of						
	Tornadoes	At facility	(b)	High	Section 5.1.1.6 (see footnote c)	Medium	8.3.1.12
	Cloud-to-ground lightning strikes	At facility	(b)	Medium	About 18/yr, magnitude unknown	Medium	8.3.1.12
	Sandstorms and wind-storms	At facility	(b)	High	Table 5-8, and Section 5.1.1.6	Medium	8.3.1.12
	Snow fall and ice storms	At facility	Rare, low magnitude	High	Rare, low magnitude	Medium	8.3.1.12
	Repository surface flooding	At facility	PMF[d]	High	PMF[d]	Medium	8.3.1.16
	Surface and sub-surface seismic events	In region	(b)	High	(e)	(e)	8.3.1.17
	Fault movement within the repository	Surface and subsurface	(b)	High	Section 1.5.2	Medium	8.3.1.17
	Drift roof fall and collapse or failure	Underground	(f)	Medium	Data not available	Data not available	8.3.2.4
	Landslides	At facility	(f)	Medium	Data not available	Data not available	8.3.1.14

Table 8.3.5.5-2. Parameters required for Issue 2.3 (accidental radiological releases) (page 2 of 5)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
	Volcanic ash fall	At facility	(f)	Medium	Data not available	Data not available	8.3.1.17
	Nearby brush fires	Near facilities	(f)	Low	Data not available	Data not available	8.3.1.13
	Aircraft crashes	At facility	(f)	High	1×10^{-5} to 1×10^{-7} per year	Medium	8.3.1.13
	Criticality events	In surface and subsurface	Criticality events precluded	High	Not credible	High[g]	8.3.5.5
	Other potential accidents	Natural or site-related	(h)	High	(h)	(h)	PRAM program[i]
C,I	Wind speeds	80 km radius	(b)	High	Figures 5-3 to 5-7, and Tables 5-6 and 5-7	Medium	8.3.1.12
C,I	Wind direction	80 km radius	(b)	High	Figures 5-3 to 5-7, and Tables 5-6 and 5-7	Medium	8.3.1.12
C,I	Atmospheric stability	80 km radius	(b)	Medium[j]	Table 5-11	Medium	8.3.1.12
C,I	Mixing layer depth	80 km radius	(b)	Medium	(k)	Medium	8.3.1.12
C,I	Average ambient temperature	80 km radius	(b)	Medium	Tables 5-2 and 5-3	Medium	8.3.1.12
C,I	Atmospheric moisture	80 km radius	(b)	Medium	Tables 5-2 and 5-5	Medium	8.3.1.12
C,I	Precipitation type, amount, intensity, etc.	80 km radius	(b)	Medium	Tables 5-2 and 5-4	Medium	8.3.1.12

Table 8.3.5.5-2. Parameters required for Issue 2.3 (accidental radiological releases) (page 3 of 5)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
C,I	Barometric pressure	80 km radius	(b)	Medium	Table 5-2	Medium	8.3.1.12
C,I	Size and distance of topographic features from release points	80 km radius	Topographic features beneficial to dispersion	Medium	See U.S. Geological Survey topographic maps	High	Literature
D	Bioaccumulation of radionuclides in terrestrial flora	80 km radius	(b)	Medium	1×10^{-28} to 1×10^{-14} Ci/kg (see footnote m)	Medium	(l)
D	Bioaccumulation of radionuclides in terrestrial fauna	80 km radius	(b)	Medium	1×10^{-25} to 1×10^{-15} Ci/kg (see footnote n)	Medium	(l)
D	Types of crops raised	80 km radius	(b)	Medium	(o)	Medium	(l)
D	Amounts of crops raised	80 km radius	(b)	Medium	1×10^{4} to 1×10^{7} kg/yr (see footnote p)	Medium	(l)
D	Types of crops consumed	80 km radius	(b)	Medium	(q)	Medium	(l)
D	Amounts of crops consumed	80 km radius	(b)	Medium	1×10^{4} to 1×10^{5} kg/yr	Medium	(l)
D	Types of animals raised	80 km radius	(b)	Medium	(r)	Medium	(l)
D	Number of animals raised	80 km radius	(b)	Medium	1×10^{1} to 1×10^{5} kg/yr	Medium	(l)
D	Types of animals consumed	80 km radius	(b)	Medium	(s)	Medium	(l)
D	Amounts of meat consumed	80 km radius	(b)	Medium	1×10^{4} to 1×10^{6} kg/yr	Medium	(l)
D	Animal consumption of forage	80 km radius	(b)	Medium	1×10^{1} to 1×10^{4} kg/yr	Medium	(l)

Table 8.3.5.5-2. Parameters required for Issue 2.3 (accidental radiological releases) (page 4 of 5)

Related performance goal[a]	Performance or design parameter	Parameter descriptor	Tentative parameter goal	Needed confidence	Expected parameter value	Current confidence	SCP section providing parameter
D	Forage storage time	80 km radius	Values given in Regulatory Guide 1.109 (NRC, 1977a)	Medium	Data not available	Data not available	(l)
D	Grazing yield and period	80 km radius	(b)	Medium	75 to 100% of the year	High	(l)
D	Radius of crop and animal area	80 km radius	(b)	Medium	50 km to bulk of cropland and farms (W to SW)	High	(l)
D	Volumetric flow of surface water to water bodies	80 km radius	Little or no surface runoff	Medium	Environmental Assessment Section 3.3.1	Medium	(l)
D	Population served by local drinking water	80 km radius	(b)	Medium	1×10^2 to 1×10^4	Medium	(l)
D	Volumetric flow of local drinking water	80 km radius	(b)	Low	Section 3.3.1 in Environmental Assessment (DOE, 1986b)	Medium	(l)
D	Recreational uses of water bodies	80 km radius	Very little recreational use of water	Low	(t)	(t)	(l)
E,F,G,H,I, J,K	Reference repository design, operating plan, and supporting analysis	No additional site characterization data needed--see footnote u.					

[a]The letters in this column key the performance parameters on this table to the tentative performance goals in Table 8.3.5.5-1.
[b]Tentative goal is to have further measurements of this parameter verify the range of expected values listed here.
[c]Probability at Yucca Mountain is approximately 7.5×10^{-4} in any given year; magnitude is F-0 on Fujita tornado scale (very weak).

Table 8.3.5.5-2. Parameters required for Issue 2.3 (accidental radiological releases) (page 5 of 5)

Footnotes (continued)

[d]PMF = probable maximum flood; the PMF is still under investigation.

[e]Information on seismic events may be found in "Ground Motion Evaluation at Yucca Mountain, Nevada, with Application to Repository Conceptual Design and Siting," (URS/Blume, 1986).

[f]Parameter goal to be evaluated in terms of frequency and consequence.

[g]Design will preclude criticality accidents per 10 CFR 60.131(b)(7).

[h]Other accident-specific goals to be evaluated as appropriate under preclosure risk assessment methodology.

[i]PRAM = preclosure risk assessment methodology.

[j]Medium confidence requirements are intended to indicate that these parameters need to be site-specific.

[k]See Quiring (1968).

[l]Collection of these data are part of the environmental program planned activities and is addressed in the Radiological Monitoring Plan discussed in Section 8.3.1.13.

[m]This range covers all flora for which data are now available; specific values are flora and radionuclide specific.

[n]This range covers all fauna for which data are now available; specific values are fauna and radionuclide specific.

[o]Wheat/grains, corns, apples, potatoes, alfalfa, alfalfa seed, hay, silage, peppers, melons, berries, pecans, leafy vegetables, and honey.

[p]Specific values depend on available crops, crop areas, and crop densities.

[q]Includes all crops listed in footnote o except alfalfa, hay, and silage.

[r]Beef cattle, dairy cattle, goats, hogs, sheep, and poultry.

[s]Includes all animals listed in footnote r plus quail, freshwater fish, ducks, geese, rabbit, and deer.

[t]Very limited use of Crystal Reservoir; swimming pool data not yet available.

[u]For purposes of communicating the design information needed to evaluate worker radiological safety under normal conditions, the input items from Issue 4.4 (obtained through Issue 2.7) are collectively listed as parameter.

8.3.5.9 Performance Allocation Tables for Waste Package Containment

Issue 1.4 addresses compliance with the postclosure waste package performance objective in 10 CFR 60.113. System elements, performance measures with goals and estimates of needed confidence are provided in Table 8.3.5.9-1. One objective of the waste package program is to provide adequate characterization of the near-field waste package environment and the water quality performance parameters listed in Table 8.3.5.9-2 reflects this focus. The current estimated range for each parameter is provided together with the current and needed confidence in the parameter value. Table 8.3.5.9-3 provides the performance parameters for glass and spent fuel waste forms, with goals, estimated ranges, and current and needed confidence. The performance allocation table for the waste package containers covers both copper based and austenitic alloys (Table 8.3.5.9-4). The last aspect of the allocation for the containment issue is the input needed for the container degradation models, which is presented in Table 8.3.5.9-5.

Table 8.3.5.9-1. Performance measures and goals for Issue 1.4 (containment by waste package)

System element	Performance measure	Tentative goal[a]	Needed confidence
Engineered environment[b]	Quantity of liquid water that can contact the container	For $t \leq 300$: No liquid water contacting the container for 95% of packages, <5 L per package per year for the remaining 5%	High
		and	
		<1.0%/yr of the total number of emplacement hole walls will be initially contacted by liquid water	High
		For $300 < t \leq 1000$: No liquid water contacting the container for 90% of packages, <5 L per package per year for the remaining 10%	High
		and	
		<1.0%/yr of the total number of emplacement hole walls will be initially contacted by liquid water	High
	Quality of liquid water that can contact the container	Constrain water chemistry to acceptable levels for performance of container and waste form	High
	Rock-induced load on waste package	Load less than design basis (see Table 8.3.4.2-3)	High

Table 8.3.5.9-1. Performance measures and goals for Issue 1.4 (containment by waste package) (continued)

System element	Performance measure	Tentative goal[a]	Needed confidence
Container	Maximum fraction of containers that failed in any given year[c]	For containers with no liquid water contact:	
		For $t \le 100$: < 0.0001/yr	High
		For $100 < t \le 300$: < 0.0005/yr	High
		For $300 < t \le 1{,}000$: < 0.001/yr	High
		For containers with liquid water contact:	
		For $t \le 300$: < 0.0005/yr	High
		For $300 < t \le 1{,}000$: < 0.001/yr	High
Waste form	Cumulative release of radionuclides from the ensemble of breached packages	For $t \le 300$ yr: $< 2.0 \times 10^{-2}$ of the total curie inventory of the ensemble of breached packages	High

Table 8.3.5.9-1. Performance measures and goals for Issue 1.4 (containment by waste package) (continued)

System element	Performance measure	Tentative goal[a]	Needed confidence
		For $300 < t \leq 1000$: $<1 \times 10^{-2}$ of the total curie inventory of the ensemble of breached packages	High

[a]t = years after repository closure.
[b]Envelope for anticipated processes and events.
[c]Failure is defined as a breach allowing air flow of 1×10^{-4} atm-cm^3/s.
A value for the limit of cumulative failures will be determined as part of the container material studies and will be consistent with regulatory intent.

Table 8.3.5.9-2. Water quality performance parameters and goals for Issue 1.4 (containment by waste package) (page 1 of 2)

Performance measure	Performance parameter	Tentative goals[a]	Needed confidence	Current estimated range	Current confidence
Quality of liquid water that can contact the container	pH	5.5 to 9	High	6.1 to 7.7	Medium
	Cl^-	<20 ppm	High	<10 ppm	Medium
	F^-	<6 ppm	High	<5.4 ppm	Medium
	NO_3^-	<15 ppm	High	0 to 11 ppm	Medium
	SO_4^{2-}	<50 ppm	High	15 to 35 ppm	Medium
	CO_3^{2-}, HCO_3^-	<200 ppm	Medium	90 to 160 ppm	Medium
	Total anions	<220 ppm	Medium	110 to 160 ppm	Medium
	Organics	TBD[b]	TBD	NA[c]	NA
	Colloids	TBD	TBD	NA	NA
	O_2	0.1 to 8 ppm	High	<6.5 ppm	Medium
	NH_3	<1 ppm	High	<1 ppm	Low
	Si^{4+}	>20 ppm	High	20 to 550 ppm	Medium
	Na^+	<100 ppm	High	30 to 80 ppm	Medium
	K^+	<50 ppm	High	1 to 30 ppm	Medium
	Na/Ca	>1	High	>2	Medium

Table 8.3.5.9-2. Water quality performance parameters and goals for Issue 1.4 (containment by waste package) (page 2 of 2)

Performance measure	Performance parameter	Tentative goals[a]	Needed confidence	Current estimated range	Current confidence
	Total heavy metals[d]	<2 ppm	High	NA	Low
	Total other cations	<50 ppm	High	<30 ppm	Low

[a]Not all combination of the limits on the goals given will result in acceptable water chemistries; see Section 8.3.4.2.
[b]TBD = to be determined.
[c]NA = not available.
[d]Atomic number >Fe.

Table 8.3.5.9-4. Performance parameters and goals for containers subdivided by alloy family and degradation mode[a] (page 1 of 4)

Performance measure	Degradation modes	Performance parameter	Tentative goals[b]	Needed confidence	Current estimated range	Current confidence
		COPPER BASED ALLOYS				
Fraction of containers that have failed	Metallurgical and mechanical effects	Brittle phase fraction	Phase fraction <0.01	High	Phase fraction <0.01	Medium
		Reduction in fracture toughness	J(emb)/J <0.7	High	To be determined	NA[c]
	Low temperature oxidation	Oxidation rate (R)	Average rate ≤0.1 d per 1,000 yr	High	R ≈ 0.03 to 3 µm/yr	Medium
	General aqueous corrosion	General corrosion rate (R)	Average rate ≤0.1 d per 1,000 yr	High	R ≈ 0.4 to 5 µm/yr	Medium
	Hydrogen effects	H content	[H] <0.1 [H(crit)]	Medium	To be determined	NA
		Oxide inclusion phase fraction	Phase fraction <0.01	High	Phase fraction <0.01	Medium
	Localized attack	Critical potential for initiation	E(crit) - E(corr) >100 mV	High	E(crit) - E(corr) ≈ (100 to 800) mV	Low

Table 8.3.5.9-4. Performance parameters and goals for containers subdivided by alloy family and degradation mode[a] (page 2 of 4)

Performance measure	Degradation modes	Performance parameter	Tentative goals[b]	Needed confidence	Current estimated range	Current confidence
	Stress corrosion cracking (SCC)	Critical potential	E(critSCC) - E(corr) > 100 mV	High	To be determined	Low
		Ammonia (NH_3) concentration	$[NH_3]$ <2 ppm	High	$[NH_3]$[d] < det. ≈ 2 ppm	Medium
		Stress intensity (K)	K < K(SCC)	Medium	K ≈ (0.1 to 3) K(SCC)	Low
	Other effects	To be determined	To be determined	To be determined	NA	NA
			AUSTENITIC ALLOYS			
	Metallurgical and mechanical effects	Brittle phase fraction	Phase fraction <0.01	High	Fraction ≈ 0 to 0.03	Medium
		Reduction in fracture toughness	J(emb)/J <0.7	High	J(emb)/J ≈ 0.5 to 1.0	Medium
	Low temperature oxidation	Oxidation rate (R)	Average rate ≤0.1 d per 1,000 yr	High	R ≈ 0.02 to 0.1 μm/yr	High

Table 8.3.5.9-4. Performance parameters and goals for containers subdivided by alloy family and degradation mode[a] (page 3 of 4)

Performance measure	Degradation modes	Performance parameter	Tentative goals[b]	Needed confidence	Current estimated range	Current confidence
		AUSTENITIC ALLOYS (continued)				
	General aqueous corrosion	General corrosion rate (R)	Average rate ≤0.1 d per 1,000 yr	High	R ≈ 0.04 to 0.3 μm/yr	Medium
	Intergranular attack and intergranular stress corrosion cracking (IGSCC)	Degree of sensitization, R(A) (activation ratio in EPR[e] test)	R(A) <5%	High	R(A) ≈ 0 to 20%	Medium
		Stress intensity, K	K < K(IGSCC)	Medium	K ≈ (0.1 to 3) K(IGSCC)	Low
	Hydrogen effects	H content	[H] <0.1 [H(crit)]	Medium	To be determined	NA
		Martensite fraction, M	M <0.01 by volume	High	M <0.01 by volume	Medium
	Localized attack	Critical potential	E(crit) - E(corr) >100 mV	High	E(crit) - E(corr) ≈ (0 to 900) mV	Low
		Chloride ion content	[Cl⁻] <100 ppm	High	[CL⁻] ≈ 5 to 150 ppm	Medium

Table 8.3.5.9-4. Performance parameters and goals for containers subdivided by alloy family and degradation mode[a] (page 4 of 4)

Performance measure	Degradation modes	Performance parameter	Tentative goals[b]	Needed confidence	Current estimated range	Current confidence
	Transgranular stress corrosion cracking (TGSCC)	Critical potential	E(critTGSCC) - E(corr) > 100 mV	High	To be determined	NA
		Chloride ion content	$[Cl^-]$ <50 ppm	High	$[Cl^-] \approx 5$ to 150 ppm	Medium
		Stress intensity	K < K(TGSCC)	Medium	K ≈ (0.1 to 3) K(TGSCC)	Low
	Other effects	To be determined	To be determined	To be determined	NA	NA

[a]See text discussion for explanations of degradation modes. Section 8.3.5.9.3 contains additional material explaining some of the interactions between the chemical, physical, metallurgical, or mechanical properties.

[b]Parameters not defined in table are as follows: J(emb) = impact strength of the embrittled material; J = normal impact strength; d = container wall thickness, 1 cm < d < 3 cm; H(crit) = critical hydrogen; E(crit) = critical potential; E(corr) = corrosion potential; K = stress intensity factor; K(SCC) = critical value of K at which stress corrosion cracking takes place; K(IGSCC) = critical value of K at which intergranular stress corrosion cracking takes place; E(critTGSCC) = critical potential with respect to transgranular stress corrosion; K(TGSCC) = critical value of K at which transgranular stress corrosion cracking takes place.

[c]NA = not applicable.

[d]det. = detection limit.

[e]EPR = electrochemical potentiokinetic reactivation.

Table 8.3.5.9-5. Container degradation model inputs

Model	Model inputs	Needed confidence	SCP section
	COPPER-BASED ALLOY FAILURE MODELS		
Metallurgical aging and phase stability	Temperature-time projections	High	8.3.5.9.3.1.1
	Quantity of phase segregation	High	8.3.5.9.3.1.1
	Mechanical properties of the segregation products	Medium	8.3.5.9.3.1.1
	Electrochemical differences between segregation products and base metal	Medium	8.3.5.9.3.1.1
	Strain in the container body material and in the heat affected zone around the closure	Medium	8.3.5.9.3.1.1
	Residual stress	Medium	8.3.5.9.3.1.1
Low temperature oxidation	Oxidation rate	High	8.3.5.9.3.1.2
	Temperature	High	8.3.5.9.3.1.2
	Radiation field intensity	High	8.3.5.9.3.1.2
	Identification and quantity of radiolysis products	Medium	8.3.5.9.3.1.2
General aqueous	General corrosion rate	High	8.3.5.9.3.1.3
	Composition of water	High	8.3.5.9.3.1.3
	Composition of corrosion product layers	Medium	8.3.5.9.3.1.3
	Identification and quantity of radiolysis products	Medium	8.3.5.9.3.1.3
Hydrogen entry and embrittlement	Hydrogen production rate by radiolysis and corrosion	Medium	8.3.5.9.3.1.4
	Hydrogen recombination rate	Medium	8.3.5.9.3.1.4
	Rate of hydrogen entry into the alloy	Medium	8.3.5.9.3.1.4
	Concentration of hydrogen in the alloy	High	8.3.5.9.3.1.4
	Phase structure of the alloy	High	8.3.5.9.3.1.4
	Mechanical property changes from hydrogen degradation	High	8.3.5.9.3.1.4

Table 8.3.5.9-5. Container degradation model inputs (continued)

Model	Model inputs	Needed confidence	SCP section
Pitting, crevice, and other localized attacks	Critical concentration of ions known to favor these modes of attack	High	8.3.5.9.3.1.5
	Temperature	High	8.3.5.9.3.1.5
	Solution pH	High	8.3.5.9.3.1.5
Pitting, crevice, and other localized attacks (continued)	Metal microstructure	High	8.3.5.9.3.1.5
	Corrosion potential	High	8.3.5.9.3.1.5
	Pitting (and other critical potentials)	High	8.3.5.9.3.1.5
Stress corrosion cracking	Concentration of ammonia (and other species) known to favor stress corrosion cracking	High	8.3.5.9.3.1.6
	Temperature	High	8.3.5.9.3.1.6
	Stress (and stress cracking)	Medium	8.3.5.9.3.1.6
	Alloy segrations	Medium	8.3.5.9.3.1.6
	Corrosion potential	High	8.3.5.9.3.1.6
	Critical potential for crack initiation	High	8.3.5.9.3.1.6
Other potential degradation modes	To be determined	Not applicable	8.3.5.9.3.1.7
	AUSTENITIC ALLOY FAILURE MODELS		
Metallurgical aging and phase transformation	Temperature-time projections	High	8.3.5.9.3.2.1
	Kinetics of phase transformation reactions	High	8.3.5.9.3.2.1
	Mechanical properties of the transformation products	Medium	8.3.5.9.3.2.1
	Alloy composition of the base metal and the weld metal	High	8.3.5.9.3.2.1
	Strain in the container body material and in the heat affected zone around the closure	Medium	8.3.5.9.3.2.1
	Residual stress	Medium	8.3.5.9.3.2.1

Table 8.3.5.9-5. Container degradation model inputs (continued)

Model	Model inputs	Needed confidence	SCP section
Low temperature oxidation	Oxidation rate loss or gain tests under relevant conditions	High	8.3.5.9.3.2.2
	Temperature	High	8.3.5.9.3.2.2
	Radiation field intensity	High	8.3.5.9.3.2.2
	Identification and quantity of radiolysis products	Medium	8.3.5.9.3.2.2
General aqueous corrosion	General corrosion rate	High	8.3.5.9.3.2.3
	Composition of water	High	8.3.5.9.3.2.3
	Composition of corrosion product layers	Medium	8.3.5.9.3.2.3
	Identification and quantity of radiolysis products	Medium	8.3.5.9.3.2.3
Intergranular attack and intergranular stress corrosion cracking	Temperature-time projections	High	8.3.5.9.3.2.4
	Diffusion rate of chromium in the metal as a function of temperature	High	8.3.5.9.3.2.4
	Diffusion mechanism for chromium in the metal	Medium	8.3.5.9.3.2.4
	Strain	Medium	8.3.5.9.3.2.4
	Alloy composition	High	8.3.5.9.3.2.4
	Effects of transformation products on diffusion rates	Medium	8.3.5.9.3.2.4
	Composition of carbide precipitates formed	Medium	8.3.5.9.3.2.4
	Amounts of sigma and chi phases	Medium	8.3.5.9.3.2.4
Hydrogen entry and embrittlement	Hydrogen production rate by radiolysis and corrosion	Medium	8.3.5.9.3.2.5
	Hydrogen recombination rate	Medium	8.3.5.9.3.2.5
	Rate of hydrogen entry into the alloy	Medium	8.3.5.9.3.2.5
	Concentration of hydrogen in the alloy	High	8.3.5.9.3.2.5
	Phase structure of the alloy	High	8.3.5.9.3.2.5
	Mechanical property changes from hydrogen degradation	High	8.3.5.9.3.2.5

Table 8.3.5.9-5. Container degradation model inputs (continued)

Model	Model inputs	Needed confidence	SCP section
Pitting, crevice, and other localized attack	Critical concentration of ions known to favor these modes of attack	High	8.3.5.9.3.2.6
	Temperature	High	8.3.5.9.3.2.6
	Solution pH	High	8.3.5.9.3.2.6
	Metal microstructure	Medium	8.3.5.9.3.2.6
	Corrosion potential	High	8.3.5.9.3.2.6
	Pitting potential	High	8.3.5.9.3.2.6
Transgranular stress corrosion cracking	Chloride concentrations of water	High	8.3.5.9.3.2.7
	Temperature	High	8.3.5.9.3.2.7
	Stress	Medium	8.3.5.9.3.2.7
	Alloy constituents	Medium	8.3.5.9.3.2.7
	Other ions in solutions	Medium	8.3.5.9.3.2.7
	Corrosion potential	High	8.3.5.9.3.2.7
Other potential degradation modes	To be determined	Not applicable	8.3.5.9.3.2.8

8.3.5.10 Performance Allocation Tables for Engineered Barrier System Release Rates

Issue 1.5 addresses compliance with the performance objective for the EBS release rate specified in 10 CFR 60.113. The performance allocation for the EBS release rate begins with the definition of the input needed for predictive modeling in Table 8.3.5.10-1. System elements of the EBS, performance measures with goals and estimates of needed confidence are provided in Table 8.3.4.10-2. One objective of the engineered barrier program is to provide adequate characterization of the near-field environment and the list of water quality performance parameters listed in Table 8.3.5.10-3a reflects this focus. The current estimated range for each parameter is provided together with the current and needed confidence in the parameter value. Table 8.3.5.10-3b provides the performance parameters for glass and spent fuel waste forms, with goals, estimated ranges, and current and needed confidence. The performance allocation for radionuclide migration in the near-field host rock is provided in Tables 8.3.5.10-4 and 8.3.5.10-5.

Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates (page 1 of 7)

Model	Model input	Needed confidence	SCP section
Scenarios	Parameters for nominal case and for potentially significant disturbed scenarios	High	8.3.5.13
	Parameters for modeling changes in geologic, hydrologic, and geomechanical conditions	Medium to high	8.3.1.4, 8.3.1.5, 8.3.1.6, 8.3.1.7, 8.3.1.8
	Parameters for modeling changes in geo-hydrologic geochemical conditions	Medium to high	8.3.1.2, 8.3.1.3
	Characteristics of shaft and borehole seals	Medium to high	8.3.3.2
	Characteristics of repository and engineered barriers	Medium to high	8.3.2.2
	Characteristics of waste package designs	High	8.3.4.2.2, 8.3.4.2.3, 8.3.4.2.4
	Waste package container failure modes and times	High	8.3.5.9.4
Waste package performance assessment	Scenarios	High	8.3.5.10.3.1
	Waste package geometry model	High	8.3.5.10.3.5
	Radiation attenuation model	Medium	8.3.5.10.3.5
	Heat transfer model	High	8.3.5.10.3.5
	Mechanical stress model	High	8.3.5.10.3.5
	Waste package environment (water movement and chemistry) model	High	8.3.4.2.4
	Container corrosion and degradation model	High	8.3.5.9.3
	Waste form release model	High	8.3.5.10.3.5, 8.3.5.10.3.2, 8.3.5.10.3.3

Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates (page 2 of 7)

Model	Model input	Needed confidence	SCP section
Waste form release	EQ3/6 model for glass and spent fuel	High	8.3.5.10.3.5
	Gas release model	High	8.3.5.10.3.3
	Container failure rate	High	8.3.5.9.4
	Container configurations after failure	High	8.3.5.9.4
	Temperature from heat transfer model	High	8.3.5.10.3.5
	Water flow quantity	High	8.3.4.2.4.2
	Mechanism of water contact with waste package	High	8.3.5.9.4, 8.3.4.2.4.2
	Water quality	High	8.3.4.2.4.1
EQ3/6 waste model	Waste form degradation models		8.3.5.10.3
	Spent fuel	High	8.3.5.10.3.3
	Hardware and cladding	High	8.3.5.10.3.3
	Glass	High	8.3.5.10.3.4
	Temperature	High	8.3.5.10.3.1
	Water flux contacting waste	High	8.3.4.2.4.1
	Water chemistry contacting waste	High	8.3.4.2.4.1
	Thermodynamic data for solids, gases, and aqueous species resulting from waste release	High	8.3.5.10.3.2.1
	Waste degradation scenarios	High	8.3.5.10.3.1
Spent fuel release	Water flux contacting waste		8.3.4.2.4.1
	Near-field flux	High	8.3.4.2.4.1
	Water entering container	High	8.3.5.10.3.5.3
	Water contact scenario	High	8.3.5.10.3.1
	Water chemistry contacting waste		8.3.4.2.4.1
	Initial chemistry	High	8.3.4.2.4.1.3

Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates (page 3 of 7)

Model	Model input	Needed confidence	SCP section
Spent fuel release (continued)	Radiation-induced changes	Medium	8.3.4.2.4.1.5
	Repository material-induced changes	High	8.3.4.2.4.1.2
	Temperature-induced changes	High	8.3.4.2.4.1.1
	Corrosion-induced changes	High	8.3.4.2.4.1.6
	Temperature	High	8.3.5.10.3.1
	Fuel composition	High	8.3.5.10.1.1.1
	Fission gas release	High	8.3.5.10.1.1.1
	Oxidation state	High	8.3.5.10.2.1.2
	Cladding condition	Medium	8.3.5.10.2.1.3
	Fuel degradation rate constants	High	8.3.5.10.2.1
	Fuel dissolution rates	High	8.3.5.10.2.1.1
	Effect of		
	Burnup	High	8.3.5.10.2.1.1
	Oxidation state	High	8.3.5.10.2.1.1
	Reactor type	Medium	8.3.5.10.2.1.1
	Grain size	High	8.3.5.10.2.1.1
	Radiation field	Medium	8.3.5.10.2.1.1
	Radionuclide content (at time of water contact)	High	8.3.5.10.1.1.1
	Container material	Medium	8.3.5.10.1.1.1
	Other waste characteristics	Medium	8.3.5.10.1.1.1
	Other repository characteristics	Medium	8.3.5.10.1.1.3
Glass release	Water flux contacting waste		8.3.4.2.4.1
	Near field flux	High	8.3.4.2.4.1
	Water entering container	High	8.3.5.10.3.5.3
	Water contact scenario	Medium	8.3.5.10.3.1

Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates (page 4 of 7)

Model	Model input	Needed confidence	SCP section
Glass release (continued)	Water chemistry contacting waste		8.3.4.2.4.1
	Initial chemistry	High	8.3.4.2.4.1.3
	Radiation-induced changes	Medium	8.3.4.2.4.1.5
	Repository material-induced changes	High	8.3.4.2.4.1.2
	Temperature-induced changes	High	8.3.4.2.4.1.1
	Corrosion-induced changes	Medium	8.3.4.2.4.1.6
	Temperature	High	8.3.5.10.3.1
	Glass composition	High	8.3.5.10.1.1.2
	Glass degradation rate constants	High	8.3.5.10.2.2
	Glass dissolution rates	High	8.3.5.10.2.2.1
	Effect of interactions on rates	High	8.3.5.10.2.2.2
	Radionuclide content (at time of water contact)	High	8.3.5.10.1.1.2
	Ratio of glass surface area to water volume	High	8.3.5.10.3.1
	Container material	Medium	8.3.5.10.1.1.2
	Pour canister material	High	8.3.5.10.1.1.2
	Glass handling history	High	8.3.5.10.1.1.2
	Conformation with waste acceptance specifications	High	8.3.5.10.1.1.2
	Other waste characteristics	Medium	8.3.5.10.1.1.2
	Other repository characteristics	Medium	8.3.5.10.1.1.3
Hardware and cladding release	Water flux contacting waste		8.3.4.2.4.1
	Near field flux	High	8.3.4.2.4.1
	Water entering container	High	8.3.5.10.3.5.3
	Water contact scenario	High	8.3.5.10.3.1
	Water chemistry contacting waste		8.3.4.2.4.1
	Initial chemistry	High	8.3.4.2.4.1.3
	Radiation-induced changes	Medium	8.3.4.2.4.1.5

Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates (page 5 of 7)

Model	Model input	Needed confidence	SCP section
Hardware and cladding release (continued)	Repository material-induced changes	High	8.3.4.2.4.1.2
	Temperature-induced changes	High	8.3.4.2.4.1.1
	Corrosion-induced changes	Medium	8.3.4.2.4.1.6
	Temperature	High	8.3.5.10.3.1
	Hardware and cladding composition	High	8.3.5.10.1.1.1
	Degradation rate constants	High	8.3.5.10.2.1.3, 8.3.5.10.2.1.4
	Humidity	Medium	8.3.5.10.2.1.3, 8.3.5.10.2.1.4
	Metal compatibilities	High	8.3.5.10.2.1.3, 8.3.5.10.2.1.4
	Radiation field	Medium	8.3.5.10.2.1.3, 8.3.5.10.2.1.4
	Irradiation history	High	8.3.5.10.2.1.3, 8.3.5.10.2.1.4
	Oxide thickness on cladding	High	8.3.5.10.2.1.3
	Hydride content of cladding	Medium	8.3.5.10.2.1.3
	Radionuclide content (at time of water content)	High	8.3.5.10.1.1.1
	Container material	Medium	8.3.5.10.1.1.1
	Other waste characteristics	Medium	8.3.5.10.1.1.1
	Other repository characteristics	Medium	8.3.5.10.1.1.3
Spent fuel gas release	Gas release scenario	High	8.3.5.10.3.1
	Temperature	High	8.3.5.10.3.1
	Fuel composition	High	8.3.5.10.1.1.1
	Cladding composition	High	8.3.5.10.1.1.1
	Hardware composition	High	8.3.5.10.1.1.1

Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates (page 6 of 7)

Model	Model input	Needed confidence	SCP section
Spent fuel gas release (continued)	Fuel oxidation state	High	8.3.5.10.2.1.2
	Cladding condition	Medium	8.3.5.10.2.1.3
	Humidity	Medium	8.3.5.10.2.1.3, 8.3.5.10.2.1.4
	Radiation field	Medium	8.3.5.10.2.1.3, 8.3.5.10.2.1.4
	Irradiation history	High	8.3.5.10.2.1.3, 8.3.5.10.2.1.4
	Oxide thickness on cladding	High	8.3.5.10.2.1.3
	Radionuclide content	High	8.3.5.10.1.1.1
	Container material	Medium	8.3.5.10.1.1.1
	Other waste characteristics	Medium	8.3.5.10.1.1.1
	Other repository characteristics	Medium	8.3.5.10.1.1.3
Waste package geometry and thermal/mechanical properties	Geometry model	High	8.3.5.10.3.5
	Radiation attenuation model	Medium	8.3.5.10.3.5
	Heat transfer model	High	8.3.5.10.3.5
	Mechanical stress model	High	8.3.5.10.3.5
Geometry	Borehole and waste package configuration, dimensions	High	8.3.4.2.2, 8.3.4.2.3
	Waste package content		
	Materials	High	8.3.4.2.2
	Mass	High	8.3.4.2.2
	Elemental composition	Medium	8.3.5.10.1.1, 8.3.4.2.2

Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates (page 7 of 7)

Model	Model input	Needed confidence	SCP section
Geometry (continued)	Isotopic composition		
	Important constituents	High	8.3.5.10.1.1
	Minor constituents	Medium	8.3.5.10.1.1
Radiation attenuation	Radiation source strength	High	8.3.5.10.1.1
	Gamma ray attenuation coefficients of materials	Medium	8.3.4.2.2
	Dose rate at waste form surface	Medium	8.3.5.10.1.1
	Dose rate at package surface	Medium	8.3.4.2.2
	Decay heat generation rates	High	8.3.4.2.2
Heat transfer (thermal) model	Thermal properties (heat capacity, conductivity) of single materials	High	8.3.4.2.2
	Effective thermal properties of composite materials	High	8.3.4.2.2
	Surface properties for convective and radiative heat transfer	Medium	8.3.4.2.2
	Interaction with host rock heat transfer	High	8.3.4.2.4.3
	Decay heat generation rate	High	8.3.4.2.4.3
Mechanical model	Mechanical properties of single materials	High	8.3.4.2.2
	Mechanical properties of composite materials	Medium	8.3.4.2.2
	Mechanical loads	High	8.3.4.2.2, 8.3.4.2.4.3
	Temperature field within package	Medium	8.3.4.2.4.4

Table 8.3.5.10-2. Performance measures and goals for Issue 1.5 (engineered barrier system release rates)

System element	Performance measure	Tentative goal[a]	Needed confidence
Engineered environment[b]	Quantity of liquid water that can contact the	No liquid water contacting waste container forms for 90% of packages that may be contacted by negligible quantities of water. For the 10% of the packages, <20 L of liquid water per package per year contacts the waste form	High
		Rate of breached dry packages becoming wet <0.01/yr	High
	Water quality	Constrain water chemistry to acceptable levels for waste form performance	High
	Rock-induced load on waste package	Load less than design basis (see Table 8.3.4.2-3)	High
Container	Fraction of containers that have breached[c]	For t >1,000 for containers with no liquid water contact: <0.001/yr	High
		For t >1,000 for containers with liquid water contact: <0.01/yr	High
	Fractional release due to mass transfer resistance of breached containers (and cladding)	For t >1,000 for containers with liquid water contact: <0.1 (see Section 8.3.5.10.3)	High

Table 8.3.5.10-2. Performance measures and goals for Issue 1.5 (engineered barrier system release rates) (continued)

System element	Performance measure	Tentative goal[a]	Needed confidence
Waste Form	Release fractions or rates from waste form components	Release rates from breached packages via all mechanisms, together with the mass transfer resistance of packages, of <1 part in 10,000 (of 1,000 yr inventory) per year for each radionuclide	High

[a]t = years after repository closure.
[b]Envelope for anticipated processes and events.
[c]Breach is defined as allowing air flow of 1×10^{4} atm-cm^3/s. The maximum fraction of total failures will be determined as part of the container material studies and will be consistent with regulatory intent.

Table 8.3.5.10-3a. Performance parameters and goals for water composition for Issue 1.5 (engineered barrier system release rates)

Performance measure	Performance parameters	Tentative performance parameter goal	Needed confidence	Current estimated range	Current confidence
Water quality[a]	pH	5.5-9	High	6.1-7.7	Medium
	Cl^-	<20 ppm	High	<10 ppm	Medium
	F^-	<6 ppm	High	<5.4 ppm	Medium
	NO_3^-	<15 ppm	High	0-11 ppm	Medium
	$SO_4^=$	<50 ppm	High	15-35 ppm	Medium
	$CO_3^=, HCO_3^-$	<200 ppm	Medium	90-160 ppm	Medium
	Total anions	<220 ppm	Medium	110-160 ppm	Medium
	Organics	TBD[b]	TBD	NA[c]	NA
	Colloids	TBD	TBD	NA	NA
	O_2	0.1-8 ppm	High	<6.5 ppm	Medium
	NH_3	<1 ppm	High	<1 ppm	Low
	Si	>20 ppm	High	20-550 ppm	Medium
	Na	<100 ppm	High	30-80 ppm	Medium
	K	<50 ppm	High	1-30 ppm	Medium
	Na/Ca	>1	High	>2	Medium
	Total heavy metals (>Fe)	<2 ppm	High	TBD	Low
	Total other cations	<50 ppm	Medium	<30 ppm	Low

[a]Not all combinations of the limits on the goals given in the above table will result in acceptable water chemistries (See Section 8.3.4.2).
[b]TBD = to be determined.
[c]NA = not applicable.

Table 8.3.5.10-3b. Performance parameters and goals for spent fuel and glass waste forms for Issue 1.5 (engineered barrier system release rates) (page 1 of 8)

Performance measure	Performance parameter	Performance goal (Concentration of radionuclide in effluent water) (mg/L)	(Ci/L) (see note a)	Needed confidence	Current estimated range (mg/L)	Current confidence
SPENT FUEL WASTE FORM (see notes b and c)						
	(see note d)				(see note e)	
Release rate from bare waste form inside failed container	C-14[f]	2.06	1.80E-05[g]	High	<40	Low
	Cl-36	5.61E-01	1.80E-05	High	To be determined	Low
	Ca-41	1.65E-01	1.80E-05	High	<20	Medium
	Ni-59		5.28E-05	High		
	Ni-63	127	1.80E-05	High	<4	Medium
	Se-79	8.55E-01	1.80E-05	High	<6.0E-3	Low
	Zr-93	1900	1.99E-05	High	<1	High
	Nb-93m		1.89E-05	High		
	Nb-94	7.32	1.80E-05	High	<1	High
	Mo-93	2890	1.80E-05	High	To be determined	Low
	Tc-99	7.98	1.34E-04	High	<0.8	Low
	Pd-107	220	1.80E-05	High	<10	Low
	Sn-126	88.1	1.80E-05	High	<.010	High
	I-129	110	1.80E-05	High	<0.2	Low
	Cs-135	79.3	1.80E-05	High	<1.6	Low
	Sm-151	94.9	1.80E-05	High	<1	High
	Ho-166m	1.00E-02	1.80E-05	High	<1	Low
	Pb-210	2.22E-04	1.80E-05	High	<4.0E-8	Medium
	Ra-226	1.82E-02	1.80E-05	High	<8.0E-2	Low
	Ac-227	2.47E-04	1.80E-05	High	To be determined	Low

Table 8.3.5.10-3b. Performance parameters and goals for spent fuel and glass waste forms for Issue 1.5 (engineered barrier system release rates) (page 2 of 8)

Performance measure	Performance parameter	Performance goal (Concentration of radionuclide in effluent water) (mg/L)	(Ci/L) (see note a)	Needed confidence	Current estimated range (mg/L)	Current confidence
		SPENT FUEL WASTE FORM (continued)				
Release rate from bare waste form inside failed container (continued)	Th-230	8.91E-01	1.80E-05	High	<1.0E-08	
	U-233		1.80E-05			
	U-234		2.10E-05			
	U-235	9970	1.80E-05	High	<10	High
	U-236		1.80E-05			
	U-238		1.80E-05			
	Np-237	25.5	1.80E-05	High	To be determined	Medium
	Pu-238		1.80E-05			
	Pu-239		3.15E-03			
	Pu-240	77.8	4.94E-03	High	<5.0E-3	High
	Pu-241		1.80E-05			
	Pu-242		1.80E-05			
	Am-242m		1.80E-05			
	Am-243	8.08E-01	1.61E-04	High	<1.0E-2	High
	Cm-245		1.80E-05			
	Cm-246	1.28E-01	1.80E-05	High	<1.0E-3	Medium

Table 8.3.5.10-3b. Performance parameters and goals for spent fuel and glass waste forms for Issue 1.5 (engineered barrier system release rates) (page 3 of 8)

Performance measure	Performance parameter	Performance goal (Concentration of radionuclide in effluent water) (mg/L)	(Ci/L) (see note b)	Needed confidence	Current estimated range (mg/L)	Current confidence
		SPENT FUEL WASTE FORM (see notes b and c) (continued)				
Release rate from bare waste form inside failed container (continued)	Activity of $^{14}CO_2$ released as a gas (gaseous release)	(see note f)		High	To be determined	Low
		GLASS WASTE FORM (see notes h and i)				
	Ni-59 Ni-63	1.4E-01	1.09E-05 8.78E-07	High	3.3E-04 to 4.9E-03[j]	Medium
	Se-79	8.1E-03	5.62E-07	High	1.9E-05 to 2.9E-04[j]	Medium
	Rb-87	2.1E+03	1.76E-07	Low	1.1E-03 to 1.6E-01[k]	Medium
	Zr-93	2.4E-00	6.22E-06	High	5.8E-03 to 8.8E-01[j]	High
	Nb-93m Nb-94	9.5E-04	6.22E-06 1.76E-07	High	2.3E-06 to 3.4E-05[k]	Medium

Table 8.3.5.10-3b. Performance parameters and goals for spent fuel and glass waste forms for Issue 1.5 (engineered barrier system release rates) (page 4 of 8)

Performance measure	Performance parameter	Performance goal (Concentration of radionuclide in effluent water) (mg/L)	(Ci/L) (see note a)	Needed confidence	Current estimated range (mg/L)	Current confidence
		GLASS WASTE FORM (continued)				
Release rate from bare waste form inside failed container (continued)	Tc-99	6.1E-01	1.03E-05	High	1.5E-03 to 2.2E-01[k]	Low
	Pd-107	3.4E-01	1.76E-07	Medium	2.4E-04 to 3.6E-03[k]	Medium
	Sn-126	2.9E-02	8.22E-07	High	7.0E-05 to 1.0E-03[j]	Medium
	Cs-135	5.3E-01	4.66E-07	High	1.3E-03 to 1.9E-01[j]	Medium
	Sm-151	1.5E-05	3.83E-07	High	3.5E-08 to 5.3E-07[j]	Medium
	Pb-210	2.3E-06	1.76E-07	Medium	1.9E-10 to 2.8E-09[k]	Medium
	Ra-226	1.8E-04	1.76E-07	Medium	1.9E-08 to 2.9E-07[k]	Medium
	Ac-227	2.4E-06	1.76E-07	Low	4.7E-12 to 7.1E-11[k]	Low

Table 8.3.5.10-3b. Performance parameters and goals for spent fuel and glass waste forms for Issue 1.5 (engineered barrier system release rates) (page 5 of 8)

Performance measure	Performance parameter	Performance goal (Concentration of radionuclide in effluent water) (mg/L)	(Ci/L) (see note a)	Needed confidence	Current estimated range (mg/L)	Current confidence
		GLASS WASTE FORM (continued)				
Releaase rate from bare waste form inside failed container (continued)	Th-230	8.6E-03	1.76E-07	Medium	8.5E-10 to 8.5E-09[l]	High
	Pa-231	3.7E-03	1.76E-07	Low	9.5E-09 to 1.4E-07[k]	Low
	U-232	8.5E+01	1.76E-07	High	2.6E-01 to 2.6E-01[l]	Medium
	U-233		1.76E-07			
	U-234		4.54E-06			
	U-235		1.76E-07			
	U-236		1.85E-07			
	U-238		1.76E-07			
	Np-237	2.5E-01	1.76E-07	Medium	3.2E-04 to 4.8E-03[k]	Medium
	Pu-238	1.0E-00	1.20E-06	High	1.2E-06 to 1.2E-05[l]	Low[m]
	Pu-239		5.14E-05			
	Pu-240		3.00E-05			
	Pu-241		1.76E-07			
	Pu-242		1.76E-07			

Table 8.3.5.10-3b. Performance parameters and goals for spent fuel and glass waste forms for Issue 1.5 (engineered barrier system release rates) (page 6 of 8)

Performance measure	Performance parameter	Performance goal (Concentration of radionuclide in effluent water) (mg/L)	(Ci/L) (see note a)	Needed confidence	Current estimated range (mg/L)	Current confidence
		GLASS WASTE FORM (continued)				
Release rate from bare waste form inside failed container (continued)	Am-241 Am-242m Am-243	1.5E-02	5.01E-05 1.76E-07 1.76E-07	High	3.7E-05 to 5.6E-04[j]	Low[m]
	Cm-245	1.0E-03	1.76E-07	Low	4.7E-10 to 7.1E-09[k]	Low

[a]The concentrations are derived from the 1 x 10^{-5} per year or 0.1% calculated release rate limit (CRRL) (1.8 x 10^{-6}) requirement for each individual radioisotope based on 20 liters per package per year flux for up to 10 percent of the packages together with the package loading assumptions in notes c and h.

[b]Limiting concentrations include stable isotopes of an element and were calculated assuming that all isotopes of an element are released congruently at a level determined by the limiting concentration of the radioisotope of that element requiring the most stringent control.

[c]All calculations based on 33,000 MWd/MTU fuel at 1,000 yr out-of-reactor. Inventory includes cladding and hardware. Calculations assume 62,000 MT of unoxidized spent fuel in 30,000 containers of which 10 percent are contacted by 20 liters of liquid water per year. Issue 1.4 allocates performance to the cladding in order to limit the quantity of oxidized fuel to less than 1 percent of the repository inventory, thereby controlling the release of those radionuclides in the fuel that are made more available for aqueous release by oxidation (e.g., Tc-99).

[d]Table includes all radionuclides that have half-lives greater than 10 yr and have total inventories per package such that, at the allowed release rate, it would take more than 10 yr to release the entire inventory.

Table 8.3.5.10-3b. Performance parameters and goals for spent fuel and glass waste forms for Issue 1.5 (engineered barrier system release rates) (page 7 of 8)

Footnotes (continued)

[e]Current estimated ranges are based on experimental results discussed in Chapter 7, Section 7.4.3.1.1, and theoretical modeling of phase solubility. Ranges for Se, Tc, Pd, I, Cs, and Pb were estimated assuming that 1 g of U reacts per liter of water entering a container. The inventory of these elements associated with 1 g of U was then assumed to remain in solution. Note that 1 g of U per liter is far in excess of the expected U solubility.

[f]The allowed aqueous concentration of C-14 assumes that no C-14 is released as a gas. Similarly, the allowed gaseous release was calculated assuming no C-14 is released in solution. To meet the actual release requirements, the sum of the aqueous plus gaseous release must total <3.6E-05 Ci/yr per package.

[g]1.80E-05 is notation for 1.8×10^{-5}.

[h]Allowed maximum concentration in mg/L for all the radioisotopes of each element. Note that nonradioactive isotopes are not included.

[i]Inventory data for Defense Waste Processing Facility (DWPF) glass taken from 1,000-year inventory, Table 7-21. Allowed effluent per container in the maximum 20 liters water per package per year for 10 percent of the packages is calculated from the allowed release; 1 part in 100,000 or 0.1% of the calculated release rate limit (CRRL). Radionuclides whose total inventory could be released from the waste package at the allowed rate, in less than 10 yr, have been excluded from this table (e.g., Sr-90). Radionuclides whose half-lives are less than 10 yr (short-lived daughter products) have also been excluded; they are controlled by controlling the parent nuclide.

[j]Estimated range in concentration based on the congruent breakdown of glass. The allowed total for each radionuclide (note i) is equivalent to a silica concentration in solution of 4,150 mg/L (approximately 50 percent of the 1,660 kg glass in each DWPF container is silica; one part in 100,000, times the 10 percent of the containers that are contacted by water, partitioned into 20 liters, is 4,150 mg/L). Silica releases of this magnitude are not anticipated. Estimated ranges were obtained by considering that total silica released from glass (including that recrystallized) would not exceed that equivalent to 150 mg/L. This is the upper limit in the estimated range. The lower limit assumes that glass dissolves slowly at long times, and an equivalent silica release of 10 mg/L was used.

[k]For these radionuclides, the allowed release is 0.1 percent of the CRRL. However, the estimated release reflects the actual inventory (see Table 7-21, 1,000-yr inventory), which may be much smaller.

Table 8.3.5.10-3b. Performance parameters and goals for spent fuel and glass waste forms for Issue 1.5 (engineered barrier system release rates) (page 8 of 8)

Footnotes (continued)

[l]For these radionuclides, the estimated concentrations based on either (j) or (k) exceeded the expected solubility of these elements in well J-13 water, as calculated using EQ3/6. The estimated range given is the calculated solubility at 25C, pH 7.6, with 1 order of magnitude uncertainty.

[m]Although these radionuclides are at or near the current predicted solubility limit, the current confidence is given as low because of the possibility that additional solution species (other ligands) may be found that raise the solubility, and the possibility that colloid transport may contribute significantly to release.

Table 8.3.5.10-3c. Performance parameters and goals for components of spent fuel waste for Issue 1.5 (engineered barrier system release rates)

Performance measure	Performance parameter	Tentative goals	Needed confidence	Current estimated range	Current confidence
Release fractions or rates from components waste form	Fraction of total inventory of gap and grain boundary elements available for rapid release from unoxidized fuel	< 0.02	High	0.005 to 0.04	Medium
	Fraction of C-14 inventory available for rapid release as a gas under temperatures pre-vailing after 1,000 yr	< 0.001	High	<0.002	Low
	Fraction of soluble matrix radionuclides releasable to water within waste package	< 0.001/yr	High	0.0001 to 0.002/yr	Medium
	Fraction of other radionuclides releasable to water within waste package	$< 1 \times 10^{-5}$/yr	High	$<1 \times 10^{-5}$/yr	Medium

Table 8.3.5.10-4. Performance allocation for radionuclide migration in near-field host rock

SCP section requesting parameter	System element	Function	Process or condition	Performance measure	Goal	Needed confidence
8.3.5.13	Topopah Spring tuff	Limit migration of radionuclides through the near-field host rock	Radionuclide transport	Concentrations of radionuclide species in gas phase, liquid water, and adsorbed to solid phases within the near-field host rock	Adequate to determine effectiveness of natural barriers	High

Table 8.3.5.10-5. Performance measures, parameters, and parameter goals for calculating radionuclide source term for near-field host rock (page 1 of 2)

System element	Performance measure	Parameter	Parameter goal	Current confidence	Needed confidence	Sections where parameters are developed
Topopah Spring tuff	Concentrations of radionuclide species in gas phase, liquid water, and adsorbed to solid phases within the near-field host rock	Host rock hydrologic properties	Properties known with accuracy sufficient to calculate differences in flow through the near-field rock resulting from anticipated and unanticipated events	Low	High	8.3.1.2.2
		Radionuclide sorption properties	Properties known with accuracy sufficient to calculate radionuclide sorption to the near-field rock resulting from anticipated and unanticipated events	Low	High	8.3.1.3.4
		Radionuclide transport properties	Properties known with accuracy sufficient to calculate transport through the near-field rock resulting from anticipated and unanticipated events	Low	High	8.3.1.3.1, 8.3.1.3.4, 8.3.1.3.5, 8.3.1.3.6, 8.3.1.3.7
		Host rock thermal properties	Properties known with accuracy sufficient to calculate heat flow and temperature in the near-field rock resulting from anticipated and unanticipated events	Medium	High	8.3.1.15.1, 8.3.1.15.2, 8.3.4.2.4

Table 8.3.5.10-5. Performance measures, parameters, and parameter goals for calculating radionuclide source term for near-field host rock (page 2 of 2)

System element	Performance measure	Parameter	Parameter goal	Current confidence	Needed confidence	Sections where parameters are developed
Topopah Spring tuff (continued)	Concentrations of radionuclide species (continued)	Releases from engineered barrier system	Knowledge of the engineered barrier system release rate	Medium	High	8.3.5.10.4
		Anticipated and unanticipated processes and events	Events described in detail sufficient for resolution of Issues 1.1 and 1.5 (Section 8.3.5.13 and this section)	Medium	High	8.3.5.10.3

8.3.5.12 Performance Allocation Tables for Ground-Water Travel Time

Issue 1.6 addresses compliance with the performance objective for pre-waste emplacement ground-water travel time in 10 CFR 60.113 (a) (2). Because this requirement is placed on the natural barriers at the site, the selection of system elements is presented as the sequence of rock units through which the travel time will be calculated. Table 8.3.5.12-1 presents the rock units (labeled hydrogeologic components available), an allocation of reliance on each hydrogeologic component as primary, secondary or auxiliary, a corresponding performance measure, with goals and confidence needed in the goal. The corresponding performance parameters are presented in Table 8.3.5.12-2, with their estimated range, goals and current and desired confidence. Because of the need for detailed site data to meet this requirement, Table 8.3.5.12-3 provides the parameters needed from the site program to complete the analyses to be performed to assess pre-emplacement ground-water travel time. Calculation of the ground-water travel time is to begin at the boundary of the disturbed zone; Table 8.3.5.12-4 provides the performance allocation for defining the boundary of the disturbed zone.

Table 8.3.5.12-1. Summary of performance allocation for Issue 1.6 (ground-water travel time) (page 1 of 2)

Hydrogeologic components available[a]	Allocation of reliance[b]	Process[c]	Performance measure	Performance goal (yr)	Needed confidence[d]	Performance parameters
TSw	Secondary	Darcian flow	GWTT[e]	1,000 10,000	Low Very low	See Table 8.3.5.12-2
CHnv	Primary	Darcian flow	GWTT	1,000 10,000	High Low	See Table 8.3.5.12-2
CHnz	Primary	Darcian flow	GWTT	1,000 10,000	High Low	See Table 8.3.5.12-2
PPw	Auxiliary	Darcian flow	GWTT	1,000 10,000	Medium Very low	See Table 8.3.5.12-2
PPn	Auxiliary	Darcian flow	GWTT	1,000 10,000	Medium Low	See Table 8.3.5.12-2
BFw	Auxiliary	Darcian flow	GWTT	1,000 10,000	Medium Very low	See Table 8.3.5.12-2
BFn	Auxiliary	Darcian flow	GWTT	1,000 10,000	Medium Very low	See Table 8.3.5.12-2
SZ	Secondary	Darcian flow	GWTT	1,000 10,000	Low Very Low	See Table 8.3.5.12-2

Table 8.3.5.12-1. Summary of performance allocation for Issue 1.6 (ground-water travel time) (page 2 of 2)

Hydrogeologic components available[a]	Allocation of reliance[b]	Process[c]	Performance measure	Performance goal (yr)	Needed confidence[d]	Performance parameters
Combination of all units		Darcian flow	GWTT	1,000 10,000	High High	

[a]TSw = Topopah Spring welded; CHnv = Calico Hills nonwelded vitric; CHnz = Calico Hills nonwelded zeolitized; PPn = Prow Pass nonwelded; BFw = Bullfrog welded; BFn = Bullfrog nonwelded; SZ = saturated zone.

[b]If a significant thickness of the unit occurs along the fastest path of likely radionuclide travel.

[c]Darcian flow (advection) with dispersion will be relied upon for matrix dominated flow; Darcian flow with both dispersion and diffusion will be relied upon if substantial continuous fracture flow is identified during characterization.

[d]High, at least two standard deviations below the mean; medium, at least one standard deviation below the mean; low, less than the mean; very low, less than one standard deviation above the mean (see Step 4, performance goals). Goals and confidence levels were established to guide site studies for the hydrology of the entire site to support resolution of Issues 1.1 and 1.6.

[e]GWTT = ground-water travel time along the fastest path of likely radionuclide travel.

Table 8.3.5.12-2. Performance parameters for resolving Issue 1.6 (page 1 of 2)

Hydrogeologic unit[a]	Performance parameter[b]	Current estimated range[c]	Performance parameter goal[d,e]	Current confidence	Desired confidence
TSw	q	<0.5 mm/yr	<0.5 mm/yr	Low	Low
	q/K_s	0.005 to 50	<0.85	Low	Low
	n_e	0.01 to 0.2	>0.05	Low	Low
	d	0 to 60 m	>10 m (100%)	Medium	Low
CHnv	q	< 0.5 mm/yr	<0.5 mm/yr	Low	High
	q/K_s	0.00005 to 5	<0.95	Medium	High
	n_e	0.15 to 0.45	>0.2	Medium	High
	d	0 to 160 m	>2.5 m (100%)	Low[f]	High
			>25 m (80%)	Low[f]	Medium
CHnz	q	<0.5 mm/yr	<0.5 mm/yr	Medium	High
	q/K_s	0.005 to 50	<0.9	Medium	High
	n_e	0.2 to 0.4	>0.2	Medium	High
	d	0 to 140 m	>2.5 m (100%)	Low[f]	High
			>25 m (80%)	Low[f]	Medium
PPw	q	<0.5 mm/yr	<0.5 mm/yr	Low	Medium
	q/K_s	0.0005 to 0.5	<0.85	Low	Medium
	n_e	0.015 to 0.35	>0.1	Low	Medium
	d	0 to 40 m	>5 m (80%)	Medium	Medium
PPn	q	< 0.5 mm/yr	<0.5 mm/yr	Low	Medium
	q/K_s	0.005 to 0.5	<0.95	Low	Medium
	n_e	0.1 to 0.45	>0.2	Low	Medium
	d	0 to 140 m	>2.5 m (50%)	Low	Medium
BFw	q	<0.5 mm/yr	<0.5 mm/yr	Low	Medium
	q/K_s	0.0005 to 0.05	<0.85	Low	Medium
	n_e	0.05 to 0.4	>0.1	Low	Medium
	d	0 to 70 m	>5 m (20%)	Low	Medium

Table 8.3.5.12-2. Performance parameters for resolving Issue 1.6 (page 2 of 2)

Hydrogeologic unit[a]	Performance parameter[b]	Current estimated range[c]	Performance parameter goal[d,e]	Current confidence	Desired confidence
BFn	q	<0.5 mm/yr	<0.5 mm/yr	Low	Medium
	q/K_s	0.0005 to 0.5	<0.95	Low	Medium
	n_e	0.1 to 0.4	>0.2	Low	Medium
	d	0 to 50 m	>2.5 m (10%)	Low	Medium
SZ	dh/dl	0.005	<0.001	Low	Low
	K_s	0.1 to 1000 m/yr	<10 m/yr	Low	Low
	n_e	0.0001 to 0.01	>0.01	Low	Low
	d	0 to 5000 m	1000 m	Low	Medium

[a]TSw = Topopah Spring welded unit; CHnv = Calico Hills nonwelded vitric unit; CHnz = Calico Hills nonwelded zeolitized unit; PPw = Prow Pass welded unit; PPn = Prow Pass nonwelded unit; BFw = Bullfrog welded unit; BFn = Bullfrog nonwelded unit; SZ = saturated zone.

[b]q = flux; K_s = hydraulic conductivity of saturated matrix pores; n_e = effective porosity; d = distance along flow paths.

[c]Based on Section 3.9, Figure 8.3.5.12-4., and Sinnock et al. (1986).

[d]Parenthetical values for d indicate the desired percentage of the repository area underlain by the indicated thickness.

[e]A thickness of greater than 10 m for 100 percent of the area below the repository is based on a disturbed zone thickness less than 50 m.

[f]Low current confidence in meeting the goal is based on a moderate to high confidence that the goal will not be met because of the absence of the units below portions of the current repository area (see Figure 8.3.5.12-4); additional site data are unlikely to increase current confidence, relocation of the repository facilities is probably required to achieve the desired confidence, therefore achievement of these goals must be considered in the context of trade offs with goals for design issues (Sections 8.3.2.2 and 8.3.2.5) relating to facility siting.

Table 8.3.5.12-3. Supporting performance parameters used by Issue 1.6 (ground-water travel time)[a] (page 1 of 6)

Performance parameter	Material type	Spatial location	Stratigraphic unit	Statistical measures desired[b]	Needed confidence[c]	SCP Section where current estimate is discussed	Current confidence[d]
MODEL TYPE: CALCULATION OF GROUND-WATER TRAVEL TIME IN THE UNSATURATED ZONE							
Inital and Boundary Conditions							
Flux, percolation rate	Fault zones	R-area	UZ, TSw2, repository level	Mean	Medium	NA[d]	NA
	Fault zones	R-area	UZ, TSw2, repository level	SCor	Low	NA	NA
	Fault zones	R-area	UZ, TSw2, repository level	SDev	Low	NA	Low
	Fractures	R-area	UZ, TSw2, repository level	Mean	Medium	3.9.3	NA
	Fractures	R-area	UZ, TSw2, repository level	SCor	Low	NA	NA
	Fractures	R-area	UZ, TSw2, repository level	SDev	Low	NA	Medium
	Rock matrix	R-area	UZ, TSw2, repository level	Mean	High	3.9.3	NA
	Rock matrix	R-area	UZ, TSw2, repository level	SCor	Medium	NA	NA
	Rock matrix	R-area	UZ, TSw2, repository level	SDev	Medium	NA	NA
Moisture content (volumetric)	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	Mean	High	3.9.2.1	Low
	Rock matrix	R-area	UZ, each hydro unit below repository	SCor	High	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SDev	High	NA	NA
Pressure head (matric potential)	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	Mean	Medium	3.9.1.2	Low
	Rock matrix	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
Saturation	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	Mean	High	3.9.2.1	Low
	Rock matrix	R-area	UZ, each hydro unit below repository	SCor	Medium	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
Temperature, in situ	Rock mass	R-area	UZ, below repository	Mean	Medium	1.6.2.2.4	Medium

Table 8.3.5.12-1. Supporting performance parameters used by Issue 1.6 (ground-water travel time)[a] (page 2 of 6)

Performance parameter	Material type	Spatial location	Stratigraphic unit	Statistical measures desired[b]	Needed confidence[c]	SCP Section where current estimate is discussed	Current confidence[d]
Material Properties							
Density, bulk	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	Mean	Medium	2.4.2, 1.6.2	Medium
	Rock matrix	R-area	UZ, each hydro unit below repository	SCor	Medium	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
Moisture retention curve	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	Mean	Medium	3.9.2.1	Low
	Rock matrix	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
Permeability, relative	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
Permeability, relative pneumatic	Fault zones	R-area	UZ, each hydrologic unit	Mean	Medium	NA	NA
	Fractures	R-area	UZ, each hydrologic unit	Mean	Medium	NA	NA
	Fractures	R-area	UZ, each hydrologic unit	SDev	Low	NA	NA
	Rock matrix	R-area	UZ, each hydrologic unit	Mean	Medium	NA	NA
	Rock matrix	R-area	UZ, each hydrologic unit	SDev	Low	NA	NA
Permeability, saturated	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA

Table 8.3.5.12-3. Supporting performance parameters used by Issue 1.6 (ground-water travel time)[a] (page 3 of 6)

Performance parameter	Material type	Spatial location	Stratigraphic unit	Statistical measures desired[b]	Needed confidence[c]	SCP Section where current estimate is discussed	Current confidence[d]
	Rock mass	R-area	UZ, each hydro unit below repository	Mean	High	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	Mean	High	3.9.2.1	Low
	Rock matrix	R-area	UZ, each hydro unit below repository	SCor	High	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SDev	High	NA	NA
Porosity, effective	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	Mean	High	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	SCor	Medium	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	Mean	High	3.9.2.1	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SCor	Medium	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
<u>System Geometry</u>							
Contact altitude, hydrologic units	Rock mass	R-area	UZ, each hydro unit below repository	Mean	High	8.3.5.12	Medium
	Rock mass	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Rock mass	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
Fault displacement	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Medium	1.3.2.2	Low
	Fault zones	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
Fault locations	Fault zones	R-area	UZ, each hydro unit below repository	Mean	High	1.3.2.2	Low
	Fault zones	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
<u>Validation of Model Concepts</u>							
Isotopic ratios, ground-water residence time	Fault zone	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fault zone	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA

Table 8.3.5.12-3. Supporting performance parameters used by Issue 1.6 (ground-water travel time)[a] (page 4 of 6)

Performance parameter	Material type	Spatial location	Stratigraphic unit	Statistical measures desired[b]	Needed confidence[c]	SCP Section where current estimate is discussed	Current confidence[d]
MODEL TYPE: CALCULATION OF GROUND-WATER TRAVEL TIME IN THE SATURATED ZONE							
Inital and Boundary Conditions							
Flux, flow rate	Rock mass	C-area	SZ, upper 100 m	Mean	Medium	3.9.4	Low
Pressure head function of depth	Ground water	C-area	SZ, upper 100 m	Mean	Medium	3.6.3	Low
Temperature, in situ	Rock mass	C-area	SZ, upper 100 m	Mean	Medium	1.6.2	Medium
Material Properties							
Density, bulk	Fault zones	C-area	SZ, each litho unit in upper 100 m	Mean	Low	NA	NA
	Fault zones	C-area	SZ, each litho unit in upper 100 m	SDev	Low	NA	NA
	Rock matrix	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	2.4.2, 1.6.2	Medium
	Rock matrix	C-area	SZ, each litho unit in upper 100 m	SCor	Medium	NA	NA
	Rock matrix	C-area	SZ, each litho unit in upper 100 m	SDev	Medium	NA	NA
Permeability, saturated	Fault zones	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	NA	NA
	Fault zones	C-area	SZ, each litho unit in upper 100 m	SDev	Low	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	3.6.4, 3.9.2.2	Low
	Fractures	C-area	SZ, each litho unit in upper 100 m	SCor	Low	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	SDev	Medium	NA	NA
	Rock mass	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	3.6.4, 3.9.2.2	Low
	Rock mass	C-area	SZ, each litho unit in upper 100 m	SCor	Low	NA	NA
	Rock mass	C-area	SZ, each litho unit in upper 100 m	SDev	Medium	NA	NA
	Rock matrix	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	3.6.4, 3.9.2.2	Medium
	Rock matrix	C-area	SZ, each litho unit in upper 100 m	SDev	Low	NA	NA
Porosity, effective	Fault zones	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	NA	NA
	Fault zones	C-area	SZ, each litho unit in upper 100 m	SDev	Low	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	3.6.4	Low
	Fractures	C-area	SZ, each litho unit in upper 100 m	SCor	Low	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	SDev	Medium	NA	NA
	Rock mass	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	3.9.2.2, 3.6.4	Low
	Rock mass	C-area	SZ, each litho unit in upper 100 m	SCor	Low	NA	NA
	Rock mass	C-area	SZ, each litho unit in upper 100 m	SDev	Medium	NA	NA
	Rock matrix	C-area	SZ, each litho unit in upper 100 m	Mean	Low	3.6.4, 3.9.2.2	Low
	Rock matrix	C-area	SZ, each litho unit in upper 100 m	SDev	Low	NA	NA

Table 8.3.5.12-3. Supporting performance parameters used by Issue 1.6 (ground-water travel time)[a] (page 5 of 6)

Performance parameter	Material type	Spatial location	Stratigraphic unit	Statistical measures desired[b]	Needed confidence[c]	SCP Section where current estimate is discussed	Current confidence[d]
System Geometry							
Aquifer geometry	Rock mass	C-area	SZ, upper 100 m	Mean	Medium	3.6.1, 3.6.2, 3.9.3	Low
Contact altitude, lithologic units	Rock mass	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	3.6.1, 3.6.2, 3.9.3	Low
Fault displacement	Fault zones	C-area	SZ, upper 100 m	Mean	Medium	NA	NA
Fault locations	Fault zones	C-area	SZ, upper 100 m	Mean	Medium	NA	NA
Validation of Model Concepts							
Water table altitude	Ground water	C-area	SZ, water table level	Mean	High	3.9.1.2	Medium
	Ground water	C-area	SZ, water table level	SDev	Low	NA	NA
			MODEL TYPE: CALCULATION OF SPATIAL CORRELATION STRUCTURE				
Material Properties							
Porosity, total	Fault zones	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	NA	NA
	Fault zones	C-area	SZ, each litho unit in upper 100 m	SDev	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	SCor	Low	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	SDev	Medium	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Medium	NA	NA
	Rock mass	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	3.9.2.2	Low
	Rock mass	C-area	SZ, each litho unit in upper 100 m	SCor	Low	NA	NA
	Rock mass	C-area	SZ, each litho unit in upper 100 m	SDev	Medium	NA	NA
	Rock matrix	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	2.4.2, 2.5	Medium
	Rock matrix	C-area	SZ, each litho unit in upper 100 m	SCor	Medium	NA	NA
	Rock matrix	C-area	SZ, each litho unit in upper 100 m	SDev	Medium	3.9.2, 2.4.2, 2.5	Medium
	Rock matrix	R-area	UZ, each hydro unit below repository	Mean	High	NA	NA
	Rock matrix	R-area	UZ, each hydro unit below repository	SCor	High	NA	NA
			MODEL TYPE: CALCULATION OF FRACTURE HYDROLOGIC CHARACTERISTICS				
Material Properties							
Fracture aperture	Fault zones	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	NA	NA
	Fault zones	C-area	SZ, each litho unit in upper 100 m	SDev	Low	NA	NA

Table 8.3.5.12-3. Supporting performance parameters used by Issue 1.6 (ground-water travel time)[a] (page 6 of 6)

Performance parameter	Material type	Spatial location	Stratigraphic unit	Statistical measures desired[b]	Needed confidence[c]	SCP Section where current estimate is discussed	Current confidence[d]
	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	SDev	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Medium	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
Fracture frequency	Fault zones	C-area	SZ, each litho unit in upper 100 m	Mean	Low	NA	NA
	Fault zones	C-area	SZ, each litho unit in upper 100 m	SDev	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	Mean	Medium	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	SCor	Low	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	SDev	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Medium	3.9.2.1	Low
	Fractures	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
Fracture length	Fault zones	C-area	SZ, each litho unit in upper 100 m	Mean	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	Mean	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
<u>System Geometry</u>							
Fracture orientation	Fault zones	C-area	SZ, each litho unit in upper 100 m	Mean	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fault zones	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA
	Fractures	C-area	SZ, each litho unit in upper 100 m	Mean	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	Mean	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below respository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA

[a]SZ = saturated zone; UZ = unsaturated zone; GWTT = ground-water travel time; C-area = controlled area; R-area = repository area; litho = lithological; hydro = hydrological.

[b]Mean = spatially dependent mean value; SDev = spatially dependent standard deviation; SCor = spatial correlation coefficient.

[c]High = high confidence, highest priority; Medium = medium confidence, medium priority; Low = low confidence, low priority.

[d]NA = not available.

Table 8.3.5.12-4. Summary of performance allocation for defining the boundary of the disturbed zone

Hydrologic unit	Process concern	Performance measure	Performance goal	Needed confidence[a]	Approach
Topopah Spring welded unit	Thermomechanical processes: fracture activation caused by mining and heating	Boundary of repository induced changes in effective fracture porosity	Less than a factor of 2 increase in fracture aperture along flow path 50 m from the underground facilities boundary if predominately fracture flow	Medium	Studies are not presently planned because flow is expected to be predominately in the matrix
	Thermochemical processes: alteration within the portion of the Topopah Spring that is considered to be the repository horizon	Boundary of repository induced changes in effective matrix porosity and matrix permeability	Less than a factor of 2 decrease in effective porosity or less than an order of magnitude increase in permeability along the flow path to the accessible environment	Medium	Studies will be completed to determine if mineral alteration can cause factor of 2 decreases in effective porosity or order of magnitudes increases in permeability
Calico Hills nonwelded zeolitic unit	Zeolite alteration below the repository horizon	Temperature	<115°C	Medium	At the temperatures listed as goals, minimal property changes as a result of mineral alteration are expected. Studies will be completed at these temperatures to test the position that there will be minimal changes in rock properties
Calico Hills nonwelded vitric unit	Glass alteration below the repository horizon	Temperature	<115°C	Medium	
Altered vitrophyre below the Topopah Spring welded unit	Clay alteration below the repository horizon	Temperature	<115°C	Medium	

[a]Medium equals a value corresponding to one standard deviation on the most deleterious side of a probability distribution function of the performance measure.

8.3.5.13 Performance Allocation Tables for Total System Performance

Issue 1.1 addresses compliance with the performance objective for total system performance specified in 10 CFR 60.112 and 40 CFR 191.13. To meet this requirement, the performance allocation considers both a set of undisturbed conditions, which includes the range of likely natural events, and the set of disturbed conditions that are sufficiently credible to warrant consideration. In order to systematically allocate performance over the range of disturbed conditions, scenario classes were defined (Table 8.3.5.13-3). The top-level performance allocation for the total system release requirements is presented in Table 8.3.5.13-8. For each release scenario class from Table 8.3.5.13-3, the release pathways of concern, the primary barriers and the components of the primary barriers are defined. The primary processes and conditions, performance measures, goals and confidence for each scenario class are also provided in Table 8.3.5.13-8. For each scenario class from Table 8.3.5.13-8, Tables 8.3.5.13-9 through 8.3.5.13-16, respectively, provide the performance parameters, goals and current and needed confidence estimates, and a reference to the SCP section providing the parameter values.

Because the evaluation of undisturbed natural conditions also requires an adequate site database, Table 8.3.5.13-17 provides a detailed list of supporting parameters that are needed according to the type of calculation to be made. The supporting parameters are defined with regard to spatial location where data is needed, as well as estimates of the current and needed confidence in the parameter values. References are provided to the SCP sections where the studies and activities that will obtain the supporting parameter values are described.

Table 8.3.5.13-3. Categories of scenarios delineated according to potential impacts on barriers of the geologic repository (scenario classes)

Disturbed performance of barriers.

(A) Direct Releases:

1) direct release in an extrusive magmatic event;

2) direct release associated with human intrusion

(B) Partial failure of engineered barriers[a]

(C) Partial failure of unsaturated zone barriers:

1) accelerated releases to the WT attending increased flux from sources above the repository;

2) accelerated releases to the WT attending a rise in the WT (foreshortening of unsaturated zone);

3) accelerated releases to the WT attending changes in unsaturated zone rock-hydrologic properties or geochemical properties.

(D) Partial failure of saturated zone barriers:

1) accelerated releases to the accessible environment owing to appearance of discharge points within 5 km downgradient of controlled area (foreshortening of the saturated zone flow path), or changes in flow direction in saturated zone.

2) accelerated releases to the accessible environment owing to increased linear water velocity in the saturated zones, changed rock-hydrologic properties, or changed geochemical properties.

Undisturbed and nominal performance of all barriers.

(E) Undisturbed performance of all natural barriers:
(matrix flow predominates in unsaturated zone barriers, some carbon-14 released in gas phase)

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[a]No independent, potentially significant classes have been associated with this category.

Table 8.3.5.13-8. Preliminary performance allocation for Issue 1.1 (page 1 of 2)

Release scenario class	Pathway	System elements: Primary barriers	System elements: Primary barrier components	Primary processes or conditions	Performance measure (EPPM)[a]	Tentative goal	Needed confidence
			NOMINAL CASE				
E	Water	Unsaturated zone; saturated zone, EBS[b] as backup	Combined facies of Calico Hills; other units as backup	Equivalent-porous-media transport through matrix with adsorptive retardation	EPPM	< 0.01	High
	Gas	EBS; overburden as backup	Container and structural components	Limited rapid release of carbon-14 as carbon dioxide	EPPM	< 0.2	Medium
			DIRECT RELEASES				
A-1 A-2	Direct	(No allocation: see text for explanation)			EPPM EPPM	< 0.1 < 0.1	High Medium
			FAILURE OF UNSATURATED ZONE BARRIERS				
C-1	Water	Repository overburden	Paintbrush Tuff unit and Topopah Spring	Flooding-pulse delay times > 10,000 yr	EPPM	< 0.01	High
	Gas	None	None	None			High
C-2	Water	Saturated zone; EBS and residual unsaturated zone as backup	Saturated zone to boundary of AE[c] (or discharge points)	Equivalent-porous-media transport with adsorptive retardation	EPPM	< 0.1	Medium
	Gas	None	None	None			High

Table 8.3.5.13-8. Preliminary performance allocation for Issue 1.1 (page 2 of 2)

Release scenario class	Pathway	System elements: Primary barriers	System elements: Primary barrier components	Primary processes or conditions	Performance measure (EPPM)[a]	Tentative goal	Needed confidence
		FAILURE OF UNSATURATED ZONE BARRIERS (continued)					
C-3	Water	Saturated zone; EBS and residual unsaturated zone as backup	Saturated zone to boundary of AE (or discharge points)	Equivalent-porous-media transport with adsorptive retardation	EPPM	< 0.01	High
	Gas	None	None	None			High
		FAILURE OF SATURATED ZONE BARRIERS (does not affect gas-phase releases)					
D-1	Water	Residual saturated zone + residual unsaturated zone, EBS as backup		Equivalent-porous-media transport with adsorptive retardation	EPPM	< 0.1	Medium
D-2	Water	Residual saturated zone + residual unsaturated zone, EBS as backup		Equivalent-porous-media transport with adsorptive retardation	EPPM	< 0.1	High

[a]Maximum EPPM for each event/process associated with scenario/class (see subsection on discussion of issue-resolution strategy for Issue 1.1).
[b]EBS = engineered barrier system.
[c]AE = accessible environment.

Table 8.3.5.13-9. Performance parameters for scenario class E (the nominal case) (page 1 of 3)

Performance measure[a]	Performance parameter[b]	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence
EPPM for liquid pathway, unsaturated zone (UZ) barrier only	$\bar{q}_u$ - average flux through R-area UZ	< 0.5 mm/yr	None	Medium	High
	$\bar{n}_e$ - average effective matrix porosity, R-area UZ	> 0.1	3.9.2.1	Low	High
	$\bar{R}_i$ - average chemical retardation factor for i^{th} species	≥ 1	4.1.3.3, 8.3.1.3	High	High
	$\bar{d}_u$ - average thickness of R-area UZ between repository and water table	> 100 m	8.3.5.12, 3.9.1.2	Medium	High
	r_i - fractional mass release rate from engineered barrier system (EBS) for i^{th} species	< 10^{-4}/yr, all species[c]	8.3.5.10	Low	Medium
EPPM for liquid pathway, saturated zone (SZ) barrier only[d]	$\bar{q}_s$ - average discharge in SZ under C-area	< 32 mm/yr	None	Low	Medium

Table 8.3.5.13-9. Performance parameters for scenario class E (the nominal case) (page 2 of 3)

Performance measure[a]	Performance parameter[b]	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence
EPPM for liquid pathway, saturated zone (SZ) barrier only[d] (continued)	$\bar{n}_f$ - average effective matrix porosity, C-area, SZ	> 0.1	3.9.2.1	Low	Medium
	$\bar{R}_i$ - average chemical retardation factor for i^{th} species, C-area, SZ	≥ 1	4.1.3.3, 8.3.1.3	High	Medium
	$\bar{d}_s$ - average length of flow paths through SZ from C-area to accessible environment boundary	> 5,000 m	3.6.4	Low	Medium
	r_i - fractional mass release rate from EBS for i^{th} species	< 10^{-4}/yr, all species[c]	8.3.5.10	Low	Medium
EPPM for gas pathway	Fraction of total carbon-14 inventory that could be released as carbon-14 dioxide	Fraction < 1% of inventory at closure	8.3.5.10	Low	High

Table 8.3.5.13-9. Performance parameters for scenario class E (the nominal case) (page 3 of 3)

Performance measure[a]	Performance parameter[b]	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence
EPPM for gas pathway (continued)	Mean residence time of released carbon-14 dioxide in UZ units	Show residence time > 10,000 yr	None	Low	High

[a]EPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution functions and significant processes and events.

[b]R-area = the projection of primary area and extensions onto the surface; C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

[c]The performance allocation for Issue 1.5 (engineered barrier system release rates, Section 8.3.5.10) sets a goal for the fractional mass release rate from the EBS at 10-5 per yr to comply with the performance objective in 10 CFR 60.113.

[d]Performance parameters and goals apply only if equivalent-porous-media transport is valid in the SZ, otherwise, the SZ cannot act as a backup barrier to water-pathway releases.

Table 8.3.5.13-10. Performance parameters for scenario class A-1 (extrusive magmatic events)

Performance measure	Initiating event or process	Performance parameter	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM[a]	Volcanic eruption penetrates repository and causes direct releases to the accessible environment	Annual probability of volcanic eruption that penetrates the repository	$<10^{-6}$/yr	1.5.1	Low	High	8.3.1.8.1
		Effects of volcanic eruption penetrating repository, including area of repository disrupted	Given occurrence, show <0.1% of repository area is disrupted with a conditional probability of <0.1 of being exceeded in 10,000 yr	1.5.1	Low	Medium	8.3.1.8.1

[a]EPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution function and significant processes and events.

Table 8.3.5.13-11. Performance parameters for scenario class A-2 (exploratory drilling)

Performance measure	Initiating event or process	Performance parameter[a]	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM[b]	Exploratory drilling intercepts a waste package and brings waste up with core or cuttings.	Presence and readability of C-area markers over next 10,000 yr.	>50% chance that markers are readable over next 10,000 yr.	None	Low	Medium	8.3.1.9.1
		Expected drilling rate (no. of boreholes per square kilometer per year) R-area over the next 10,000 yr.	Expected drilling rate $\leq 3 \times 10^{-4}$ boreholes per square kilometer per year	None	Low	Low	None
		Distribution of depths of exploratory drillings.	No goal	None	Low	Low	None
		Distribution of diameters of exploratory drill holes.	No goal	None	Low	Low	None

[a]R-area = the projection of primary area and extensions onto the surface; C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

[b]EPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution function and significant processes and events.

Table 8.3.5.13-12. Performance parameters for scenario class C-1 (local or extensive increases in percolation flux through unsaturated zone) (page 1 of 2)

Performance measure	Initiating event or process	Intermediate performance measure	Performance parameter[a]	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM[b]	Climatic change causes increase in infiltration over C-area[d]	Radionuclide transport time through unsaturated zone (UZ), given fixed UZ thickness, rock hydrologic properties, and geochemical properties	Expected magnitude of flux change due to climatic changes over next 10,000 yr; quantitative confidence bounds on expected magnitude of change	Flux change will be < 0.5 mm/yr with 67% confidence or more	3.9.3.3	Low	High	8.3.1.5.2
	Offset on faults creates surface impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds	Radionuclide transport time through UZ, given fixed UZ thickness, rock hydrologic properties, and geochemical properties	Probability of offset >2 m on a fault in the C-area in 10,000 yr	$<10^{-1}$	1.3.2.2	Low	Medium	8.3.1.8
			Probability of changing dip by >2° in 10,000 yr by faulting	$<10^{-4}$ per 10,000 yr	None	Low	Low	8.3.1.8
			Effect of faulting on flux	Faulting will not affect flux because of low slip rate	None	Low	Medium	8.3.1.8
	Volcanic eruption causes flows or other changes in topography that result in impoundment or diversion of drainage	Radionuclide transport time through UZ, given fixed UZ thickness, rock hydrologic properties and geochemical properties	Annual probability of volcanic events within C-area	$<10^{-5}$/yr	1.5.1	Low	Medium	8.3.1.8
			Effects of a volcanic event on topography and flow rates	Topographic changes are not enough to affect flux	None	Low	Low	8.3.1.8
	Igneous intrusions, such as a sill, that could result in a change in flux	Radionuclide transport time through UZ, given fixed UZ thickness, rock hydrologic properties and geochemical properties	Annual probability of significant igneous intrusions in the C-area	$<10^{-5}$/yr	1.5.1	Low	High	8.3.1.8
			Effects of an igneous intrusion on flux	Igneous intrusion will not affect flux because of depth, location, and extent of intrusion	None	Low	Low	8.3.1.8
	Tectonic folding changes dip of tuff beds in C-area, thereby changing flux	Radionuclide transport time through UZ, given fixed UZ thickness, rock hydrologic properties and geochemical properties	Probability of changing dip by >2° in 10,000 yr by folding	$<10^{-4}$ per 10,000 yr	1.3.2	Low	Low	8.3.1.8

Table 8.3.5.13-12. Performance parameters for scenario class C-1 (local or extensive increases in percolation flux through unsaturated zone) (page 2 of 2)

Performance measure	Initiating event or process	Intermediate performance measure	Performance parameter[a]	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM (continued)	Uplift or subsidence changes drainage, thereby changing flux	Radionuclide transport time through UZ, given fixed UZ thickness, rock hydrologic properties and geochemical properties	Probability of exceeding 30 m elevation change in 10,000 yr	$<10^{-4}$ per 10,000 yr	1.1.3.3	Low	Low	8.3.1.8
	Subsidence of mined repository creates impoundments or diverts drainage	Radionuclide transport time through UZ, given fixed UZ thickness, rock hydrologic properties, and geochemical properties	Probability that continuously displaced surfaces from subsidence originating at repository will intersect interface of TSw and PTn units in 10,000 yr	$<10^{-4}$	None	Low	Medium	None
	Natural surface-water impoundments are formed over access shafts connecting surface and repository	Radionuclide transport time through UZ, given fixed UZ thickness, rock hydrologic properties, and geochemical properties	Expected magnitude of local flux change, and quantitative bounds on magnitude of flux change, due to flooding through access shafts	Show $<25,000\ m^3/yr$ would pass through access shafts	None	Low	Medium	None
			Expected fraction of waste containers which are subject to changed flux	Show less than 0.01% of containers would be subject to more than a 100% flux change caused by flooding through access shafts.	None	Low	Medium	None
	Extensive irrigation is conducted near the C-area	Radionuclide transport time through UZ, given fixed UZ thickness, rock hydrologic properties, and geochemical properties	Expected magnitude of flux change due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3
	Large scale surface-water impoundments are constructed near the C-area	Radionuclide transport time through UZ, given fixed UZ thickness, rock hydrologic properties, and geochemical properties	Expected magnitude of flux change due to presence of an artificial lake near the C-area in next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3

[a]TSw = Topopah Spring welded unit; PTn = Paintbrush nonwelded unit; C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.
[b]EPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution functions and significant processes and events.

Table 8.3.5.13-13. Performance parameters for scenario class C-2 (foreshortening of the unsaturated zone) (page 1 of 2)

Performance measure	Initiating event or process	Intermediate performance measure	Performance parameter	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM[a]	Climatic change causes an increase in altitude of water table	Radionuclide transport time through unsaturated zone (UZ), given fixed UZ rock hydrologic and geochemical properties	Expected magnitude of change in water-table level due to climatic changes over the next 10,000 yr	Expected magnitude of change in water-table altitude will not bring water table to within 100 m of repository horizon in 10,000 yr	3.7.4, 3.9.8	Low	High	8.3.1.5.2
	Igneous intrusion causes barrier to flow or thermal effects that alter water-table level	Radionuclide transport time through UZ, given fixed UZ rock hydrologic and geochemical properties	Annual probability of significant igneous intrusion within 0.5 km of C-area[b] boundary	$<10^{-5}$/yr	1.5.1	Low	Medium	8.3.1.8
			Barrier-to-flow effects of igneous intrusions on water-table levels	Expected magnitude of change in water-table altitude will not bring water table to within 100 m of repository horizon in 10,000 yr	None	Low	Low	8.3.1.8
			Thermal effects of igneous intrusions on water-table levels	Expected magnitude of change in water-table altitude will not bring water table to within 100 m of repository horizon in 10,000 yr	None	Low	Low	8.3.1.8
	Offset on fault juxtaposes transmissive and nontransmissive units, resulting in either the creation of a perched aquifer or a rise in water table	Radionuclide transport time through UZ, given fixed UZ rock hydrologic and geochemical properties	Probability of total offsets >2.0 m in 10,000 yr on faults within C-area boundary	$<10^{-1}$	1.3.2.2	Low	Medium	8.3.1.8
			Effects of fault offsets on water-table levels	Expected magnitude of change in water-table altitude will not bring water table to within 100 m of repository horizon in 10,000 yr	None	Low	Low	8.3.1.8

Table 8.3.5.13-13. Performance parameters for scenario class C-2 (foreshortening of the unsaturated zone) (page 2 of 2)

Performance measure	Initiating event or process	Intermediate performance measure	Performance parameter[a]	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM (continued)	Episodic changes in strain in the rock mass due to faulting causes changes in water-table level	Radionuclide transport time through UZ, given fixed UZ rock hydrologic and geochemical properties	Probability that strain-induced changes increase potentiometric level to >850 m mean sea level	$<10^{-5}$/yr	1.3.2.3	Low	Low	8.3.1.8
	Folding, uplift or subsidence lowers repository with respect to water table	Radionuclide transport time through UZ, given fixed UZ rock hydrologic and geochemical properties	Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr	$<10^{-4}$ per 10,000 yr	1.1.3	Low	Low	8.3.1.8
	Extensive irrigation is conducted near the C-area	Radionuclide transport time through UZ, given fixed UZ rock hydrologic and geochemical properties	Expected magnitude of change in altitude of water table under C-area due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3
	Large-scale surface-water impoundments are constructed near the C-area	Radionuclide transport time through UZ, given fixed UZ rock hydrologic and geochemical properties	Expected magnitude of change in water-table level under C-area due to placement of artificial lake near C-area in next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3
	Extensive surface or subsurface mining occurs near C-area	Radionuclide transport time through UZ, given fixed UZ rock hydrologic and geochemical properties	Expected magnitude of change in water-table level under C-area due to mine water usage or mine dewatering near C-area in next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3
	Extensive ground-water withdrawal occurs near C-area	Radionuclide transport time through UZ, given fixed UZ rock hydrologic and geochemical properties	Expected magnitude of change in water-table level under C-area due to extensive ground-water withdrawal near C-area in next 10,000 yr	No goal (human activity)	3.8.1	Not applicable	Not applicable	8.3.1.9.3

[a]EPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution function and significant processes and events.
[b]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

Table 8.3.5.13-14. Performance parameters for scenario class C-3 (changes in rock, hydrologic, and geochemical properties in the unsaturated zone) (page 1 of 2)

Performance measure	Initiating event or process	Intermediate performance measure	Performance parameter	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM[a]	Igneous intrusion causes changes in rock hydrologic properties	Radionuclide transport time through unsaturated zone (UZ), given fixed thickness of UZ	Annual probability of significant igneous intrusion within 0.5 km of C-area[b] boundary	$<10^{-5}$/yr	1.5.1	Low	Medium	8.3.1.8
			Effects of igneous intrusion on local permeabilities and effective porosities	No significant changes in rock hydrologic properties	None	Low	Low	8.3.1.8
	Igneous intrusion causes changes in rock geochemical properties	Radionuclide transport time through UZ, given fixed thickness of UZ	Annual probability of significant igneous intrusion within 0.5 km of C-area boundary	$<10^{-5}$/yr	1.5.1	Low	Medium	8.3.1.8
			Effects of igneous intrusions on local rock geochemical properties	Potential changes in mineralogy will not be extensive	None	Low	Low	8.3.1.8
	Episodic offset on faults causes local changes in rock hydrologic properties, thereby destroying existing barriers to flow, or creating new conduits for drainage	Radionuclide transport time through UZ, given fixed thickness of UZ	Annual probability of faulting events on Quaternary faults within 0.5 km of C-area boundary	$<10^{-4}$/yr	1.3.2.2	Low	Medium	8.3.1.8
			Effects of fault motion on local permeabilities and effective porosities	Change in fracture permeability is less than a fac- of 2 and fracture porosity decreases	None	Low	Medium	8.3.1.8
	Offset on a fault causes changes in movement of ground water that result in mineralogical changes along the fault zone	Radionuclide transport time through UZ, given fixed thickness of UZ	Probability of movement within 2 km of surface and location of Quaternary faults in C-area	$<10^{-4}$/yr per fault	1.3.2.2	Low	Medium	8.3.1.8
			Degree of mineralogic change in fault zone in 10,000 yr	Adverse changes in mineralogy will not occur	None	Low	Low	8.3.1.8
	Offset on a fault changes potential radionuclide travel pathway to one with different geochemical properties	Radionuclide transport time through UZ, given fixed thickness of UZ	Probability of total offsets >2.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-1}$	1.3.2.2	Low	Medium	8.3.1.8
			Effects of fault offsets on travel pathway	Significant changes will not occur	None	Low	Low	8.3.1.8

Table 8.3.5.13-14. Performance parameters for scenario class C-3 (changes in rock, hydrologic, and geochemical properties in the unsaturated zone) (page 2 of 2)

Performance measure	Initiating event or process	Intermediate performance measure	Performance parameter	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM[a] (continued)	Changes in stress or strain in C-area resulting from episodic faulting, folding or uplift causes changes in the hydrologic properties of the rock mass	Radionuclide transport time through UZ, given fixed thickness of UZ	Effects of changes of stress or strain on hydrologic properties of the rock mass	Changes in conductivity and porosity of rock mass are less than a factor of 2	1.3.2.3	Low	Low	8.3.1.8
	Tectonic processes cause changes in ground water table or movement that results in mineralogic changes in C-area	Radionuclide transport time through UZ, given fixed thickness of UZ	Degree of mineralogic change in the controlled area resulting from changes in water-table level or flow paths in 10,000 yr	Adverse changes in mineralogy will not occur	None	Low	Low	8.3.1.8
	Extensive irrigation is conducted near C-area	Radionuclide transport time through UZ, given fixed thickness of UZ	Expected magnitude of changes in distribution coefficients, solubilities and chemical reactivity of the engineered barrier system and UZ units due to extensive irrigation near C-area in next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3, 8.3.1.3.7
	Large-scale surface water impoundments are constructed near the C-area	Radionuclide transport time through UZ, given fixed thickness of UZ	Expected magnitude of changes in distribution coefficients, solubilities and chemical reactivity of the engineered barrier system and UZ units due to presence of an artifical lake near C-area in next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3, 8.3.1.3.7
	Extensive surface or subsurface mining occurs near C-area	Radionuclide transport time through UZ, given fixed thickness of UZ	Expected magnitude of changes in distribution coefficients, solubilities and chemical reactivity of the engineered barrier system and UZ units due to mining activities near the C-area in next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3, 8.3.1.3.7

[a]EPPM - expected partial performance measure; see subsection on discussion of complementary cumulative distribution functions and significant processes and events.
[b]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

Table 8.3.5.13-15. Performance parameters for scenario class D-1 (appearance of surficial discharge points within the C-area[a]; foreshortening of the saturated zone) (page 1 of 2)

Performance measure	Initiating event or process	Intermediate performance measure	Performance parameter	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM[b]	Climate change causes appearance of surficial discharge points within C-area	Radionuclide transport time through UZ, given fixed SZ rock hydrologic and geochemical properties	Expected locations of surficial discharge points within C-area over next 10,000 yr	That no surficial discharge points could appear within C-area given a water table rise <160 m	None	Low	Medium	8.3.1.5.2
	Igneous intrusion causes barrier to flow or thermal effects that alter water-table level	Radionuclide transport time through saturated zone (SZ), given fixed SZ rock hydrologic and geochemical properties	Annual probability of significant igneous intrusion within 0.5 km of C-area boundary	$<10^{-5}$/yr	1.5.1	Low	Medium	8.3.1.8
			Barrier-to-flow effects of igneous intrusions on water-table levels	Show water table will not rise to within 100 m of repository horizon in 10,000 yr	None	Low	Low	8.3.1.8
			Thermal effects of igneous intrusions on water-table levels	Show water table will not rise to within 100 m of repository horizon in 10,000 yr	None	Low	Low	8.3.1.8
	Offset on fault juxtaposes transmissive and nontransmissive units, resulting in either the creation of a perched aquifer or a rise in the water table	Radionuclide transport time through SZ, given fixed SZ rock hydrologic and geochemical properties	Probability of total offsets >1.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-1}$	1.3.2.2	Low	High	8.3.1.8
			Effects of fault offset on water-table levels	Show water table will not rise to within 100 m of repository horizon in 10,000 yr	None	Low	High	8.3.1.8
	Episodic changes in strain in the rock mass due to faulting cause changes in water-table level	Radionuclide transport time through SZ, given fixed SZ rock hydrologic and geochemical properties	Probability that strain-induced changes increase potentiometric level to greater than 850 m mean sea level	$<10^{-5}$/yr	1.3.2.3	Low	Low	8.3.1.8

Table 8.3.5.13-15. Performance parameters for scenario class D-1 (appearance of surficial discharge points within the C-area[a]; foreshortening of the saturated zone) (page 2 of 2)

Performance measure	Initiating event or process	Intermediate performance measure	Performance parameter	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM (continued)	Folding, uplift, or subsidence lowers repository with respect to water table	Radionuclide transport time through SZ, given fixed SZ rock hydrologic and geochemical properties	Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr	$<10^{-4}$	1.1.3.3	Low	Low	8.3.1.8

[a]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.
[b]EPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution functions and significant processes and events.

Table 8.3.5.13-16. Performance parameters for scenario class D-2 (increased head gradients or changed rock, hydrologic, or geochemical properties in the saturated zone) (page 1 of 2)

Performance measure	Initiating event or process	Intermediate performance measure	Performance parameter	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM[a]	Climatic change causes an increase in the gradient of the water table within the C-area[b]	Radionuclide transport time through saturated zone (SZ), given fixed distances to accessible environment boundary	Expected magnitude of change in water-table gradient due to climatic change over the next 10,000 yr	Gradients change less than a factor of 4	3.7.1	Low	Medium	8.3.1.5.2
	Igneous intrusion causes barriers to flow or thermal effects that alter water-table (or hydraulic gradients)	Radionuclide transport time through SZ, given fixed distances to accessible environment boundary	Annual probability of a significant igneous intrusion within 0.5 km C-area boundary	$<10^{-5}$/yr	1.5.1	Low	Medium	8.3.1.8
			Barrier-to-flow effects of igneous intrusions on water table level	Show water table will not rise to within 100 m of repository horizon in 10,000 yr	None	Low	Low	8.3.1.8
			Thermal effects of igneous intrusions on hydraulic gradients	Gradients change less than a factor of 4	None	Low	Low	8.3.1.8
	Offset on faults juxtaposes transmissive and nontransmissive units, resulting in either the creation of a perched aquifer or a rise in the water table (or a change in hydraulic gradients)	Radionuclide transport time through SZ, given fixed distances to accessible environment boundary	Probability of total offset > 2.0 m in 10,000 yr on faults within 0.5 km of C-area	$<10^{-1}$	1.3.2.2	Low	Medium	8.3.1.8.3
			Effects of fault offsets on water-table levels	Show water table will not rise to within 100 m of repository horizon in 10,000 yr;	None	Low	Medium	8.3.1.8.3
			Effects of fault offsets on hydraulic gradients	Show gradients change less than a factor of 4				
	Extensive irrigation is conducted near C-area	Radionuclide transport time through SZ, given fixed distances to accessible environment boundary	Expected magnitude of changes in head gradients of SZ in C-area due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3

Table 8.3.5.13-16. Performance parameters for scenario class D-2 (increased head gradients or changed rock, hydrologic, or geochemical properties in the saturated zone) (page 2 of 2)

Performance measure	Initiating event or process	Intermediate performance measure	Performance parameter	Tentative parameter goal	SCP section providing expected parameter values	Current confidence	Needed confidence	SCP section
EPPM (continued)	Extensive irrigation is conducted near C-area (continued)		Expected magnitude of changes in distribution coefficients of SZ due to extensive irrigation near C-area over the next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3, 8.3.1.3.7
	Large-scale surface-water impoundments are constructed near the C-area	Radionuclide transport time through SZ, given fixed distances to accessible environment boundary	Expected magnitude of changes in head gradients of SZ in C-area due to presence of an artificial lake near C-area over the next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3
			Expected magnitude of changes in distribution coefficients of SZ units due to presence of an an artificial lake near C-area in next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3, 8.3.1.3.7
	Extensive surface or subsurface mining occurs near C-area	Radionuclide transport time through SZ, given fixed distances to accessible environment boundary	Expected magnitude of changes in gradients of water table under C-area due to extensive surface or subsurface mining near C-area in next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3
			Expected magnitude of changes in distribution coefficients of SZ units due to extensive surface or subsurface mining near C-area in next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3, 8.3.1.3.7
	Extensive ground-water withdrawal occurs near C-area	Radionuclide transport time through SZ, given fixed distances to accessible environment boundary	Expected magnitude of changes in gradients of water table under C-area due to ground-water withdrawal near C-area in next 10,000 yr	No goal (human activity)	None	Not applicable	Not applicable	8.3.1.9.3

[a]EPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution functions and significant processes and events.
[b]C-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

Table 8.3.5.13-17. Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases (page 1 of 6)

Issue 1.1 calculation using supporting parameter[a]	Supporting parameter: Description	Supporting parameter: Modifier	Lateral spatial location where needed[b]	Unit where needed[c]	SCP section providing expected parameter values	Characterization goal[d]	Current confidence[e]	Needed confidence[e]	SCP section
Specific-discharge field in UZ (Klavetter and Peters, 1986); moisture contents of UZ units; hydrodynamic response times in overburden	Saturated permeability	Rock matrix	R-area	UZ-units, Ovb	3.9.2.1	m,v,a	NA	H,M,L	8.3.1.2.2
		Fracture network	R-area	UZ-units, Ovb	3.9.2.1	m,v,a	NA	H,M,L	8.3.1.2.2
	Relative liquid permeability (wetting and draining)	Rock matrix	R-area	UZ-units, Ovb	None	m,v	NA	M,L	8.3.1.2.2
		Fracture network	R-area	UZ-units, Ovb	None	m,v	NA	L,L	8.3.1.2.2
	Effective porosity[f]	Rock matrix	R-area	UZ-units, Ovb	3.9.2.1	m,v,a	NA	H,M,L	8.3.1.2.2
		Fracture network	R-area	UZ-units, Ovb	None	m,v,a	NA	L,L,L	NA
	Moisture retention curve (wetting and draining)	Rock matrix	R-area	UZ-units, Ovb	3.9.2.1	m,v	M,M	L,L	3.9.2.1
		Fracture network	R-area	UZ-units, Ovb	None	m,v	NA	L,L	NA
	Altitudes of hydrogeologic unit contacts	As a function of lateral spatial location	C-area	UZ-units, Ovb	8.3.5.12	m,v	M,M	H,M	8.3.1.4.2, 8.3.1.4.3, 8.3.1.2.2
	Altitude of water table	Ambient, as a function of lateral spatial location	C-area	NA	3.9.1.2	m,v	M,M	H,M	8.3.1.3.1
Specific-discharge field in fault zones in UZ; moisture content in fault zones; hydrodynamic response times of fault zones	Location, width, and offset of fault zones	As a function of lateral spatial location	C-area	UZ-units, Ovb	1.3.2.2.2	m,v	L	H	8.3.1.4.2, 8.3.1.8.5
	Saturated permeability	Fault-zone rock-mass	C-area	UZ-units, Ovb	None	m,v	NA	M,L	8.3.1.2.2
	Effective porosity	Fault-zone rock-mass	C-area	UZ-units, Ovb	None	m,v	NA	L,L	8.3.1.2.2

Table 8.3.5.13-17. Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases (page 2 of 6)

Issue 1.1 calculation using supporting parameter[a]	Supporting parameter: Description	Supporting parameter: Modifier	Lateral spatial location where needed[b]	Unit where needed[c]	SCP section providing expected parameter values	Characterization goal[d]	Current confidence[e]	Needed confidence[e]	SCP section
Coupling factors and radionuclide retardation factors in UZ and SZ (Wilson and Dudley, 1987)	Bulk density	Rock matrix	C-area	All units	1.6.2.2 & Chapter 2	m,v	M,L	M,M	8.3.1.15.1, 8.3.1.2.2
	Fracture frequency	Fracture networks	C-area	All units	3.9.2.1, 1.3.2.2.2	m,v,a	L,L,L	M,L,L	8.3.1.2.2
	Fracture frequency	Fault-zone rock-mass	C-area	All units	1.3.2.2.2	m,v,a	L,L,L	M,L,L	8.3.1.4.2
	Liquid constrictivity/tortuosity factor	Rock matrix	C-area	All units	None	m,v	L,L	M,L	8.3.1.2.2, 8.3.1.3
		Fracture networks	C-area	All units	None	m,v	L,L	L,L	8.3.1.2.2, 8.3.1.3
		Fault-zone rock-mass	C-area	All units	None	m,v	L,L	L,L	8.3.1.2.2, 8.3.1.3
	Distribution coefficients (K_ds)	Rock matrix, for the following chemical species: Sr, Cs, Pu, Am, C, U, Np, Tc, Zr, I, Cm	C-area	All units	4.1.3.3, 8.3.1.3	m,v,a	M,L,L	M,M,L	8.3.1.3.4
Specific-discharge field in SZ (ISOQUAD code, Pinder, 1976); also hydrodynamic dispersion in SZ; hydrodynamic response times of SZ times of SZ	Effective thickness of saturated zone	As a function of lateral spatial location	C-area	SZ-units	3.6.4	m	L	L	8.3.1.3.3
	Hydraulic conductivity	Rock matrix	C-area	SZ-units	3.6.4, 3.9.2.2	m,v,a	M	H,L,L	8.3.1.3.3
		Fracture networks	C-area	SZ-units	3.9.2.2, 3.6.4	m,v,a	L	H,L,L	8.3.1.3.3
	Effective porosity	Rock matrix	C-area	SZ-units	3.9.2.2, 3.6.4	m,v,a	L,L,L	M,M,L	8.3.1.3.3
		Fracture networks	C-area	SZ-units	3.6.4	m,v,a	L,L,L	M,M,L	8.3.1.3.3
	Fracture compressibility	Fracture networks	C-area	All units	3.9.2.1	m	L	L	8.3.1.3.3

Table 8.3.5.13-17. Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases (page 3 of 6)

Issue 1.1 calculation using supporting parameter[a]	Supporting parameter: Description	Supporting parameter: Modifier	Lateral spatial location where needed[b]	Unit where needed[c]	SCP section providing expected parameter values	Characterization goal[d]	Current confidence[e]	Needed confidence[e]	SCP section
Model validation-coupling factors in UZ and SZ	Matrix-fracture interface permeabilities	NA	C-area	All units	4.1.3.5	Not significantly different from matrix values	L	H	8.3.1.3.6
	Matrix-fracture interface constrictivity (MF-CT factors)	NA	C-area	All units	None	Not significantly different from matrix factors	L	H	8.3.1.3.6
Gas-phase carbon-14 transport in overburden of UZ units	Relative pneumatic permeability (wetting and draining)	Rock matrix	R-area	Ovb	None	m,v	L,L	M,L	8.3.1.3.2
		Fracture network	R-area	Ovb	None	m,v	L,L	M,L	8.3.1.3.2
	Effective pneumatic porosity	Rock matrix	R-area	Ovb	None	m,v,a	L,L,L	L,L,L	8.3.1.3.2
		Fracture network	R-area	Ovb	None	m,v,a	L,L,L	H,L,L	8.3.1.3.2
	Profile of partial pressure of CO_2	Ambient, rock mass	R-area	UZ-units, Ovb	None	No goal	L	M	8.3.1.3.2
	Profiles of bicarbonate concentration, calcium ion concentration, pH, in liquid phase	Ambient, rock mass	R-area	UZ-units, Ovb	None	No goal	L	M	8.3.1.3.1, 8.3.1.2.2
	Profile of temperature	As a function of time, including effects of heat from repository	R-area	UZ-units, Ovb	1.6.2.2.4, Chapter 6	Predict profiles where temperature change exceeds 10% of ambient (°C)	L	M	8.3.1.4.2
	Profile of near-field saturation	As a function of time, including effects of heat from repository	R-area	UZ-units, Ovb	2.7.2	Prediction consistent with temperature profile (above)	L	M	8.3.1.2.2

Table 8.3.5.13-17. Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases (page 4 of 6)

Issue 1.1 calculation using supporting parameter[a]	Supporting parameter: Description	Supporting parameter: Modifier	Lateral spatial location where needed[b]	Unit where needed[c]	SCP section providing expected parameter values	Characterization goal[d]	Current confidence[e]	Needed confidence[e]	SCP section
Model calibration and validation, gas-phase carbon-14 transport in overburden of UZ	Profile of carbon-14 concentration	Ambient, rock mass pore spaces	R-area	UZ-units, Ovb	None	TBD	L	M	8.3.1.2.2, 8.3.1.3.8
	Major-ion water chemistry (i.e. composition, Eh, pH)	Ambient, rock mass pore fluids	R-area	UZ-units, Ovb	None	TBD	L	M	8.3.1.3.1, 8.3.1.2.2
	Profiles of abundances of secondary calcite, carbon-14 in calcite	Ambient, rock mass	R-area	UZ-units, Ovb	None	TBD	L	L	8.3.1.3.2
	Profile of Darcy velocity of air flow	Ambient, rock mass pore spaces	R-area	UZ-units, Ovb	None	TBD	L	H	8.3.1.2.2
Source term - liquid and gas-phase releases from waste packages	Geometry of waste package	Diameter, length and proposed orientation with respect to vertical direction	NA	NA	6.2.3	No goal (design parameter)	NA	NA	8.3.2.2.3, 8.3.4.2.2, 8.3.4.2.3
	Radionuclide inventory at closure in waste package	Expressed as kilograms (or curies) per package for radionuclides listed in Table 8.3.5.13-7	NA	NA	7.4.3.2.1, 7.4.3.1.1	m,v	L,L	H,H	8.3.4.2.2
	Areal density of k^{th} kind of waste package in repository	As a function of lateral spatial location, and, if more than one level, altitude above mean sea level	NA	NA	None	No goal (design parameter)	NA	NA	8.3.2.2.6, 8.3.4.2.2

Table 8.3.5.13-17. Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases (page 5 of 6)

Issue 1.1 calculation using supporting parameter[a]	Supporting parameter: Description	Supporting parameter: Modifier	Lateral spatial location where needed[b]	Unit where needed[c]	SCP section providing expected parameter values	Characterization goal[d]	Current confidence[e]	Needed confidence[e]	SCP section
Source term - liquid and gas-phase releases from waste packages (continued)	Containment time of k^{th} kind of waste package i.e., time after closure at which liquids would have free access to waste form	As a function of position in repository, if necessary	R-area	Host rock	None	m,v	L,L	M,M	8.3.5.9.4
	Post-containment mass release rate from k^{th} kind of waste package	Waste form to liquid phase; expected conditions; if necessary, as a function of: time since closure, position in repository, percolation flux at repository level	R-area	Host rock	7.4.3.1.1, 7.4.3.2.1	m,v Also show mean release rates for C, Tc, and I are less than 10^{-5} of 1000-yr inventory	L,L	M,M	8.3.5.10.4
	Mass release rate of carbon-14 in a gas phase from the k^{th} kind of waste package	Waste form to a gas phase; pre- and post-containment periods; if necessary, as a function of: time since closure, position in the repository	R-area	Host rock	7.4.3.1	m,v Also show that fraction of C-14 inventory that could be released in gas phase is less than 1%	L,L	H,M	8.3.5.10.4
	Degradation rates of waste form in the k^{th} kind of waste package	Ambient conditions (i.e., natural water chemistry associated with repository host rock)	R-area	Host rock	7.4.3.1.1, 7.4.3.2.1	m,v	L,L	M,M	8.3.5.10.3

Table 8.3.5.13-17. Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases (page 6 of 6)

Issue 1.1 calculation using supporting parameter[a]	Supporting parameter		Lateral spatial location where needed[b]	Unit where needed[c]	SCP section providing expected parameter values	Characterization goal[d]	Current confidence[e]	Needed confidence[e]	SCP section
	Description	Modifier							
Source term - liquid and gas-phase releases from waste packages (continued)	Maximum concentration of chemical species associated with the i^{th} radionuclide (i.e., solubility limits)	In general, for the radionuclides listed in Table 8.3.5.13-4, ambient conditions	R-area	Host rock	None	m,v	L,L	M,M	8.3.5.10.3

[a]UZ = unsaturated or partially saturated zone; SZ = saturated zone.
[b]Notation for indicating the various areas or zones around the repository: R-area = the vertical projection of primary repository area and extensions; C-area = the controlled area, i.e., the actual area which is chosen according to the 10 CFR Part 60 definition of controlled area.
[c]Ovb = overburden; i.e., all hydrogeologic units above repository floor; UZ-units = all hydrogeologic units below repository floor but above water table; SZ-units = all hydrogeologic units below water table which are included in the effective thickness of the saturated zone.
[d]Notation for statistical descriptors: m = mean value; v = variance; a = autocorrelation length. In general, these descriptors are used for spatially varying quantities, but m and v will also be used to indicate mean and variance of a scalar random variable; the supporting parameter being described should make clear which usage is intended.
[e]L = low, M = medium, H = high, and NA = not applicable.
[f]Effective porosity, sometimes called the kinematic porosity (see pp. 24-25 of DeMarsily, 1986).

8.3.5.14 Performance Allocation Tables for Individual Protection

Issue 1.2 addresses compliance with the requirement for limiting individual doses in the accessible environment to limits established in 40 CFR 191.15. Although this regulation has been vacated by judicial action, the performance allocation in the SCP was completed on the basis of the current EPA dose limitations, and will be revised at a later date if necessary. Table 8.3.5.14-1 presents the performance allocation for Issue 1.2, with the release pathway, the primary barriers, the performance measures and their goals and confidence. Table 8.3.5.14-2 provides the corresponding performance parameters and the more detailed allocation information, with a reference to the SCP sections providing the expected parameter values and the section supplying the new parameter values.

8.3.5.14-1. Performance allocation for Issue 1.2 (individual protection)

Release scenario class	Pathway	Primary barriers	Performance measure	Tentative goal	Needed confidence
Nominal (expected)	Significant ground-water source	Unsaturated zone and saturated zone	Individual dose (whole body)	Near zero (dose much less than standards)	High
	Gaseous phase	Waste container and overburden	Individual dose (whole body)		High
			External	Near zero	High
			Internal		
			Inhalation	<5 mrem/yr	High
			Ingestion	<5 mrem/yr	High

Table 8.3.5.14-2. Performance parameters for Issue 1.2 (Individual protection) the disturbed cases

System element relied on	Function	Process or conditions	Performance measure	Performance parameter	Tentative parameter goal	Needed confidence	SCP section providing expected parameter values	Current confidence	Investigations supplying parameter
Unsaturated zone and saturated zone below the repository (ground-water transport)	Retardation of radionuclide movement in ground water	Porous-media transport through matrix and adsorptive retardation	Individual dose	Ground-water[a] travel time	>1,000 yr	High	3.9.4	Low	4.3.5.12.4
				Retardation	>1	High	4.1.2.2	Medium	8.3.1.3.4
Overburden (gaseous phase transport)	Retardation of movement of gaseous nuclides	Isotope exchange, chemical equilibrium and precipitation	Individual dose	Residence time of carbon-14 in overburden	>1,000 yr	High	None	Low	8.3.1.3.4
Waste form (gaseous phase transport)	Containment and controlled release of gaseous nuclides	Distribution of radionuclides and containment	Individual dose	Inventory of rapid release fraction of carbon-14	>1,000 Ci	High	7.4.3.1	Low	8.3.5.10.2

[a]Ground-water travel time is used as a measure of the radionuclide transport time to the boundary of the accessible environment.

8.3.5.15 Performance Allocation Tables for Ground-Water Protection

Issue 1.3 addresses compliance with the requirement for protection of special sources of ground water as required by 40 CFR 191.16. As was indicated for Issue 1.2, this regulation has been vacated by judicial action. However, the performance allocation presented in the SCP is based on the current rule. Table 8.3.5.15-1 presents the performance allocation for Issue 1.3, and indicates that the determination of the existence of a special source of ground water is one of the performance measures. After this determination, if a special source exists, then the allocation for meeting the requirements of Issue 1.3 are covered by the data and methods described in Section 28 of this document (SCP Section 8.3.5.13; Issue 1.1). The allocated values are presented in the bottom portion of Table 8.3.5.15-1.

Table 8.3.5.15-1. Performance allocation for Issue 1.3 (ground-water protection)

Performance measure	Goal	Needed confidence	Performance parameters	Goal	Modifier	Current estimate	Current confidence	Needed confidence
Existence of special source of ground water	No special source	High	Existence of aquifers within 5 km of controlled area[b]	NA[a]	Valley fill (VF) Tuff (T) Lower carbonate (LC)	Exists Exists Exists	High High High	High High High
			Aquifer vulnerability to contamination	Not vulnerable within 10,000 yr	VF, T, LC	Not vulnerable within 20,000 yr	Low	Medium
			a. Population served or b. Baseflow to sensitive ecological system	<substantial None	VF T LC VF T LC	>3,000, < 5,000 <1,000 ~500 None None Exists	High Medium Medium Medium Medium Medium	High High High High High High
			Population served	<thousands	VF T LC	>3,000, <5,000 <1,000 ~500	High Medium Medium	High High High
			Existence of reasonable alternative source	Exists	VF T LC	Does not exist Exists Does not exist	Low Medium Low	High High Medium
Waste concentration in special source aquifer within 1,000-yr after disposal	<limits of 40 CFR 191.16 for 1,000 yr	High	Concentration of specified constituents as function of time	<limits specified in 40 CFR 191.16 for 1,000 yr	VF, T, LC	Meets goal	Low	High

[a]NA = not applicable.
[b]Controlled area is the actual area chosen according to the 40 CFR 191.12 definition of controlled area.

8.4 Planned Site Characterization Activities and Test Controls

8.4.1 Introduction

This section provides a general description of planned testing, the ESF configuration, and controls for construction related to surface-based testing, ESF testing and test-to-test interference.

8.4.2 Description and location of characterization studies

This section evaluates whether construction or operation of facilities or the conduct of tests at the site is likely to adversely influence the results of site characterization activities. Sections 8.4.2.2 and 8.4.2.3 assess the likelihood of test-to-test and construction-to-test interference for the surface-based and in situ activities.

8.4.2.2 Surface-based activities

Construction and testing activities are grouped in the following sections according to whether they lie within the conceptual perimeter drift boundary (CPDB), or the conceptual boundary of the controlled area.

8.4.2.2.1 General description of location and extent of testing and construction (existing and planned)

The potential disturbance from existing and planned field activities is summarized in Tables 8.4.2-4 through 8.4.2-6. The first of these tables gives the numbers of existing and planned activities of various types that are located: 1) within the CPDB, 2) within the conceptual boundary of the controlled area but outside the CPDB, and 3) outside the controlled area. The table shows that much of the disturbance from existing and planned activities, in terms of numbers of field activities, occurs away from the immediate site area. Tables 8.4.2-5 and 8.4.2-6 give estimates for the amount of area disturbed by pre-site characterization activities and planned surface-based activities, respectively. The estimates are given in terms of acreage for different categories of surface disturbance. The total of existing and planned disturbance to the area within the CPDB is estimated to be 132 acres, or about 10 percent of the area enclosed by the CPDB.

The term "surface disturbance," as used in this section, is defined as: 1) activities requiring site preparation where vegetation, surface soils, and possibly even subsoils and bedrock are removed, or 2) activities involving disposition of significant amounts of water at the surface. Most off-road vehicular access, mapping and sampling activities, and surface geophysical surveys are not included in this definition.

Information on water use for planned surface-based testing and construction activities is needed to evaluate test interference and potential site performance impacts. The amounts and locations of planned water use for surface-based testing and construction are described in Section 8.4.2.2.3.

Table 8.4.2-4. Existing and planned surface-related and drilling-related field activities (page 1 of 3)

Activity type	Within the conceptual perimeter drift boundary (CPDB)[a]		Within the controlled area,[b] outside the CPDB		Outside the controlled area	
	Existing	Planned	Existing	Planned	Existing	Planned
Unsaturated-zone boreholes						
Shallow boring (<100 ft deep)						
Neutron access holes	37	2	36	22	3	--[c]
Fortymile Wash neutron holes	--	--	--	--	--	10
Large plot rainfall simulation holes (14 sites with 10 holes per site)	--	30	--	110	--	--
Small plot rainfall simulation holes (23 sites with 4 holes per site)	--	32	--	60	--	--
Seismic shotholes	--	--	41	--	36	21-52
Deep boring						
Unsaturated zone holes[d]	4	2	4	7	--	--
VSP/UZ prototype hole	--	--	--	1	--	--
Solitario Canyon horizontal hole	--	--	--	1	--	--
Multipurpose boreholes[e]	--	2	--	--	--	--
Systematic drilling program	--	5	--	7	--	--
Coreholes						
Geologic and exploratory coreholes	2	--	9	--	4	3
Volcanic coreholes	--	--	--	--	2	4
Surface facility coreholes	--	--	12	2	--	--
Calcite silica coreholes (5 slant holes and 1 vertical, possible)	--	--	--	6	--	--

Table 8.4.2-4. Existing and planned surface-related and drilling-related field activities (page 2 of 3)

Activity type	Within the conceptual perimeter drift boundary (CPDB)		Within the controlled area, outside the CPDB		Outside the controlled area	
	Existing	Planned	Existing	Planned	Existing	Planned
Saturated-zone and water-table boreholes						
Saturated-zone holes	2	1	6	--	2	--
Water-table holes	1	--	9	5	6	3
Southern tracer complex (depends on test results)			--	4	--	--
In situ stress (1 hole planned, the need for additional drilling depends on test results and possible use of other existing holes)					--	1-22
Trenches[f]	5	1-2	33	≤17	26	9
Pavements[g]	4	--	2	2	--	--
Roads (linear miles)						
Unimproved (23 ft wide graded; plus shoulders, drainage ditches, and berms)	6	2	37	5	38	13
Trails (single lane, ungraded)	1.5	1	21	3	8	1
Other						
Surface-based testing (proposed)						
Large plot rainfall simulation sites		3	--	11	--	--
Small plot rainfall simulation sites		8	--	15	--	--
Artificial infiltration ponding sites		17	--	33	--	--

Table 8.4.2-4. Existing and planned surface-related and drilling-related field activities (page 3 of 3)

Activity type	Within the conceptual perimeter drift boundary (CPDB)		Within the controlled area, outside the CPDB		Outside the controlled area	
	Existing	Planned	Existing	Planned	Existing	Planned
Other (continued)						
Seismic surveys	See Figures 8.3.2-1 and 8.3.2-2 and maps in the Site Atlas and Surface-based Investigations Plan for locations					

[a]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design presented in Chapter 6. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al. (1987)).

[b]Controlled area is the actual area chosen according to the 40 CFR 191.12(g) definition.

[c]-- = No existing or proposed activities of this type are located in this area.

[d]Five of the existing unsaturated zone boreholes that are less than 500 ft deep will be reentered and drilled to penetrate the water table. These holes include UE-25 UZ#4, UE-25 UZ#5, USW UZ-7, USW UZ-8, and USW UZ-13.

[e]Multipurpose boreholes MP-1 and MP-2 are described in Section 8.3.1.2.2.4.9.

[f]The number of existing trenches does not include the 31 soils investigation trenches that were excavated and reclaimed in Nye Canyon and Silver Lake. Proposed trenches include 1 or 2 trenches along the Ghost Dance fault, which traverse the repository block and controlled area, and 3 or 4 along the Bow Ridge fault and the Solitario Canyon fault that traverse the controlled area. The exact locations of these trenches have not been determined. The proposed numbers of trenches do not include possible trenching at the playas throughout the southern Great Basin (such trenching, if conducted, would be outside the controlled area boundary).

[g]All the planned pavements have not yet been sited. As many as four or more additional pavements may be sited within the CPDB.

Table 8.4.2-5. Extent of existing surface disturbance associated with pre-site-characterization testing (page 1 of 2)

Type of feature causing disturbance	Acres disturbed within conceptual perimeter drift boundary (CPDB)[a]	Acres disturbed within controlled area,[b] outside of CPDB	Acres disturbed outside the controlled area[c]	Total
Roads				
Light duty (paved, average width of disturbance 100 ft)	--[d]	50	52	102
Unimproved (average width of disturbance 50 ft)	37	224	227	488
Trails (average width of disturbance 15 ft)	3	38	15	56
Powerlines	--	8	42	50
Drill pads	21	73	24	118
Trenches	1	10	5	16
Pavements	1	<1	--	1
Seismic surveys (estimate)	2	20	13	35
Disturbance associated with drilling neutron access holes	3	3	--	6
Other disturbances (laydown areas, turnarounds, etc.)	4	44	10	58
Total	72	470	388	930

Table 8.4.2-5. Extent of existing surface disturbance associated with pre-site-characterization testing (page 2 of 2)

Footnotes

[a]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design perimeter presented in Chapter 6 of the SCP. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al., 1987).

[b]Controlled area is the actual area chosen according to the 40 CFR 191.12(g) definition.

[c]Not all impacts in this area are associated with the Yucca Mountain Project. Many of the existing roads and powerlines in the Fortymile Wash area are associated with Nevada Test Site activities. Several roads that have been constructed in the Bare Mountain, Crater Flat and Amargosa Desert areas were not constructed by the U.S. Department of Energy, nor were they constructed to support the Yucca Mountain Project.

[d]-- = No disturbance is associated with this activity category in this area.

Table 8.4.2-6. Estimates of minimal or potentially significant disturbance (as discussed in Section 8.4.2.2.2.1) associated with planned surface-based testing for site characterization (page 1 of 2)

Type of feature causing disturbance	Acres disturbed within conceptual perimeter drift boundary (CPDB)[a]	Acres disturbed within controlled area,[b] outside of CPDB	Acres disturbed outside the controlled area	Total
Roads				
Light duty (paved)	Estimate included with the exploratory studies facility (ESF)[c] category			
Unimproved (average width of disturbance 50 ft)	8	30	77	115
Trails (average width of disturbance 15 ft)	2	6	2	10
Powerlines	Estimate included with the ESF category			
Drill pads[d]	17	75	28	120
Trenches[c]	1	10	4	15
Pavements	<1	--[e]	--	<1
Seismic surveys	5	30	35	70
Disturbance associated with drilling neutron access holes	2	3	--	5
Other disturbances (laydown areas, turnarounds, etc.)[c]	5	45	10	60
ESF surface disturbances (laydown areas, turnarounds, etc.)[c]	20	25	--	45
Total	60	224	156	440

Table 8.4.2-6. Estimates of minimal or potentially significant disturbance (as discussed in Section 8.4.2.2.2.1) associated with planned surface-based testing for site characterization (page 2 of 2)

Footnotes

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[a]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design perimeter presented in Chapter 6 of the SCP. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al., 1987).

[b]Controlled area is the actual area chosen according to the 40 CFR 191.12(g) definition.

[c]Estimate based on extent of existing disturbance.

[d]Estimated using 2.5 acres maximum disturbance per drill pad, and with multiple boreholes or several such drill pads.

[e]-- = No disturbance is associated with this activity category in this area.

8.4.2.2.2 Description of locations, operations, and construction controls for surface-based activities

For implementation of the construction and testing activities required for site characterization, an integration and management control process is planned, as described in Section 8.3.1.4.1 (development of an integrated drilling program and integration of geophysical activities). Baseline control will ensure accountability for significant deviations from specifications and ensure that field changes respect any interdependence among planned activities (e.g., shared use of boreholes). Such control will also ensure that construction or testing controls are based on interference or site-performance impact considerations.

Plans for surface-based testing do not include the use of high-level radioactive materials or the introduction of radioactive artificial tracers. Radioactive sensors and sources will be used in planned testing, such as borehole geophysical logging, but are designed to be fully contained and retrievable. Any plans to use high-level radioactive materials or to introduce radioactive artificial tracers at the site will be included in SCP progress reports and will be subject to NRC review as specified by 10 CFR 60.18(e). Where applicable, state permit requirements will be met through the submittal of permit applications or requests for waivers.

8.4.2.2.2.1 Site preparation and surface-related activities

Site preparation activities include grading (i.e., access road construction), cut and fill (construction of road cuts, drill pads, and ESF support facilities), and excavation (trenches, pits, borrow areas, and pavements).

Activities involving minimal or no disturbance

Many of the data needs for site characterization require measurements at or above the ground surface without invasion of the subsurface. These include meteorological monitoring, radiometric monitoring, geodesy, seismic monitoring, evapotranspiration studies, geologic and surficial deposits mapping, and geophysical surveys (with controls as described below). The methods to be used for these measurements are standard (Section 8.3.1) and so the potential for disturbance is well understood. The following kinds of field activities will be involved:

1. Passive monitoring equipment on the surface or on towers.

2. Construction of survey monuments, small edifices, etc.

3. Geophysical use of noninvasive seismic or electrical sources.

4. Deployment of ground motion detectors or other geophysical instruments.

5. Infrequent off-road vehicular travel.

Surface-related characterization activities producing minimal or no disturbance, as summarized in Table 8.4.2-7, include surface stratigraphic studies, the Southern Great Basin Seismic Network, planned surface geophysical surveys, airborne geophysical surveys, surface stratigraphic studies, soil studies, surface sampling, and meteorological monitoring. Many of these activities are also remote

Table 8.4.2-7. Summary of planned surface-related characterization activities in the vicinity of Yucca Mountain--minimal or no disturbance is produced (page 1 of 3)

Activity category	SBIP[a] designation	SCP activity	Description
Borehole, and borehole-to surface geophysical surveys	GSB-YMATL GSB-YMG GSB-YMIPL GSB-YMLSL GSB-YMML GSB-YMPS GSB-YMRE GSB-YMSH	8.3.1.4.2.1.3	For definition of lithostratigraphic units and contacts, and the distribution of rock properties within lithostratigraphic units.
	GSBB-YM	8.3.1.4.2.2.5	Seismic tomography/vertical seismic profiling.
Surface geophysical surveys	GSE-YM	8.3.1.17.4.7.5	Evaluate surface geoelectric methods.
	GSE-YMCFJFADDV GSGI-SWYMIS GSM-SWYMIS GSS-ISSW-1 GSS-ISSW-2	8.3.1.17.4.3.1	Deep geophysical surveys in east-west transect crossing Furnace Creek fault zone, Yucca Mountain, and Walker Lane.
	GSGI-YM	8.3.1.17.4.7.2	Detailed gravity survey.
	GSM-YMAM	8.3.1.17.4.7.3	Detailed aeromagnetic survey of site area.
	GSM-YMGM	8.3.1.17.4.7.4	Detailed ground magnetic survey of specific features.

Table 8.4.2-7. Summary of planned surface-related characterization activities in the vicinity of Yucca Mountain--minimal or no disturbance is produced (page 2 of 3)

Activity category	SBIP[a] designation	SCP activity	Description
Surface geophysical surveys (continued)	GSP-S	8.3.1.4.2.1.5	Magnetic property data for stratigraphic correlations and structural interpretations.
	GSS-YMCFJF	8.3.1.17.4.7.8 and others	Evaluate shallow seismic reflection (mini-sosie) methods and if appropriate, conduct surveys of selected structures at and near Yucca Mountain.
	GSRRS-YM	8.3.1.17.4.7.6	Evaluation and possible application of methods to detect buried faults using gamma measurements.
	GBSRRS-YMM	8.3.1.17.4.7.7	Evaluation and possible application of thermal infrared methods for surface hydrologic and faulting characteristics.
	GSP-YMR	8.3.1.17.4.3.2	Evaluate Quaternary faults within 100 km of Yucca Mountain, of remote sensing and surface investigation techniques.
	GSS-SR	8.3.1.17.4.4.3	Evaluate Stagecoach Road fault system.
Engineering properties measurement	GSS-VSF	8.3.1.14.2.3.3	Measure in situ soil and rock properties; profile alluvium-bedrock contact; locate discontinuities or abnormalities; and characterize soil and rock stratigraphic units.

Table 8.4.2-7. Summary of planned surface-related characterization activities in the vicinity of Yucca Mountain--minimal or no disturbance is produced (page 3 of 3)

Activity category	SBIP[a] designation	SCP activity	Description
Structural and stratigraphic studies	Geologic mapping and soil studies	8.3.1.4.2.1.1 8.3.1.4.2.2.1 8.3.1.5.1.4.2	Geologic and surficial deposits mapping; soil sampling.
	GSB-YMCL	8.3.1.4.2.1.1	Surface and borehole stratigraphic studies of host rock and surrounding units.
Southern Great Basin Seismic Network	(b)	8.3.1.17.4.1.2	54-station short period, multicomponent telemetered network; 6 stations at Yucca Mountain.
Geodetic survey	(b)	8.3.1.17.4.10	Level lines and quadrilateral array surveyed biannually; global positioning satellite stations resurveyed periodically.
Meteorological monitoring	(b)	8.3.1.12.2.1.1	Five monitoring stations located on towers in the immediate vicinity of Yucca Mountain.

[a]SBIP = Surface-Based Investigations Plan (DOE, 1988d). (See text for further discussion of plan.)
[b]Ongoing activities; not included in Surface-Based Investigations Plan.

from Yucca Mountain, including debris-flow monitoring, erosion monitoring, surficial-deposits mapping, geomorphic mapping, portable seismic monitoring, and radiological monitoring.

Off-road travel will be required for shallow seismic-reflection studies; for shallow seismic-refraction studies; for other geophysical surveys, such as gravity surveys (Activity 8.3.1.4.2.1.2); and for geologic, geomorphic and surficial-deposits mapping and surface stratigraphic studies (Activities 8.3.1.4.2.2.1, 8.3.1.5.1.4.3, 8.3.1.6.1.1.1, 8.3.1.8.5.1.3, and 8.3.1.16.1.1.1). All these planned activities will use existing roads where possible; no new roads will be constructed for these activities. Off-road vehicular travel will be coordinated among these activities to the extent practicable. For geophysical methods that may be introduced in the future, or for which analysis is required before application, the extent of surface disturbance and the potential impacts to site performance will be evaluated before implementation. For example, the surface disturbance and potential impacts from intermediate depth (2 to 3 km) seismic reflection and refraction will be evaluated when the objectives and methods for these surveys are determined.

Activities involving potentially significant disturbance

Surface-related activities involving potentially significant surface disturbances are summarized in Table 8.4.2-8. Site performance impacts for this group are evaluated in Section 8.4.4. The group includes natural and artificial infiltration studies, trenching of faulted surface deposits, trenches or pits for soil and debris sampling, and surface fracture network ("pavement") studies. Some activities in Table 8.4.2-8 are generally remote from Yucca Mountain, specifically the regional potentiometric-level, evapotranspiration, and hydrochemistry studies; paleoclimate studies; paleoecology studies; and paleohydrology studies. The following paragraphs describe these surface-related activities involving surface disturbance, explain their locations, and discuss the associated construction controls. Roads and drill pads are also discussed, because they involve similar types of disturbances.

Roads

Two types of roads exist at or near the site, exclusive of the ESF: bladed, unimproved dirt roads, and one-lane dirt tracks or trails. Bladed roads generally are required where the amount of vehicular traffic is significant or where heavy vehicles and equipment must have access, such as many of the borehole sites. Unimproved dirt tracks or trails may be required for bulldozer and four-wheel-drive access to trenching, pavement, and infiltration study locations. To minimize the impact of roads on infiltration, each new road will be improved to the minimum extent necessary and maintained appropriately. Special measures, such as installing tile drains and culverts, may be taken to reduce alteration of surface runoff patterns. The linear extent of existing and new roads within the CPDB, within the conceptual boundary of the controlled area, and outside the controlled area are estimated in Table 8.4.2-4. Standard NTS road construction specifications and maintenance requirements have been used for existing roads; these roads have been consistently maintained since they were constructed.

In general, bladed, unimproved dirt roads are surveyed before construction. Where the road is cut into a slope, the removed material is cast off to create soft shoulders. Such roads are constructed so that minimal maintenance is necessary; this requires that water be prevented from flowing down the road surface for any significant distance. Accordingly, these roads are usually not crowned or super-elevated (banked); semicircles of 12 in. pipe or speed-bumps may be installed in the road to divert water to the side, and culverts are installed where the road crosses a drainage. Depending on

Table 8.4.2-8. Summary of planned surface-related characterization activities that could produce potentially significant disturbance in the vicinity of Yucca Mountain (page 1 of 4)

Activity category	SBIP[a] designation	SCP activity	Description
Streamflow/runoff and precipitation monitoring	P1 through P4 S1 through S24	8.3.1.2.1.2.1	Monitor precipitation and runoff to determine runoff component of hydrologic cycle for unsaturated zone investigations.
Natural infiltration studies; data collection	Neutron access holes	8.3.1.2.2.1.2	Neutron moisture logging in unsaturated zone. Geophysical logging of 74 existing and 25 additional planned holes.
Natural infiltration studies; new drilling	N11 N15 through N17 N16 N27 N31 through N39 N46 N53 N53a N54 N57 through N59 N61 through N64	8.3.1.2.2.1.2	Neutron moisture logging in unsaturated zone. (24) shallow holes up to approximately 100 ft deep.
Artificial infiltration studies, new drilling	LPRS 1A, ..., 1J . . . 14A, ..., 14J . . .	8.3.1.2.2.1.3	Large-plot and small-plot rainfall simulation rainfall simulation experiments. (10) shallow holes at each 14 locations. (4) shallow holes at each of 23 locations.

Table 8.4.2-8. Summary of planned surface-related characterization activities that could produce potentially significant disturbance in the vicinity of Yucca Mountain (page 2 of 4)

Activity category	SBIP[a] designation	SCP activity	Description
Artificial infiltration studies, new drilling (continued)	SPRS 1A, ..., 1D . . . 23A, ..., 23D		
Artificial infiltration studies; construction and testing	LPRS 1A, ..., 1J . . 14A, ..., 14J	8.3.1.2.2.1.3	Large-plot and small-plot rainfall simulation experiments; ponding and rainfall simulation experiments; see text.
	SPRS 1A, ..., 1J . . . 23A, ..., 23D		
Natural infiltration monitoring; saturated zone recharge studies	FMN #1 through FMN #10	8.3.1.2.1.3.3	Monitor infiltration into Fortymile Wash using geophysical logs. Shallow holes, located near the conceptual boundary of the controlled area.[b]
Faulting studies	Mid Valley 2a through 2d	8.3.1.17.4.2.1 8.3.1.17.4.2.2	Locate, excavate, and map one or more trenches at the conceptual location of the repository surface facilities. Located >1 km from conceptual perimeter drift boundary.[c]
	Paleohydrology	8.3.1.5.2.1.5	Investigate origin of calcite and opaline silica deposits.

Table 8.4.2-8. Summary of planned surface-related characterization activities that could produce potentially significant disturbance in the vicinity of Yucca Mountain (page 3 of 4)

Activity category	SBIP[a] designation	SCP activity	Description
Faulting studies (continued)	Stagecoach Road 1 & 2	8.3.1.17.4.4.3	Evaluate magnitude and nature of Quaternary movement on Stagecoach Road fault system. Located near conceptual boundary of controlled area.
	Yucca Mountain 1 & 2	8.3.1.17.4.6.2	Evaluate magnitude and nature of Quaternary fault movement in vicinity of Bow Ridge.
	Yucca Mountain 3 through 8	8.3.1.17.4.6.2	Evaluate magnitude and nature of Quaternary fault movement in vicinity of Busted Butte.
Vein deposits investigation	Trench 14	8.3.1.5.2.1.5	Deepen existing trench(s); investigate origin of calcite and opaline silica deposits.
Surface fracture network studies	Pavement studies	8.3.1.4.2.2.2	Clean unconsolidated material from outcrop surfaces for mapping. Outside conceptual perimeter drift boundary and close to controlled area boundary.
		8.3.1.5.2.1.3	Mapping, sampling, and geophysical activities throughout Amargosa Valley -- Death Valley ground-water system.
Terrestrial paleoecology studies		8.3.1.5.1.3	Sampling and analysis of pollen and midden materials from throughout the Yucca Mountain region.
Analog recharge studies		8.3.1.5.2.1.4	Soil hydrology studies at Pahute Mesa, Topopah, and other locations.

Table 8.4.2-8. Summary of planned surface-related characterization activities that could produce potentially significant disturbance in the vicinity of Yucca Mountain (page 4 of 4)

Activity category	SBIP[a] designation	SCP activity	Description
Paleoclimate study of Lake, Playa, and Marsh deposits		8.3.1.5.1.2	Sampling activities at location throughout the Great Basin.
Regional aquifer potentiometric, evapotranspiration and hydrochemistry studies		8.3.1.2.1.3 8.3.11.2.1.3	Various sampling and monitoring activities throughout the Amargosa Valley -- Death Valley ground-water system.
Regional paleoflood evaluation		8.3.1.5.2.1.1	Trenching in water courses of Yucca Mountain and vicinity.

[a]SBIP = Surface-Based Investigations Plan (DOE, 1988d).

[b]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design presented in Chapter 6 of the SCP. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al., 1987).

[c]Controlled is the actual area chosen according to the 40 CFR 191.12(g) definition.

the amount and type of use, road maintenance involves blading and filling to level ruts after a storm, and watering for dust suppression.

Water will probably be sprayed on unpaved access roads to control dust. This is the most commonly used method of dust control at construction and mining sites and is the method that has been used at Yucca Mountain and at the NTS. It is difficult to accurately estimate the water that will be used for this purpose before site characterization, or to predict future use of water for dust control, because of the varying environmental, traffic, and road conditions. On the basis of previous experience at Yucca Mountain, however, the equivalent of one water truck is expected to deliver approximately 600,000 gallons per month to the site on a seasonal basis for dust control during site characterization. This figure is based on one 5,000-gallon water truck making six trips per day between the water supply well (J-13) and the site area during a 5-day work week. A water truck averages about 10 mph while spraying; with spray time of 30 minutes, a 27-ft-wide road surface receives approximately 1.4 mm of water. When three drill rigs are active during site characterization, this water truck will cover the access roads at least twice a day, resulting in at least 2.8 mm per day of water applied to the road surface. Of the approximately 120 miles of existing and planned unpaved access roads that could be watered during site characterization, fewer than 8 miles will be located within the CPDB. Of the approximately 1,420 acres of surface area within the CPDB, about 26 acres (or less than 2 percent of the surface area) will receive this additional water.

In general, one-lane dirt tracks or trails will not be bladed. These roads will be constructed where necessary for access to construction or intermittent data collection. For the infiltration studies, including natural infiltration monitoring, rainfall simulation, and ponding studies, the shortest distance to a road or trail that is passable to semitrailer transport must not exceed 200 ft. For the infiltration studies, roads and trails will be located to approach the experiments but maintain a reasonable distance to avoid interfering with the measured processes.

Drill pads

Deep drilling will require construction of level, compacted dirt drill pads, which will include area for parking and equipment storage. For boreholes drilled in the controlled area with fluid, a lined pit will be constructed on the pad for discharge of any recovered drilling fluid and cuttings. Boreholes drilled outside the controlled area may be lined, as conditions warrant. Present plans for additional boreholes are summarized in Table 8.4.2-4. In some cases, such as planned boreholes USW UZ-2 and USW UZ-3, more than one deep borehole will be drilled at a single site, thus reducing the extent of necessary surface preparation. Pad size will be minimized to the extent practicable; the actual size will be determined on a location-specific basis, and will depend on the method of drilling, type of drill rig, etc. Because each pad will be level and compacted, moderate precipitation will result in puddling, and subsequent evaporation and possible runoff. The effects of this type of surface disturbance on planned testing are discussed in Section 8.4.2.2.3. Fluid components of drilling fluid residue will be allowed to evaporate from the discharge pits. Pits will be backfilled, compacted, and reclaimed after drilling is complete. Materials such as bentonite and polymer or detergent residues will thus be buried in lined pits at the drill site where they are used. Special procedures will be developed to dispose of other types of residue, if other types of drilling fluids are used.

Trenches

Trenching activities are needed for tectonic studies of faults and fault zones (Studies 8.3.1.17.4.3 and 8.3.1.17.4.4) and for paleohydrology studies (Activities 8.3.1.5.2.1.1 and 8.3.1.5.2.1.5). Trenches and test pits will be excavated by bulldozers or articulated shovels. The material removed during excavation will be stored at the surface next to each trench and will be controlled in such a way as to minimize channeling of runoff from the surrounding area into the trench. Trenches that are oriented approximately parallel to slope gradient will be constructed where practicable, so that water in the trench can drain back to grade at the lower end to reduce puddling. Existing trenches within the CPDB were excavated on slopes parallel to gradient, including those excavated to study the Ghost Dance, Abandoned Wash imbricate, and Solitario Canyon fault zones. Planned trenches will be similarly situated and constructed where practicable. After completion of studies in the trenches, they will be refilled and compacted using the originally removed material.

Approximately 26 new trenches are planned for tectonic studies in the Yucca Mountain region, at features including the Bare Mountain fault zone (Activity 8.3.1.17.4.3.4), the Mine Mountain fault system (Activity 8.3.1.17.4.4.2), the Stagecoach Road fault zone (Activity 8.3.1.17.4.4.3), the Cane Spring fault system (Activity 8.3.1.17.4.4.4), the Paintbrush Canyon fault (Activity 8.3.1.17.4.6.2), the Bow Ridge fault (Activity 8.3.1.17.4.6.2), the Windy Wash fault zone (Activity 8.3.1.17.4.6.2), the Ghost Dance fault (Activity 8.3.1.17.4.6.2), the Solitario Canyon fault (Activity 8.3.1.17.4.6.2), and the proposed location of the repository surface facilities in Midway Valley (Study 8.3.1.17.4.2). Trench depths will range from 10 to 20 ft, widths will be 10 to 16 ft, and lengths will be up to 1,000 ft. Planned trenches within the CPDB or immediate vicinity will be approximately 100 ft or less in length; the longest trenches will be in Midway Valley, about one mile east of the CPDB. Trenches longer than about 100 ft may be excavated as a series of 100- to 200-ft long trenches that are parallel but offset in both the transverse and longitudinal directions to facilitate excavation.

For the calcite-silica studies, Trench 14 will be deepened and widened for half its length and one new trench will be excavated 10 ft deep, 13 ft wide, and about 66 ft long. Of the planned trenches, one or two will be located within the CPDB, 16 or 17 within the controlled area, and 9 outside the controlled area boundary (Table 8.4.2-4). Field reconnaissance will be necessary to determine the exact locations of proposed trenches. Several soil pits up to 5 ft deep and requiring mechanized digging equipment are planned in conjunction with surface mapping (Activities 8.3.1.4.2.2.1 and 8.3.1.5.1.2.2); these will be refilled immediately after use.

Pavements

In this context, the term "pavement" refers to a bedrock surface that has little or no regolith covering; pavements are uneven natural surfaces and are commonly located on slopes. Pavement studies involve mapping and measurement of fracture patterns in bedrock. The objective of these studies is to provide fracture information for evaluating the geomechanical response of stratigraphic units at the site and for hydrologic modeling, as described in Activity 8.3.1.4.2.2.2. Planned pavement studies will be undertaken only where bedrock is relatively close to the surface. In some instances, clearing of thin layers of surficial material may be required to expose a sufficient amount of bedrock (up to 800 m^2 of cleared area is needed per pavement, depending on the geologic aspects of each pavement location). Where necessary, bedrock will be cleared by spraying water under moderate pressure on the surface. Water for this purpose will be hauled to the site by truck. Displaced surface material will collect adjacent to the cleared area. Water is expected to puddle on the uneven bedrock surface, run into fractures, and possibly run off into nearby drainages. Currently, four pavements exist within the CPDB and two pavements within the controlled area. A comparable number of additional pavements in similar locations is planned.

Seismic shotholes

Boreholes have been drilled to depths of 15 to 60 m (50 to 200 ft) for use as shotholes in previous seismic surveys. A north-south linear array of 20 boreholes was drilled north of the site area for a reflection survey (McGovern, 1983), and an east-west line of 21 boreholes was drilled east of the site area for seismic refraction (Sutton, 1985; F&S, 1987a). In addition, some boreholes (approximately 36) were drilled regionally for refraction experiments. For seismic reflection, the boreholes were used to place small charges (e.g., 10 lb of dynamite), whereas for the refraction experiments larger charges (up to 4,000 lb of ammonium nitrate) were used. In each instance, measures were taken before shooting, such as stemming to the surface with gravel to minimize surface disturbance.

Plans for seismic exploration in Section 8.3.1.17 are categorized according to the depth of the objective horizons: shallow, intermediate, or deep. Shotholes are not planned for shallow seismic surveys. The methods to be used for intermediate and deep work are contingent on feasibility studies conducted away from the site area (Activities 8.3.1.17.4.3.1 and 8.3.1.17.4.7.1), and on a decision to proceed (Section 8.4.2.1.4). If seismic surveys across the immediate site area are proposed that involve the use of shothole explosive sources, then the associated impacts to other tests or to site performance will be considered in the decision to proceed. At present, no shotholes have been drilled or used within the CPDB, nor are any planned.

Natural infiltration studies

The main purpose of the shallow infiltration studies is to define the upper flux-boundary conditions for Yucca Mountain during both present and simulated wetter-climatic conditions. Knowledge of flux-boundary conditions is necessary to model flow through the thick unsaturated zone beneath Yucca Mountain. Field studies will be confined mainly to the upper 30 ft of surficial rock and alluvium. However, some activities may extend to 100 ft in the deepest of the neutron-access boreholes.

The neutron-access boreholes (for use of neutron moisture probes and crosshole gamma probes) are a principal aspect of infiltration studies at the site. Currently, 74 neutron-access boreholes exist in the vicinity of Yucca Mountain, in which moisture logging has been conducted since July 1984. The boreholes were drilled dry and cased using the ODEX system with air circulation. For this application, the ODEX 115 system (nominal 15-cm borehole diameter) was mounted on an all-terrain, rubber-tired carrier system to minimize the nature and extent of surface disturbance. An air hose connected the drilling apparatus to a compressor located up to 200 ft away, where there was road or trail access suitable for delivery of drill and compressor. The boreholes were drilled and cased simultaneously, and at the conclusion of drilling a small amount of cementitious grout was applied around the casing at the ground surface to inhibit infiltration through the annulus. In addition, an operable steel closure was welded to the top of the casing, which remains closed except during periodic logging operations. The boreholes constructed in this manner will continue to be monitored during site characterization (Activity 8.3.1.2.2.1.2).

An additional 24 neutron-access boreholes are planned using this same method. Using existing roads will eliminate the need to construct additional improved roads within the CPDB or immediate vicinity for Activity 8.3.1.2.2.1.2. The proposed locations for the new boreholes are approximate. As construction proceeds, the need will arise for some one-lane trails to provide access for construction, testing, and periodic data collection. In general, these access routes will not be bladed and will approach the infiltration experiment locations so as not to interfere with the measured processes.

Initially, neutron-access boreholes were located with respect to two broad hydrogeologic-surficial classifications: alluvium-colluvium in canyon bottoms, and upland bedrock typically covered by a thin layer of unconsolidated material. The first 46 boreholes were drilled at distributed locations that sampled both of these classifications. Evaluation of collected data indicated that different stratigraphic units in upland bedrock locations exhibit different infiltration characteristics. The properties probably are related to fracture densities in the various units, so the hydrogeologic-surficial units in upland areas were redefined according to the geologic subunits defined by Scott and Bonk (1984). Since then, these criteria have been used to site an additional 28 neutron-access boreholes. Planned drillholes will be sited in different topographic settings within each hydrogeologic unit. These various locations will be used to examine the effects of soil thickness on infiltration within different units. Of the neutron-access boreholes drilled in lower canyons with alluvial-colluvial deposits, some were along traverses perpendicular to the canyon axis to examine the effects on infiltration of the thickness of the deposits, proximity to the canyon walls, and proximity to the center of the most recently formed channels. Other boreholes were sited along traverses parallel to the main canyon axis to study the effects of increased drainage area.

A secondary use of the neutron-access boreholes is in the artificial-infiltration studies (Activity 8.3.1.2.2.1.3). Neutron moisture logging will be used with other monitoring techniques for ponding experiments. These experiments will also be conducted in the various hydrogeologic units and topographic settings to estimate hydraulic conductivity as a function of water content.

Artificial infiltration experiments

A series of four different types of infiltration experiments is proposed in Activity 8.3.1.2.2.1.3: double-ring infiltrometer measurements, ponding studies, small-plot rainfall simulation studies, and large-plot rainfall simulation studies. These studies are successively more complex and involve increasing amounts of water. The double-ring infiltrometry studies will be used in the vicinity of existing neutron-access boreholes in various surficial geologic settings to characterize infiltration rates at a small scale within approximately the upper foot of surficial material. Drilling is not required, and insignificant amounts of water are involved.

Ponding studies will be conducted at the sites of existing neutron-access boreholes, which will be used to monitor moisture influx during the tests. A low berm will be constructed of impervious material around a preexisting borehole or pair of holes, enclosing about 100 ft^2. A dye tracer will be mixed with the ponded water to indicate pathways, and the water will be tagged with an appropriate chemical tracer. The total water use will not be more than about 20,000 gallons per location, and may be less, depending on the rate of wetting front advancement. The rock mass beneath some highly fractured locations may be excavated to a depth of as much as 25 ft following ponding, and flow pathways will be mapped from tracer indications. As many as six such deep openings will be constructed using mining methods. Shallower excavations will be constructed at the other ponding locations, using surface excavation methods similar to trenching. At the conclusion of mapping and related studies at each location, the excavation will immediately be backfilled and compacted.

The small plot rainfall simulation studies will measure unsaturated hydraulic conductivity and other flow parameters in approximately the upper one meter. The plots will be about 10 ft^2, and will be instrumented to detect and sample moisture, measure moisture potential, and measure surface runoff. At each small-plot site, an array of approximately four shallow (5-ft) monitoring boreholes will be drilled dry and instrumented. A water distribution system similar to irrigation systems will be used to simulate discrete rainfall events. Plans call for several tests at each site, with each test to involve up to a few hundred gallons of water. Specific parameters for these tests have not been determined, and may also be varied during the field program. The water used will contain a dye tracer for infiltration detection and monitoring, and will be tagged with an appropriate chemical tracer. A control plot will be located adjacent to each small plot rainfall simulation test plot in an equivalent hydrogeologic setting. Control plots will be similarly instrumented but will receive only natural rainfall.

After completion of the small plot rainfall simulation studies, more complex large plot rainfall simulation studies will be conducted at several locations that represent the range of surficial conditions affecting infiltration. At each site, an array of deeper monitoring boreholes (10 to 50 ft deep) will be drilled dry and instrumented. Surface instrumentation will also be used to monitor water distribution, evapotranspiration, and runoff. Water will be distributed over an area of about 100 to 300 ft^2; several tests will be conducted at each location, each involving a few thousand gallons of water. After the subsurface region is sufficiently wet, the subsurface drainage of the region will be monitored.

8.4.2.2.2.2 Drilling-related activities

Unsaturated-zone boreholes, the multipurpose borehole activity, and the systematic drilling program

The unsaturated-zone drilling program (Activity 8.3.1.2.2.3.2, site vertical boreholes study), the multipurpose-borehole testing activity (Activity 8.3.1.2.2.4.9), and the systematic drilling program (Activity 8.3.1.4.3.1.1) involve similar drilling methods, sampling requirements, and technical objectives. Each of these activities will provide detailed information on hydrologic properties, moisture content, and moisture potential in the unsaturated zone. Drilling and coring will be performed dry to minimize contamination of samples, and (in support of monitoring applications associated with the unsaturated zone holes and the proposed multipurpose borehole (MPBH) activity) to reduce disturbance to the in situ hydrologic conditions.

Samples and information collected by the site vertical boreholes study and the systematic drilling program will be of sufficient distribution and quality for characterization of the vertical variability of matrix saturation and unsaturated matrix flow properties at each borehole location. In this respect, the three activities are basically equivalent. After drilling, the site vertical boreholes and the MPBHs will be tested and the site vertical boreholes will be instrumented, whereas the boreholes of the systematic drilling program will be shut in and maintained for possible future use.

Integration of vertical boreholes with the repository layout will be undertaken using an approach based on sealing concepts. Each borehole will be located, to the extent practicable given the preliminary nature of the repository design, in an unexcavated pillar in the underground facility with a minimum separation from the nearest drift opening or waste container. Separation ensures that once a seal is installed, it responds to environmental changes in the rock mass (e.g., temperature and stress changes) but is undisturbed by the associated effects of nearby openings (e.g., stress concentration). This integration strategy relies on the design flexibility called for by 10 CFR 60.133(b) and would be sensitive to concerns of 10 CFR 60.134(a) and (b), while providing the planning and coordination stipulated in 10 CFR 60.15(c)(4).

Site vertical borehole studies (Activity 8.3.1.2.2.3.2)

The drilling program under this activity involves dry drilling and coring of 17 vertical boreholes, within and in the immediate vicinity of the CPDB. At present, seven of these boreholes have been at least partially drilled. This includes a series of relatively shallow unsaturated zone boreholes designed to penetrate only to the top of the TS welded unit, and several deeper boreholes that penetrate the repository horizon and most of the unsaturated portion of the CH nonwelded unit. The shallow boreholes were drilled dry using the ODEX 115 system with continuous wireline coring to depths up to 430 ft (F&S, 1987b). Plans call for deepening of UE-25 UZ#4, UE-25 UZ#5, USW UZ-7, USW UZ-8, and USW UZ-13 to the WT.

The balance of the unsaturated-zone program consists of 10 boreholes drilled to just above the WT. Two of these boreholes (USW UZ-1 and USW UZ-6) have already been drilled dry using a reverse vacuum rotary method (Whitfield, 1985). The depth of penetration attained with the reverse vacuum method exceeded that possible with the ODEX method used for shallow borehole drilling and coring in the unsaturated zone. A third borehole (USW UZ-6s) has also been drilled dry near USW UZ-6 to a depth of about 519 ft using the ODEX 165 system (nominal 8.5-in. borehole diameter; F&S, 1987b). Neither the reverse vacuum method nor the ODEX 165 method provided core samples. Accordingly, the particular drilling method that will be used for the planned UZ boreholes has not yet been determined.

At least two candidate drilling schemes have been considered for planned dry drilling to the WT, with continuous sampling suitable for hydrologic data needs: 1) dual-tube reverse circulation rotary or down-the-hole hammer technology, and 2) a telescoping ODEX concept similar to the shallow UZ program, with provision for stepdown tool sizes to attain required depth penetration. The selection of the drilling method for the unsaturated-zone boreholes, the MPBHs, and the systematic drilling program will be based on prototype testing.

The oil content of circulation air will be limited to the extent practicable by filtration, unless a down-the-hole motor or hammer is used (i.e., ODEX drilling), in which case oil will be required for tool lubrication in amounts consistent with standard drilling practices. If such drilling methods are used, bench-scale testing will be performed to evaluate the effects of oil on matrix hydrologic properties. Similarly, the drying effects of circulating air on matrix-property measurements and in situ hydrologic conditions are currently under investigation in the wet vs. dry prototype test in G-tunnel on the NTS.

Each of the unsaturated-zone boreholes will be pneumatically tested using straddle packers (Activity 8.3.1.2.2.3.2). Where boreholes are closely spaced, crosshole testing will be performed. A gaseous tracer will be added to injected air. The specific intervals to be tested, test durations, and other parameters have not yet been determined. At the conclusion of pneumatic testing at each location or complex of boreholes, instrument packages will be installed in each of the unsaturated-zone boreholes. These long-term installations will be used for monitoring, similar to the instrumentation of USW UZ-1 (Montazer et al., 1985).

After the conclusion of monitoring at some future time yet TBD, water-injection testing is planned. The sampling apparatus and stemming configuration from monitoring will be used for injecting moderate quantities of water. These tests are tentative and have, therefore, not been included in the test interference discussion of Section 8.4.2.2.3. The potential test interference and site performance impacts of this type of water injection will be evaluated before its implementation, on the basis of information acquired from the preceding parts of the study.

The primary objective of the unsaturated-zone drilling program is to characterize natural conditions of moisture percolation and gaseous circulation. Models will be developed, verified and calibrated from the data collected. The rationales for siting the individual boreholes are based on the need to examine the effects of faulting, topographic relief, and surface drainage on hydrologic conditions at depth. The two clustered sets of boreholes (USW holes UZ-6, UZ-2, and UZ-3; and UE-25 holes UZ#9, UZ#9a, and UZ#9b) will support multihole pneumatic flow testing for vertical and lateral flow properties, in different surface hydrologic and structural settings. The USW UZ#9 complex will also support gas tracer diffusion studies. Boreholes USW UZ-11 and USW UZ-12 will be drilled on either side of the Solitario Canyon fault, and USW UZ-7 and USW UZ-8 will straddle the Ghost Dance fault, to investigate flux on either side of each fault. Boreholes UE-25 UZ#4 and UE-25 UZ#5 are located in the relatively deeply alluvial-filled Pagany Wash. USW UZ-14 will be near existing borehole USW UZ-1, for investigation of the apparent perching of drilling fluid from borehole USW G-1. USW UZ-13 will sample conditions south of the CPDB.

Multipurpose borehole activity (Activity 8.3.1.2.2.4.9)

The proposed MPBH activity would involve drilling a vertical borehole near the location of each shaft of the ESF to collect baseline data, which would allow the evaluation of interference of ESF shaft and drift construction with testing and the detection and characterization of possible perched water. Possible interference effects include: 1) alteration of natural hydrochemistry from dilution of other interaction with artificially introduced fluid, 2) deposition of such fluid in fractures, and 3) deposition of such fluid in the rock matrix. The proposed MPBH activity would also detect and characterize possible perched water, characterize in situ hydrologic conditions, and obtain samples for analysis before constructing the shafts. If perched water is intersected by either shaft, various practical problems (e.g., the geometry of exposure and contamination from fluid use in shaft construction) could prevent adequate characterization of the aquifer. The proposed MPBH activity would be designed to minimize this potential problem by detecting and characterizing perched water before shaft construction. If results warrant, a third MPBH would be drilled intermediate between the two shafts.

Tracer analysis is a component of the strategy to ensure the representativeness of samples obtained from the ESF for matrix hydrologic properties, hydrochemistry, and other investigations. The proposed MPBH activity would provide an important comparative basis for evaluating the quality of these samples.

Each of the proposed MPBH activity boreholes would be drilled to the maximum depth of the respective shaft. The specific location of each hole would be determined to meet the requirement for long-term surface access for monitoring, the requirement to locate the boreholes at least two drift diameters away from any underground openings, and the requirement to not penetrate the mechanical zone of influence expected to occur around each shaft. Dry drilling and coring are necessary. The drilling method for this application has not been selected; the selection would be based on feasibility testing conducted in conjunction with the unsaturated-zone drilling program. At the conclusion of drilling, a surface casing would be cemented in place, and geophysical logging and pneumatic packer testing will commence. Short-term logging and packer testing would be repeated throughout the process of ESF surface facilities construction, shaft construction, and testing in the shafts. Long-term monitoring would monitor the behavior of the rock mass between the MPBH and the shaft. The boreholes would be uncased throughout the monitoring period; the surface casing would be capped when testing is not in progress to inhibit moisture efflux. The option of instrumenting the boreholes would be maintained.

Systematic drilling program (Activity 8.3.1.4.3.1.1)

The systematic drilling program consists of drilling twelve boreholes within the CPDB or in its immediate vicinity, to collect samples and data on lithostratigraphy, basic physical properties, fracture characteristics, mineralogy, in situ moisture conditions, and other characteristics. This information will address various information needs, particularly for the model for unsaturated-zone flow and transport. The systematic drilling program is also an important source of samples for geomechanical, geochemical, and geophysical studies. Seven of these boreholes are distributed across the site area, and in conjunction with other planned drilling will provide areal coverage of the site with about 3,000-ft spacing between boreholes. The other five boreholes of the systematic drilling program are clustered immediately to the southeast of the CPDB to provide information on small-scale lateral variability of matrix hydrologic properties and other parameters. Each borehole will be drilled to approximately 200 ft below the WT. Nonwelded and partially welded intervals will be continuously cored, and welded intervals will be continuously cored if feasible; otherwise, they will be spot cored on a regular basis. The boreholes will be drilled dry to reduce disturbance to the hydrologic and hydrochemical properties of the samples acquired. The drilling method has not been determined, and the selection will be based on results from the feasibility testing described above.

The locations of the drillholes in the systematic drilling program will be determined using several criteria: 1) integration with the conceptual repository design; 2) areal coverage of the CPDB; 3) accommodation of basic geostatistical principles; and 4) integration with other boreholes, both existing and planned, that can provide additional supporting data for modeling spatial variability of rock characteristics. The planned systematic drilling is based on statistical principles, and will thereby provide a basis for evaluating representativeness of samples and data (Sections 8.4.2.1.5.3 and 8.3.1.4.3.1.1).

Solitario canyon horizontal borehole study (Activity 8.3.1.2.2.3.3). This borehole will be drilled laterally into the TS welded unit, at the Solitario Canyon scarp where the upper part of this unit is exposed at the site (Activity 8.3.1.2.2.3.3). The location of this borehole has been tentatively identified as about 2,000 ft north-northwest of the CPDB. The borehole will be drilled dry to provide representative information on in situ moisture conditions. The length of the borehole will be sufficient to penetrate the zone of fracturing or alteration associated with the fault; this could require a borehole up to 1,000 ft long. Important uncertainties pertaining to this planned borehole are: 1) the engineering feasibility of drilling, testing, and stemming a long horizontal hole through relatively highly fractured conditions, and 2) the method of plugging a horizontal borehole, should this be required. These questions will be evaluated before drilling of the borehole.

Geologic coreholes. A series of three coreholes is planned for Activity 8.3.1.4.2.1.1, to investigate subsurface structure and stratigraphy north and south of the site area. Each corehole will be drilled using standard wireline coring methods to 5,000-ft depth. The drilling method for these coreholes will be similar to that used for existing boreholes USW G-1, USW G-2, and USW G-3 (F&S, 1987c), in which the principal circulation medium was water with additives (bentonite mud and other materials were occasionally used for circulation control). As indicated in Section 8.4.2.2.1, the proposed geologic coreholes USW G-5, USW G-6, and UE-25 G#7 are located outside the conceptual boundary of the controlled area, and outside the possible expansion areas proposed in the Yucca Mountain environmental assessment (Figure 3-8; DOE, 1986b). New roads are required for access to the proposed locations; the existing road network will be used to the extent practicable, and new road construction will be away from the CPDB and mostly outside the controlled area.

The planned geologic coreholes will allow interpolation of lithologic characteristics between the repository area, where more densely spaced boreholes may be drilled (e.g., systematic drilling program), and the controlled area boundary. The objectives of these coreholes will be to better explain inferred geologic and geophysical anomalies and to characterize large-scale lithologic variability in the Paintbrush Tuff, tuffaceous beds of CH, and Crater Flat Tuff.

Corehole USW G-5 will be sited along the northeastern flank of Yucca Mountain to determine if abrupt changes in lithologies of underlying units or changes in structural style within Yucca Wash are factors that influence the steeper gradient in the potentiometric surface north of drillhole USW G-1. The planned location of USW G-6 is on the northwest flank of Yucca Mountain, in the vicinity of Windy Wash and is expected to provide representative stratigraphic data for this area and allow correlation of thickness of key stratigraphic units across the site area. USW G-7 will be sited about 5 km southeast of Busted Butte in the southern part of Yucca Mountain, within the area where the Paintbrush Tuff thins and appears to onlap an inferred high in the pre-eruptive topography. This corehole will be used to determine the nature of this feature and its effect on ground-water travel times and potential flow paths in southern Yucca Mountain for saturated-zone flow modeling.

Saturated-zone exploration, sampling, and testing

Eight boreholes are planned specifically for exploration and sampling of the saturated-zone in the vicinity of the site, in addition to the 16 such boreholes that already exist (Activity 8.3.1.2.3.1.2). Also, a new borehole (USW H-7) is planned just within the CPDB to address multiple objectives. A program of sampling will be conducted in the water-table boreholes (existing and proposed), and a series of pumping tests will be performed in USW H-7 and in other boreholes in the site vicinity (USW H-6 and USW WT-8).

Water-table boreholes

The locations of the eight WT boreholes planned for Activity 8.3.1.2.3.1.2 are presented in Section 8.4.2.2.1. Two of these boreholes, USW WT-21 and USW WT-22, will be drilled in connection with the regional potentiometric-level evaluation discussed below. The other six (USW WT-8, USW WT-9, USW WT-23, USW WT-24, UE-25 WT#19, and UE-25 WT#20) will be added to the site potentiometric-level network. Presently, 25 geologic, hydrologic, and water-table drillholes are part of the monitoring network near the site. The objectives of this drilling program are to provide data needed to refine understanding of the configuration of the potentiometric surface, analyze the character and magnitude of water-level fluctuations to determine their causes, and measure water-level variations with time. In addition, the boreholes will be used to sample the upper part of the saturated-zone and to sample gases immediately above the WT.

Water-table drillholes USW WT-8 and USW WT-9 will be located near the Solitario Canyon fault to characterize the hydrologic effects of that structural feature (Activity 8.3.1.2.3.1.1). Drillholes USW WT-23 and USW WT-24 will be sited to the north near Drill Hole Wash to obtain needed data on the steep gradient in this area. Drillhole WT-23 will be sited in Drill Hole Wash, northwest of drillhole USW UZ-1, and borehole WT-24 will be sited between drillholes USW G-2 and UE-25 WT#18. Drillholes UE-25 WT#19 and UE-25 WT#20 will augment the potentiometric-level monitoring network south and east of the repository site. Borehole WT#19 will be sited 3 km east of water well J-13 and borehole WT#20 will be sited 5 km southwest of well J-13.

The Solitario Canyon boreholes USW WT-8 and USW WT-9 will be drilled dry, using a method similar to that used for the systematic drilling program and based on feasibility testing performed for the unsaturated-zone drilling program described earlier. The other WT boreholes are farther from the CPDB and will be drilled using a simple rotary method with conventional circulation and air foam. The depth of each borehole will be 100 to 200 ft below the static water level (1,300 to 2,000 ft below ground level). The boreholes will be uncased except for a cemented surface casing with an operable closure, and they will have a string of small-diameter tubing hung from the surface to the WT for water-level monitoring. Fluid use was not monitored during the construction of the 16 existing WT boreholes; however, borehole history information (F&S, 1986) and supporting drillers' logs may be used to infer that about 100,000 gallons of water-soap mixture was typically lost to the unsaturated zone in each borehole. This value was estimated from the recorded number of barrels of detergent used, assuming that the water-to-soap ratio was 150 to 1, and 50 percent of the injected fluid was lost to the unsaturated zone. Similar fluid loss is expected to occur in the proposed WT boreholes, except in those that will be drilled dry.

Water-table borehole sampling

Since most of the WT boreholes will be drilled with air foam circulation, the hydrochemistry of the intercepted ground water probably will be disturbed during drilling. Special methods will therefore be used to obtain representative water samples (Activity 8.3.1.2.3.2.2). Present plans call for removing the tubing string from each WT borehole, placing a small pump on a tubing string of adequate cleanliness, and pumping for an indeterminate time period. The original tubing string will then be rehung and water-level monitoring resumed. The pump output will be continuous at approximately 15 gpm and will be maintained for up to several weeks, or until the water composition stabilizes and there are other indications that the composition represents uncontaminated ground water. The effluent water will be removed from the vicinity of the site in tank trucks, except for locations where natural drainage tends to divert discharge from the site and from unsaturated-zone hydrologic studies, including USW WT-1, USW WT-7, USW WT-10, USW WT-22, UE-25 WT#12, UE-25 WT#17, UE-25 WT#19, and UE-25 WT#20. Water that is discharged to natural drainages will be tagged with a chemical tracer.

Saturated-zone hydrologic borehole USW H-7

A 3,000-ft vertical borehole will be drilled in Solitario Canyon to obtain potentiometric-level information and to test the hydrologic properties of the Solitario Canyon fault zone in conjunction with existing borehole USW H-6 (Activity 8.3.1.2.3.1.1). This borehole will be drilled about 3,000 ft east of USW H-6, using dry drilling methods at least through the unsaturated-zone. For flow testing, a pump with lift capacity of approximately 500 gpm will be installed successively in USW H-7 and existing USW H-6. Each borehole will thus serve as a pumping and observation well in a multi-well testing scheme. A temporary pipeline will be constructed to conduct discharge water away from the site and away from sensitive hydrologic studies. The tentative route of the pipeline will be down Solitario Canyon to Crater Flat. Water discharged from the pipeline will have been tagged with a chemical tracer.

Other saturated zone testing

A series of single-well and multiple-well pumping tests will be conducted in the existing C-hole complex (UE-25c#1, UE-25c#2, and UE-25c#3). This is an existing set of 3,000-ft boreholes drilled using the rotary air foam method, in a location more than 5,000 ft southeast of the CPDB. This location was selected as representative of saturated-zone pathways from the repository to the accessible environment.

About 20 pumping tests are planned, using various pumping wells, pumping intervals, observation intervals, and tracer injection schemes (Activities 8.3.1.2.3.1.5 and 8.3.1.2.3.1.7). The single-well pumping tests will involve installing a submersible pump in an isolated interval, pumping from that interval at 50 to 200 gpm for about 3 days, and recording the pressure history in selected intervals during and after pumping. A 30-day pumping test is also planned, which will involve pumping one of the C-holes at 100 to 400 gpm and monitoring the pressure decline in the other nearby boreholes.

Water produced during these tests will be discharged through a short pipeline into the natural drainage system that flows northward for about 2 km through Midway Valley, and around the northern end of Fran Ridge into Fortymile Wash. No planned or existing hydrologic studies are located in this portion of Midway Valley, and the resulting infiltration is expected to occur west of Fran Ridge and not affect the planned recharge studies in Fortymile Wash.

Multiple-well recirculation tests are also planned at the C-hole complex. These tests will involve pumping from a selected interval in one well and injecting into another interval in a different well. Circulation will be maintained at approximately 100 to 300 gpm for several days until quasisteady state conditions are established. Conservative chemical tracers will be mixed with the injected water.

In addition to the pumping tests described above, about three drift-pumpback tests are planned in the C-hole complex. A conservative or reactive tracer solution will be placed in a test interval and allowed to drift into the formation, then be pumped out. The pumping rate for these tests will be approximately 50 to 150 gallons per minute. Pumping will continue for several days, or until the tracer material is substantially recovered. One objective of the overall tracer testing program in the C-hole complex is to determine if the variation of saturated-zone hydrologic properties across the site can be investigated through the use of single-well tests in existing boreholes. Depending on the outcome, additional single-well tracer testing may be performed in WT boreholes across the site area. If the results of single-well testing lead to the conclusion that the objectives cannot be met by such a test, a second multi-well complex for saturated-zone testing may be constructed (southern tracer complex), possibly near Busted Butte or immediately westward.

Regional potentiometric-level drillholes

A general reconnaissance will be conducted to locate previously unknown or unobserved wells, springs, and mine shafts that are not associated with the YMP and that may yield information about regional ground-water levels. Also, a commercial mining company in the Amargosa Desert has allowed the YMP to install piezometers in their boreholes for water-level data collection. In addition to these non-YMP activities, two YMP drillholes, USW WT-21 and USW WT-22, will be drilled in Crater Flat. These boreholes will be drilled to depths necessary to penetrate the WT. The objective of the regional potentiometric-level activities is to obtain data on potentiometric-levels within the regional flow system in order to reliably estimate ground-water flow directions and hydraulic gradients.

Other boreholes

In addition to those just described, several other boreholes are planned. These holes are generally remote from the site but are described here for completeness. A series of five or more shallow holes (approximately 200 ft deep) will be drilled in the vicinity of Exile Hill, just east of the site, to explore subsurface expression of the Trench 14 vein deposits. Two shallow exploratory holes (RF-series boreholes) are planned for Midway Valley east of Exile Hill for further testing of the proposed location for the repository surface facilities. Three or more boreholes to the WT and several shallow neutron-access holes are planned for recharge studies in Fortymile Wash, a few miles east of the site (FM-series boreholes). A series of four holes to about 1,000 ft depth are planned in Crater Flat to investigate the buried volcanic deposits that are the cause of aeromagnetic anomalies (V-series boreholes). One or two additional holes in the Yucca Mountain region are planned to measure in situ stress by hydraulic fracturing; the number and locations of these boreholes is yet TBD.

8.4.2.2.3 Intentionally Omitted

8.4.2.2.2.3 Intentionally Omitted

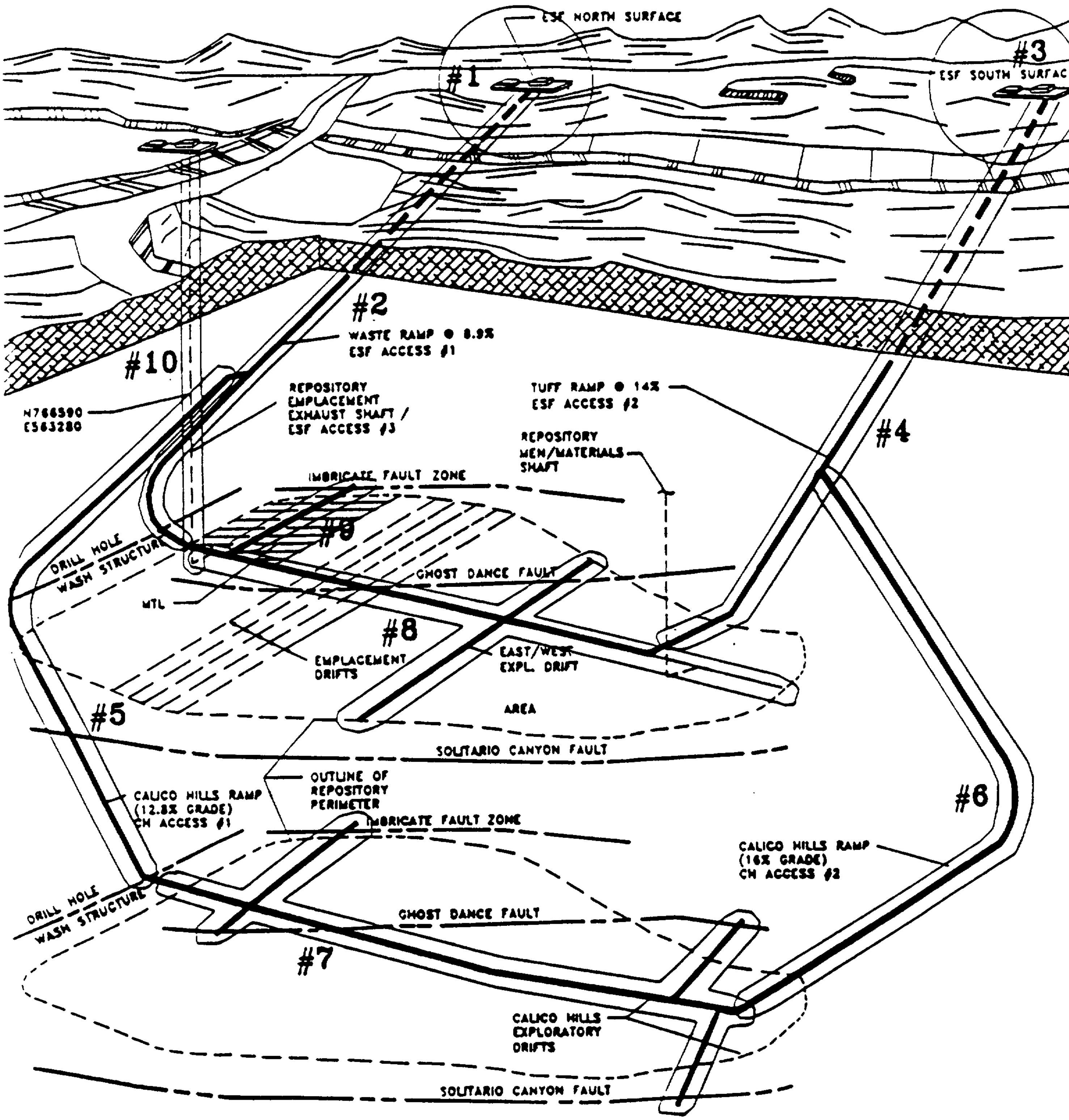
8.4.2.3 Subsurface-based activities

The subsurface-based activities that are part of the site characterization program at Yucca Mountain consist of both the testing to be performed in the ESF and the associated construction and operations activities necessary to support the testing. This section briefly describes the planned testing, the supporting facility design, operations, and construction activities, as well as evaluates the layout for the operations that assess potential interference between activities.

The ESF is illustrated conceptually in Figure 8.4.2-3. The ESF consists of surface facilities and underground excavations. The surface facilities include such items as shops, a warehouse, offices and laboratories, an electrical substation, integrated data system (IDS) acquisition facility, waste water treatment systems, and a muck-storage area. The underground excavations consist of two ramps (one in the north, one in the south) constructed to the TS level, where the potential repository horizon would be located. These ramps would be connected by a drift, and would also include some lateral drifting. The MTL core area would also be located at the TS level for both site characterization and performance confirmation testing. The north and south ramps will contain two turnouts for two ramps leading down to the CH unit, which would also be connected by a drift, including lateral drifts. An optional shaft in the north, from the surface to the TS level, is also planned.

As shown in Figure 8.4.2-3, the ESF design, construction, and testing will be conducted in phases, to allow information from early testing to influence construction and testing of ongoing/following phases. The overall strategy for ESF development is to get access to the CH level as soon as possible, in order to obtain the information needed on the characteristics of this primary barrier. The design priorities and sequence which will be followed during the preparation of the design packages for construction and testing (shown in Figure 8.4.2-3), are as follows:

1. Site Preparation and Portal of North Ramp
2. North Ramp from Portal to TS Level
3. Site Preparation and Portal of South Ramp
4. South Ramp from Portal to TS Level
5. North Ramp from CH Turnout to CH Level
6. South Ramp from CH Turnout to CH Level
7. Full Length Drift at the CH Level



NOTE: THIS IS PICTORIAL ONLY AND NOT DRAWN TO SCALE

NOTE: DESIGN, CONSTRUCTION, AND TESTING PHASES SHOWN --- #2

Figure 8.4.2-3. Reference design concept for commencing study

8. Full Length Drift at the TS Level
9. MTL Core Area at the TS Level
10. Shaft at North End-Surface to TS Level

Each design phase corresponds with a construction/testing phase, beginning with surface preparation and portal development and proceeding through exploratory drifting and MTL development on the TS Level.

Test planning and associated test-related support of phased design elements will emphasize the flexibility to accommodate changes in construction and testing for each phase. For example, surface geologic and geophysical work will be conducted to ensure that accesses are sufficiently removed from potentially adverse structures such as faults. This flexibility recognizes that data gathered from early construction phases may indicate the necessity to expand, or modify test program elements. Development of the phased design will proceed without interruption, but will be capable of incorporating later adjustments if construction and/or testing programs require modification as a result of ongoing data evaluation.

Early design emphasis (Phases 1-4) will be on the north and south ramp accesses. Phases 1 and 3, site preparation and portal development of the north and south ramps, involve site leveling and grading to accommodate the construction and operation of the portals. These phases include the design of support buildings, facilities and utilities. Phases 2 and 4 (north and south ramps from portals to TS) involve the design, construction and testing of the north and south ramps to the TS level. Declined ramps will provide access to the TS level, including construction and test-related utilities and support. The tests currently planned in the north ramp during construction include the following:

1. MPBH (may be replaced by engineering investigation boreholes for ramp accesses)

2. Geologic Mapping

3. Short Radial Boreholes

4. Hydrochemistry

5. Mineralogy/Petrology (sampling)

6. Matrix Hydrologic Properties (sampling)

7. Chlorine-36 (sampling)

8. Hydrologic Properties of Major Faults (Bow Ridge Fault and Drill Hole Wash Structure)

9. Perched Water (if encountered).

Several tests proposed or planned in the ramp will be deferred until after construction and other prioritized ESF testing activities have been completed. These deferred ramp tests are:

1. Upper Demonstration Breakout Room (DBR)

2. Heater Experiment in TSw1

3. Overcore Stress

4. Vertical Seismic Profiling

5. Long Radial Boreholes Test (status and scope TBD for ramp accesses; depends on construction of MPBH)

6. Intact Fractures

7. Excavation Effects (status and scope TBD for ramp accesses)

8. Shaft Convergence (status and scope TBD for ramp accesses).

For the south ramp (Phase 4), the only testing proposed or planned during ramp construction are Geologic Mapping, Perched Water (if encountered), and Hydrologic Properties of Major Faults (if encountered).

Phases 5 and 6 are the extensions of the north and south ramps from the CH turnouts to the CH level. Declined ramps will be designed to provide access to the CH geologic unit, including construction utilities and support to the required tests. Tests proposed or planned during construction of Phase 5 (north ramp) include the following:

1. Geologic Mapping
2. Short Radial Boreholes
3. Hydrochemistry
4. Mineralogy/Petrology (sampling)
5. Matrix Hydrologic Properties (sampling)
6. Chlorine-36 (sampling)
7. Hydrologic Properties of Major Faults (Drill Hole Wash Structure)
8. Perched Water (if encountered)

Deferred tests proposed or planned after construction and after other prioritized ESF testing activities have been completed include:

1. Vertical Seismic Profiling

2. Long Radial Boreholes Test (status and scope TBD for ramp accesses)

3. Intact Fractures

4. Excavation Effects (status and scope TBD for ramp accesses)

For the CH ramp extension in the south (Phase 6), the only tests currently proposed or planned are Geologic Mapping, Perched Water (if encountered), and Hydrologic Properties of Major Faults (if encountered).

Drifting and testing on the CH level (Phase 7) will include a drift connecting the north and south ramps, and lateral drifts to selected areas of geologic interest. The testing program for the CH level is currently being defined. Testing will be initiated during construction, and will continue after construction is complete. Tests currently proposed or planned include:

1. Geologic Mapping
2. Hydrologic Properties of Major Faults
3. Bulk Permeability
4. Mineralogy/Petrology (sampling)
5. Matrix Hydrologic Properties (sampling)
6. Chlorine-36 (sampling)
7. Perched Water (if encountered)
8. Hydrochemistry
9. Vertical Seismic Profiling
10. Diffusion
11. Intact Fractures
12. Overcore Stress

Other testing activities being evaluated for inclusion in the CH test suite include geomechanical and geochemical tests such as plate loading and migration studies. The finalization of the CH test program is an early priority in ESF design and planning.

Phase 8 will address the full length drifting on the TS level, including drifting east and west across the block. A drift connecting the north and south ramps at the TS will be designed, including construction and operational utilities to support the required tests. Additional drifting and associated utilities and test support will provide east-west exposure, including a southern Ghost Dance Fault intercept. Tests currently proposed or planned for the TS drifting phase include:

1. Geologic Mapping
2. Bulk Permeability
3. Hydrologic Properties of Major faults
4. Perched Water (if encountered)
5. Mineralogy/Petrology (sampling)
6. Matrix Hydrologic Properties (sampling)
7. Chlorine-36 (sampling)
8. Intact Fractures
9. Plate Loading
10. Vertical Seismic Profiling
11. Ground Support Monitoring
12. Evaluation of Mining Methods
13. Equipment/Development
14. Rock Mass Strength
15. Air Quality/Ventilation
16. Monitoring Drift Stability

Phase 9 includes operational design and construction of those openings required to support the required tests at the MTL core area on the TS level. Tests currently proposed or planned for the MTL core area include:

1. Lower DBR
2. Geologic Mapping
3. Mineralogy/Petrology (sampling)
4. Sequential Drift Mining
5. Canister Scale Heater
6. Heated Block

7. Thermal Stress
8. Heated Room
9. Equipment/Development
10. Plate Loading
11. Rock Mass Strength
12. Evaluation of Mining Methods
13. Ground Support Monitoring
14. Monitoring of Drift Stability
15. Air Quality/Ventilation
16. Engineered Barrier
17. Seals
18. Overcore Stress
19. Matrix Hydrologic Properties (sampling)
20. Percolation
21. Bulk Permeability
22. Perched Water (if encountered)
23. Diffusion
24. Chlorine-36 (sampling)

The ESF design will include an optional shaft (Phase 10) which would be constructed in the north, extending from the surface to the TS level near the MTL core area. The shaft would expose the geologic strata overlying the TS level. The shaft will be located at the potential repository emplacement exhaust shaft, but will be constructed only if required for collection of test information to augment characterization data obtained from the ramps.

In the next section, each of the 34 ESF test activities, including possible testing in the MPBH, is briefly described, as are the layout-related constraints imposed on the ESF design, construction, or operations. The estimated zones of influence that must be accounted for in locating and conducting the tests are also described. The ESF layout and operations is evaluated in Section 8.4.2.3.6 relative to (1) the potential for interference between tests, (2) the potential for construction and operations interference with testing, (3) the integration of the ESF and the repository designs, (4) the design flexibility, and (5) the impact of safety concerns on the design and planned operations.

8.4.2.3.1 Exploratory Studies Facility testing operations, layout constraints, and zones of influence

Each of the presently planned ESF testing studies or activities is briefly described in the following sections from an operational and design perspective. These operational descriptions are followed by a discussion of potential interferences (constraints and zones of influence) that have been considered in locating each test. The interference evaluations were used to establish minimum requirements for separating the ESF tests from each other and from other mining operations.

The extent of ESF testing could change from the tests presently identified and described in this document for several reasons. The ongoing prototype testing program, computer modeling, technical reviews, and/or improvements in instrumentation may result in future modifications to the tests. Also, the findings or performance of some of the early ESF tests, or the conditions encountered in situ will probably result in some changes to present plans. Such changes will be approved and documented as they occur through the change-control process described in Section 8.4.2.3.3.1. Significant changes in the scope of existing tests, or new tests (including constraints, zones of influence and potential waste isolation impacts), will be described in the semiannual progress reports. Plans for testing in the ESF do not include the use of high-level radioactive materials or the introduction of radioactive artificial tracers. Radioactive sensors and sources will be used in planned testing, such as borehole geophysical logging, but are designed to be fully contained and retrievable. Any plans to use high-level radioactive materials or to introduce radioactive artificial tracers at the site will be included in SCP progress reports and will be subject to NRC review as specified by 10 CFR 60.18(c).

This section also describes the constraints imposed on the design by each individual test and the potential zone of influence each test may have on the surrounding region. Test constraints are essentially requirements imposed on the ESF design that must be satisfied to ensure that the test can be fielded properly. These constraints generally arise from experimental requirements that the in situ conditions (such as stress state, degree of saturation, or temperature in the region where the experiment is to be conducted) not be significantly altered by other activities in the ESF. How test constraints and interferences influence the ESF layout are discussed further in Section 8.4.2.3.6. Flexibility in choosing the final location of some experiments can be considered an important constraint because of local variations in geology and fracture orientation. The constraints that could impact the underground layout can generally be categorized into one of three main types:

1. Sequencing constraints, which may result from a requirement that the area supporting a particular test be developed early in the ESF construction because of the extended amount of time required to run the test or because the data from the test may be required before initiating other tests.

2. Physical location constraints, which may result from requirements for flexibility to choose alternate test locations based on specific test criteria and the need to conduct some tests in isolated areas in the MTL.

3. Construction and operational constraints, which generally arise from the requirement that tests be isolated from construction or mining activities because of their sensitivity to vibration, dust, and traffic.

Table 8.4.2-13 lists the general categories of test-related constraints that could impact the underground layout. Constraints that do not impact the layout are not in Table 8.4.2-13. For example, schedule constraints associated with the geologic mapping are expected to occur routinely during ramp/shaft construction. Specific constraints and test requirements are discussed later in this section on a test-by-test basis.

Each experiment also alters or influences a surrounding region during the time the test is operational. This zone of influence becomes an important consideration in designing the MTL layout because of the requirements to separate experiments to avoid unacceptable test-to-test interference and to limit the zone of construction influence as much as possible to the dedicated testing area. The extent of the zone of influence for each test is a function of the time the test is operational and principal alteration mechanisms resulting from the test. These mechanisms include (1) mechanically altered regions due to construction of drifts and alcoves for the experiment, including additional standoffs that may be required for instrumentation emplaced in the test drifts; (2) thermally altered regions due to emplacement of heaters to simulate heat loads expected from emplaced waste or to test thermomechanical properties of the rock; (3) hydrologically altered zones due to changing the in situ saturation state; and (4) geochemically altered zones due to the introduction of chemicals or by hydrothermal activity resulting from tests that heat the rock mass. The zones of influence for each test

Table 8.4.2-13. Principal constraints imposed on the exploratory studies facility layout by test requirements, listed by general category of constraint (page 1 of 3)

Test	Sequencing	Physical location	Construction, operations	No constraints
Geologic mapping of the exploratory studies facility				X
Fracture mineralogy studies				X
Seismic tomography and vertical seismic profiling				X
Shaft convergence	X			
Demonstration breakout rooms	X	X	X	
Sequential drift mining	X	X	X	
Heater experiment in unit TSw1	X			
Canister-scale heater experiment		X	X	
Yucca Mountain heated block		X	X	
Thermal stress measurements	X	X	X	
Heated room experiment	X	X	X	
Development and demonstration of required equipment		TBD[a]	TBD	
Plate loading tests		X		

Table 8.4.2-13. Principal constraints imposed on the exploratory studies facility layout by test requirements, listed by general category of constraint (page 2 of 3)

Test	Sequencing	Physical location	Construction, operations	No constraints
Rock mass strength experiment				X
Monitoring drift stability				X
Air quality and ventilation				X
Evaluation of mining methods				X
Evaluation of ground support systems				X
Seal components testing	TBD	TBD	TBD	TBD
Overcore stress experiments		X	X	
Matrix hydrological properties testing				X
Intact-fracture test				X
Percolation tests		X	X	
Bulk permeability test		X	X	
Radial borehole tests				X
Excavation effects test				X
Perched water test				X
Hydrochemistry test				X

Table 8.4.2-13. Principal constraints imposed on the exploratory studies facility layout by test requirements, listed by general category of constraint (page 3 of 3)

Test	Sequencing	Physical location	Construction, operations	No constraints
Diffusion test		X		
Chloride and chlorine-36 measurements				X
Engineered barrier system field test (waste package test)		X	X	
Laboratory tests of geoengineering properties				X
Hydrologic properties of faults		X	X	
Multipurpose boreholes[b]	X[c]	X[c]		

[a]TBD = to be determined.
[b]Multipurpose borehole testing is described in Section 8.3.1.2.2.4.9.
[c]Constraints are based on a preliminary evaluation of multipurpose borehole concepts.

are determined from the time the test will be operational (i.e., active data collection) and the maximum extent of the principal alteration mechanism resulting from the test during the operational period.

Table 8.4.2-14 lists the principal factors (mechanism(s) considered in establishing a zone of influence for each test. Only the dominant driving mechanism(s) are given in this table even though some secondary or coupled mechanisms for altering the natural state were also considered in analyzing each test. For example, heating the rock mass also affects the local hydrological and stress conditions. Many of the tests planned for the ESF are designed to address coupled phenomena. For the purposes of establishing zones of influence for each test, however, the mechanism(s) that led to the establishment of the most pervasive zone was considered the principal mechanism, with the influence of secondary mechanisms falling within or coincident with the zones established by the principal mechanism. These principal mechanisms are given in Table 8.4.2-13. In some instances, no physical mechanism was identified that would cause additional perturbation to the natural conditions (stress, temperature, moisture, etc.) from conducting the test. In these cases the principal mechanism in Table 8.4.2-13 is listed as none. The table also lists tests, such as the proposed seal components testing, where the zone of influence is TBD. Even though concepts exist for these tests, they are not sufficiently developed at this time to establish a zone of influence. As the designs of these tests progress, interferences related to them will be analyzed and zones of influence established. These will be documented in the semiannual progress reports.

In establishing the constraints and zones of influence for each test, only test-related alterations to the local conditions were considered. That is, the alteration of the natural conditions due to normal mining and construction of ESF ramps/shaft and drifts was not considered part of the potential zone of influence of the test. Effects of construction are considered in the discussions of constraints related to standoff from support drifts that provide access to the experiment drifts. Only when special controls (over and above the strict controls already planned for use during construction) on the use of water or chemicals are required to perform a test, are they listed as additional constraints to the design.

These elements of construction and operation that have potential for interference with testing are addressed in more detail in Section 8.4.2.3.6.2. But four general points regarding these potential effects of construction on the ESF test program and their relationship to the test related zones of influence are noted here for completeness. First, there will be stringent controls on the construction methods used throughout the underground excavations. For example, water use will be part of specifications for drilling, dust control, cleaning of walls for geologic mapping, and other appropriate activities. If the standard, stringent, controls planned for use in most areas of the ESF are expected to suffice for control of water and chemical agents near a particular test, they are not mentioned specifically as a test-related constraint on the design. Only for those tests that may require additional controls are constraints noted. The effect of construction activities on the nearby rock mass has been estimated from the preliminary evaluations of West, 1988, as summarized in 8.4.3.2. In addition, construction water is estimated to penetrate, in general, less than 10 m into the formation (Section 8.4.2.3.6.2). While not specifically mentioned in Section 8.3 of the SCP, a significant number of instruments will be grouted in place. The geochemical effects of this grout are expected to be very localized (Fernandez et al., 1988). The potential zones of influence resulting from these mechanisms are within or approximately equivalent to the zone of influence of the shafts and drifts established as a result of mining induced stress alteration (Hill, 1985; Thomas, 1987; Costin and Bauer, 1988; Zimmerman et al., 1988). Therefore, a two drift diameter minimum lateral standoff was established between drifts and between the ESF and the repository drifts to preclude interference due to mining.

Table 8.4.2-14. Categories of effects considered in evaluating the zone of influence for each site characterization test (page 1 of 3)

Test	Mechanical[a]	Thermal[b]	Hydrologic[c]	Chemical[d]	No effects[e]
Geologic mapping of the exploratory studies facility					X
Fracture mineralogy studies					X
Seismic tomography and vertical seismic profiling					X
Shaft convergence	X				
Demonstration breakout rooms	X				
Sequential drift mining	X				
Heater experiment in unit TSw1		X			
Canister-scale heater experiment		X			
Yucca Mountain heated block	X	X			
stress measurements	X	X			
Heated room experiment	X	X			
Development and demonstration of required equipment					X
Plate loading tests	X				
Rock mass strength experiment	X				

Table 8.4.2-14. Categories of effects considered in evaluating the zone of influence for each site characterization test (page 2 of 3)

Test	Mechanical[a]	Thermal[b]	Hydrologic[c]	Chemical[d]	No effects[e]
Monitoring drift stability					X
Air quality and ventilation					X
Evaluation of mining methods					X
Evaluation of ground support systems					X
Seal components testing			To be determined		
Overcore stress experiments					X
Matrix hydrological properties testing					X
Intact-fracture test	X				
Percolation tests	X		X		
Bulk permeability test	X		X		
Radial borehole tests			X		
Excavation effects test					X
Perched water test					X
Hydrochemistry tests					X
Diffusion tests				X	

Table 8.4.2-14. Categories of effects considered in evaluating the zone of influence for each site characterization test (page 3 of 3)

Test title	Mechanical[a]	Thermal[b]	Hydrologic[c]	Chemical[d]	No effects[e]
Chloride and chlorine-36 measurements					X
Engineered barrier system field tests (waste package test)	X	X			
Laboratory tests of geoengineering properties					X
Hydrologic properties of faults	x		x		
Multipurpose boreholes[f]	x[g]				

[a]Mechanical effects include stress alteration due to the drifting required for the test as well as due to the test itself and potential interferences from instrumentation arrangement. The effects do not explicitly include rock damage or stress alterations due to general construction in the exploratory studies facility; these construction effects are considered in the discussions of constraints related to standoff from service drifts that provide access to the testing areas.

[b]Thermal effects include coupled effects resulting from the addition of heat; e.g., vapor movement resulting from heating

[c]Hydrologic effects include only the effects from the fluids added to the formation by the test. Fluids used in construction are not included.

[d]Chemical effects include the effects from tracers in fluids or from chemicals used in construction.

[e]No effects means no physical mechanism was identified that would cause additional perturbation to the natural condition (stress, temperature, moisture, etc.) from conducting this test. Test may be primarily observational or laboratory based with only sample collection activities in the underground excavations.

[f]Multipurpose borehole testing is described in Section 8.3.1.2.2.4.9.

[g]Zone of influence is based upon a preliminary evaluation of multipurpose borehole concepts.

Second, work is in progress to establish a basis for determining the necessary controls on water and construction methods used in the underground excavations. These studies will also help determine the effects construction water and excavation activities may have on the hydrological and chemical tests to be performed on rock samples taken during construction.

Third, as indicated in Section 8.4.1, the early testing and observations in the ESF will provide data that can be used to confirm or redefine the estimates of the zones of influence from the principal mechanisms discussed previously. Therefore, there should be sufficient data available early in the testing program and sufficient flexibility in the design layout (Section 8.4.2.3.6.4) to allow for correction of new interferences that may be identified as construction proceeds.

Finally, while every effort is being made to ensure that the test environment in the ESF is compatible with the experimental requirement, there are many uncertainties associated with underground, in situ experimentation that designers and experimenters cannot control. Unlike a laboratory setting, an underground mine environment is inherently a dirty, noisy, and potentially dangerous place to work. Rock properties and conditions are variable and, despite the most careful and complete design and analysis effort, the complete success of each and every test planned for the ESF cannot be guaranteed.

An example of the uncertainties of in situ testing is given by the experience encountered in the prototype testing conducted in G-Tunnel on the NTS. In both the heated block test (Zimmerman et al., 1986a) and the mining effects tests (Zimmerman et al., 1988), changes had to be made in the testing procedures or instrument locations based upon observations made during construction and testing.

The design is developed to provide the most favorable conditions possible for conducting the proposed testing by satisfying the test constraints and by ensuring that the zones of influence of each test and the ESF construction do not lead to significant interference problems. There are, however, many uncertainties involved with in situ testing, such as those just noted, that cannot be addressed directly in the design. Thus, a large amount of flexibility is included in the design, layout, and the operational aspects of the ESF. Including sufficient flexibility in the design (as discussed in Section 8.4.2.3.6.4), should allow many of the potential problems resulting from the uncertainties of in situ testing to be overcome.

Following are brief descriptions including a discussion of the constraints to the design that have been identified (Table 8.4.2-13) needed to properly conduct the test. Also included are the estimates of the zone of influence of each test resulting from the mechanisms identified in Table 8.4.2-14. These constraints and zones of influence form the bases for the design evaluation described in Sections 8.4.2.3.2 through 8.4.2.3.5; this evaluation is presented in Section 8.4.2.3.6.

Activity: Geologic mapping of the Exploratory Studies Facility (Section 8.3.1.4.2.2.4)

Purpose and operations

Geologic mapping and photogrammetry will be used to document lithologic and fracture variability throughout the vertical and horizontal extent of the underground excavations, to investigate structural features, and to provide siting data to confirm (or modify) planned test locations within the underground excavations. A photographic record will be obtained of exposed surfaces in the ESF ramps and of the walls and crown of drifts.

Included in this activity are cleaning the ramp or drift wall areas using minimal amounts of water (i.e., less than that used for dust control), surveying in reference points, and marking significant structural features. Geologists will map the exposed walls as described in Section 8.3 and make a permanent record of the wall rock by using twin cameras to obtain high-resolution, stereo photographs referenced to the surveyed bearings. Finally, the geologists will collect, package, and label hand specimen samples for geologic, mineralogic, petrologic, geochemical, geomechanical, or hydrochemical analyses and for archival storage.

Constraints and zones of influence

This activity is primarily observational (photogrammetric mapping) and will be conducted in the underground excavations as construction proceeds. Because it is observational, no special constraints are required to include this activity in the ESF testing, and no additional, significant perturbation to natural conditions (stress, temperature, moisture, etc.) will result from the mapping activities (that is, there is no significant zone of influence).

<u>Activity: Fracture mineralogy studies (Section 8.3.1.3.2.1.3)</u>

Purpose and operations

The fracture mineralogy studies will be conducted to determine the distribution of minerals within fractures in all stratigraphic rock masses that might provide transport pathways with some component of fracture flow. The studies will also establish the time and conditions of fracture mineralogy deposition alteration and identify fracture-coating mineral types, sorptive characteristics, and health hazard potential of fibrous zeolites.

In addition to mineralogic sampling of drill core and rubble collected at the working face in the ramps and drifts, samples will be collected on the surface from the muck removed. The muck will be segregated, either in a temporary surface storage bin or at the muck storage area, and the geologists will hand pick samples for fracture-coating mineralogy studies. The samples will be packaged and labeled for shipment to a laboratory for detailed analyses, including age determinations.

Constraints and zones of influence

<u>Stratigraphy and variability of the rock matrix</u>. This activity involves sample collection and subsequent laboratory examination of rock from the underground excavations where a variety of geologic conditions are expected to be encountered. Because only sample collection is involved, no special constraints are required to conduct this activity in the ESF, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity. No significant zone of influence results from this activity.

<u>Mineralogy of fractures and faults</u>. This activity involves sample collection and subsequent laboratory examination of rock from ramps, the dedicated test area, and the long exploratory drifts where a variety of geologic conditions are expected. Because only sample collection is involved, no special constraints are required to include this activity in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity. No significant zone of influence results from this activity.

Activity: Seismic tomography and vertical seismic profiling (Section 8.3.1.4.2.2.5)

Purpose and operations

The purpose of seismic tomography and vertical seismic profiling tests is to evaluate or develop a method for remote characterization of subsurface fracture networks using the ESF tests as a means to calibrate against mapped fracture networks.

When fracture domains are selected in the drifts as described in Section 8.3.1.4.2.2.5, short boreholes will be drilled (or existing holes used) to install geophones or similar instrumentation. When the sensor arrays are in place, seismic stimuli will be initiated by using explosives or vibrioses techniques at surface locations selected by the investigators.

Constraints and zones of influence

This activity will use surface drilled boreholes and short (≤3 m long) boreholes in the underground excavations to install seismic sensors. No special constraints are required to include this activity in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity (i.e., no significant zone of influence results from this activity).

Activity: Shaft convergence (Section 8.3.1.15.1.5.1)

The shaft convergence test is to be deferred until after construction and other prioritized ESF testing activities have been completed. The status and scope of the test is currently being addressed for ESF ramp accesses to be consistent with the reference ESF design concept. The following discussion provides information on this test as planned for the original ESF configuration (described in the SCP) with two shafts in close proximity. The test, as described below, may be conducted in the event that an optional shaft is constructed.

Purpose and operations

Shaft convergence tests will be used to monitor rock-mass deformation around the shaft opening and measure in situ horizontal stress.

Using standard overcore techniques, horizontal stress measurements will be made at each of three test locations as the shaft is being sunk.

Rock-mass deformation around the shaft will be monitored at three measurement stations consisting of two levels separated by several meters, using multiple-point borehole extensometers (MPBXs) placed at 120° intervals around the shaft circumference. The MPBXs will be installed as soon as practicable after excavation of the relevant level in the shaft. Deformations will be measured across the shaft diameter and as a function of distance from the shaft at multiple locations in the walls. The MPBX heads will not be covered by the shaft liner, so that the deformations can be monitored as a function of time. In addition to MPBX measurements, deformations will be measured with rod extensometers at each of the three measurement stations. Extensometer measurements will be made along diameters in the same plane as the MPBXs at 60° from the MPBX heads.

Hydraulic pressure cells will be installed in the shaft liner to monitor radial stress changes over time as shaft sinking continues below the test location.

Constraints and zones of influence

This experiment will be conducted during construction of the shaft. Flexibility is required in locating the tests near the three depths at which the tests are planned. Reasonably competent rock is required at the test horizon to ensure proper gage installation.

A mechanical zone of influence is created because horizontal MPBX gages will be used at each measurement station. These gages are anchored 15 m from the shaft wall. Care should be taken that any vertical boreholes from the DBRs do not pass within four hole diameters of the MPBX gauge holes to ensure that the anchors remain fixed in the rock. The zone of geochemical alteration resulting from the use of grout in the MPBX gauge holes is expected to be very small and governed by molecular diffusion. Analyses by Birgersson and Neretnicks (1982) indicate that this zone would be 0.3 ft for 3 to 12 months.

Activity: Demonstration breakout rooms (Section 8.3.1.15.1.5.2)

Purpose and operations

These tests will be used to demonstrate constructability and stability of drift openings in the upper lithophysal zone of the PTn in the upper DBR and in welded fractured tuff on the MTL.

At the DBR and in the breakout room at the MTL, mined openings will be sized to be consistent with the maximum width planned for repository drifts. Optimum blasting methods in each DBR horizon and rock stabilization requirements and techniques will be determined. Rock mass response will also be measured in the DBR excavations by using extensometers and convergence anchors.

Constraints and zones of influence

Flexibility in the orientation of the rooms is required to insure that desired alignment relative to local geological features, such as the prevailing joint structure, is achieved. This is important because one use of the data derived from this experiment will be for evaluation of structural computer models. Proper alignment of the drift is required to limit the potential for variability of the mechanical response along the drift so that models can be more effectively used to represent the excavation in computer calculations. Other constraints include a requirement that no other mining should be allowed within a distance of approximately 50 ft from the deepest MPBX anchors installed in the drift walls while the experiment is in progress. MPBX gages are anchored 50 ft into the drift walls. If other mining takes place within 50 ft of the bottom anchor (100 ft from drift wall), the MPBX anchor positions may be disturbed.

At the MTL-DBR (or lower DBR) baseline testing should be complete before proposed drifts within the required standoff region are mined. Within the constraints of adjacent drifts, a zone of flexibility is defined such that the stress altered zone due to mining will not affect other drifts that may be mined later. Depending on the orientation of the lower DBR a potential zone of influence (stress altered region) may exist, extending out on either side of the flexibility area (Costin and Bauer, 1988).

No zones of thermal or hydrological alteration will result from this test because no heat or water are used in the test. The zone of geochemical alteration resulting from the use of grout in the MPBX gage holes is expected to be very small and governed by molecular diffusion. Analyses by Birgersson and Neretnicks (1982) indicate that this zone would be 0.3 ft for 3 to 12 months.

Activity: Sequential drift mining (Section 8.3.1.15.1.5.3)

Purpose and operations

The purpose of sequential drift mining is to obtain deformation response data in rock surrounding a repository-size drift opening as it is being mined in the dedicated test area.

Two parallel instrumentation drifts will be mined and instrumentation holes will be drilled to monitor above, below, and adjacent to a central third parallel drift. Borehole sensors will be installed to monitor stress release, bulk permeability changes, and deformation. To measure rock mass response to mining, baseline data will be obtained before mining of the center parallel drift. Air and water permeability in boreholes adjacent to the new drift opening will be measured after mining.

Constraints and zones of influence

Flexibility in location and orientation of the drifts is desired because the results of this experiment will be used to evaluate structural computer models. Mining should be planned such that no mining, other than construction of the center parallel drift, will be conducted within a standoff distance of approximately two drift diameters from the edge of the instrumentation drifts while the test is in progress. This standoff distance, ensures that the construction of other drifts will not alter the deformations and stress state near the experimental drift during the testing period (Zimmerman et al., 1988). Because long-term monitoring of ground support in the sequential drift mining test is required, subsequent mining within the standoff zone must be avoided.

No thermal zone of influence will result from this activity. The small amounts of air and water that may be injected into the rock mass between the drifts for permeability testing is not expected to alter the hydrological conditions more than 1 to 2 m from the boreholes. The zone of geochemical alteration resulting from using grout in the gage holes is expected to be very small and governed by molecular diffusion. Analyses by Birgersson and Neretnicks (1982) indicate that this zone would be 0.3 ft for 3 to 12 months.

Within the area between adjacent drifts, a zone of flexibility is defined such that the stress altered zone due to mining will not affect other drifts that may be mined later. Drifts may be oriented within a 60 degree shaped fan (±30 degrees from the proposed centerline orientation) or the entire configuration may be reoriented to a direction parallel to the panel access drifts (perpendicular to the configuration shown in the Title I design layout). This results in a potential mechanical zone of influence extending 30 ft (two access drift diameters) to either side of the flexibility zone (Costin and Bauer, 1988 and Zimmerman et al., 1988). Once the drift direction is determined, the zone of influence can be narrowed; that is, additional area required by the necessary flexibility is eliminated.

Activity: Heater experiment in unit TSw1 (Section 8.3.1.15.1.6.1)

Purpose and operations

The purpose of the heater experiment is to establish thermomechanical and thermally induced hydrologic responses in high-lithophysal rock to verify scaling relationships needed for repository design and performance calculations.

In the upper DBR, a heater-emplacement hole will be drilled approximately 8 ft (2.4 m) into the drift wall. Several instrumentation holes parallel to the heater hole will be drilled and then heater and instruments (multiple point borehole extensometers (MPBX) and thermocouples) will be installed. In a borehole near the heater, neutron logs will be run before, during, and after the heating cycle to monitor moisture content changes. After the heater is started, the rock response to thermal loading, heat flow, and moisture changes will be monitored.

Constraints and zones of influence

This test will be conducted in the upper DBR and is intended to measure rock mass thermal properties, in situ water content changes due to heating and thermal expansion in the lithophysae-rich tuff. Because the test is short (approximately one month) and affects only a small amount of rock (0.3 m^3) (Zimmerman et al., 1986b), no special constraints are required. Sufficient flexibility exists to locate the test so that other activities in the DBR are not adversely affected.

<u>Activity: Canister-scale heater experiment (Section 8.3.1.15.1.6.2)</u>

Purpose and operations

The canister-scale heater experiment will monitor thermomechanical and hydrothermal responses in the repository host rock at canister scale for design and performance modeling, for the investigation of retrievability, and for the monitoring of radon emanation as a function of heat loading. During the tests, heat fluxes will be increased so that temperatures near the canister heater exceed design limits. This phase of the test is to aid in determining limits on waste-emplacement borehole stability.

At a location within the dedicated area, a 13 in. (0.37 m) diameter hole will be drilled 20 ft (6.1 m) into a drift wall. Parallel small-diameter instrumentation holes will be drilled. Baseline moisture data in neutron probe holes will be recorded. A heater and instrumentation (thermocouples, MPBXs, borehole deformation gages, and radon monitors) will be installed. Finally, heating steps will be initiated, and thermal, thermomechanical, and hydrothermal phenomena, and radon release rates, will be monitored at increasing heat loads.

Constraints and zones of influence

To limit the influence of drift openings (1) on the stresses near the heater and (2) on the temperatures produced in the rock formation, the heater should be located a minimum of 9 m (based on Bauer et al., 1988) from drifts or alcoves running parallel to the axis of the heater. The experiment needs to be located in a low traffic area because the rock surface near the heater emplacement hole will reach temperatures in excess of 200°C and may pose a hazard to personnel in the area.

At 30 months, the 100°C isotherm will be approximately 5 m radially from the center of the canister (Bauer et al., 1988). Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm. Hence, a zone of saturation may occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone extending to a maximum of 10 m beyond the 100°C isotherm (Martinez, 1988). Thus, a hydrologically altered region extending up to 14 m radially from the heater may be created. Because of the small volume of rock dehydrated, the hydrologically altered zone is likely to be less than the estimated 14 m maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). The 35°C isotherm (4°C above expected ambient temperature) will attain a maximum distance of 15 m radially from the heater and 20 m from the emplacement drift wall along the axis of the heater (Bauer et al., 1988), resulting in a thermal zone of influence of approximately 30 m by 20 m. Therefore, both the zones of potential chemical and hydrological alteration are expected to be contained within the zone of thermal alteration. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stress should not be more than 10 percent above the initial in situ stress (Bauer et al., 1988).

Activity: Yucca Mountain heated block (Section 8.3.1.15.1.6.3)

Purpose and operations

The Yucca Mountain heated block experiment will (1) measure three-dimensional deformation and temperature changes; (2) measure relationships among fracture permeability, stress, and temperature; (3) monitor moisture movement relative to temperature; and (4) evaluate cross-hole measurement methods in large blocks of welded tuff. Results from 1, 2, and 3 will be used in modeling.

At a selected location in the dedicated test area, an alcove will be mined and a 6 ft by 6 ft (2 m by 2 m) area of rock will be defined within the alcove. Baseline fracture permeabilities will be measured, reference survey pins will be established, and crosshole ultrasonic measurements will be made. Next, slots will be cut on each side of the block approximately 6 ft (2 m) deep and flatjacks will be inserted. An array of heaters will be installed in holes on opposite sides of the block. Other instrumentation holes will be drilled and instrumented with thermocouples, MPBXs, and deformation gages. Finally, cyclic tests will be conducted at various mechanical loads (imposed using flatjacks) and thermal loads (imposed using heaters). The rock responses and permeability changes under induced conditions will be monitored.

Constraints and zones of influence

Flexibility in location of the test alcove is required to ensure that the block used contains a joint spacing and orientation that is reasonably representative of the repository horizon. The experiment should be located in a low traffic area so that dust and vibrations from other construction and testing do not interfere with sensitive displacement measurements being made as the block is loaded (Zimmerman et al., 1986a).

The thermal zone (within 5°C isotherm above ambient temperature) resulting from two thermal cycles lasting a total of 100 days is calculated to extend to approximately 32.5 ft (10 m) from the center of the block (Costin and Chen, 1988). Thus, the thermal zone will extend approximately 20 ft (6 m) beyond the test alcove in a direction normal to the lines of heaters. Within the thermal zone, the 100°C isotherm will attain a maximum distance of approximately 3 ft (1 m) radially from the centerline of the heaters. Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm. Hence, a zone of saturation may occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone extending up to a maximum of approximately 33 ft (10 m) beyond the 100°C isotherm (Martinez, 1988). Thus, a hydrologically altered region that may extend to a maximum of approximately 36 ft (11 m) from the lines of the heaters is created. Because of the small volume of rock dehydrated, the hydrologically altered zone is likely to be less than the estimated 11 m maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Therefore, the zones of potential chemical and hydrological alteration are approximately coincident to the zone of thermal alteration. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses should not be more than 10 percent above the initial in situ stress.

Construction of the small alcove will produce a stress-altered zone of approximately one alcove diameter, 27 ft (8.2 m) around the experiment.

Activity: Thermal stress measurements (Section 8.3.1.15.1.6.4)

Purpose and operations

These tests will measure thermal stresses in a relatively large volume of jointed rock and relate the stress changes to thermomechanical displacement for numerical modeling. The specific number and location of these experiments has not yet been defined. At each experiment location, single slots will be cut in both the back (roof) and rib (wall) 6 ft (2 m) long and 6 ft (2 m) deep after reference pins are established on either side. Flatjacks will be installed in the slots, and heaters will be installed in the holes drilled on either side of the slots. An insulating blanket will be installed over the test area of the drift to reduce heat loss. Heaters will be started and stress changes in the near-field volume will be monitored as thermal loading increases.

Constraints and zones of influence

Flexibility with regard to rock conditions and the orientation of joints is one of the constraints in selecting the specific region of rock where the test is conducted. This test cannot begin until any other measurements in the test area are completed. Because one objective of the test is to measure stress changes induced in the rock mass by thermal loading, no mining should be conducted within a two drift diameter standoff region until the test is completed, because this could affect stress measurements in the test drift. The test should be conducted in a drift that can be isolated from normal mine traffic because of the high temperatures and stresses that will be generated in the roof of the drift.

At 90 days, for the test being conducted in the roof, the +5°C isotherm (above the expected ambient temperature) will be approximately 5 m horizontally from the drift wall and approximately 7 m vertically from the roof. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses should not be more than 10 percent above the initial in situ stress (Bauer et al., 1988). Within the 5°C isotherm, it is predicted that the 100°C isotherm will be approximately 1 m radially from the centerline of the heaters (approximately 3 m horizontally from the drift centerline). Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm. Hence a zone of saturation is likely to occur in this region. The water contained in this region is anticipated to be imbibed into the matrix in a zone that may extend to approximately 10 m beyond the 100°C isotherm (Martinez, 1988). Because of the small volume of rock dehydrated, the hydrologically altered region is likely to be less than the 10 m estimated maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Stress alteration due to mining extends two drift diameters (50 ft) laterally, which is greater than any alteration expected due to the local heat load (Bauer et al., 1988).

Activity: Heated room experiment (Section 8.3.1.15.1.6.5)

Purpose and operations

The heated room experiment is in the early stages of design definition and is intended to measure thermomechanical responses in fractured welded tuff at a drift-size scale to acquire data for evaluating both pre- and postclosure design. Measurements will also be used to support the validation phase of both empirical and numerical design methods.

In the dedicated test area at a location TBD, a drift representative of repository-size drifts is planned to be excavated and the rock around it heated. Either a preexisting drift will be used, or more likely, a new drift may be constructed in the performance confirmation area specifically for this experiment. The drift will be instrumented to provide data on rock mass deformation, rib stress change, thermal conductivity, heat capacity and thermal expansion coefficient, and ground-support loading and deformation, as well as to estimate the region in which the stress state is changed by heating. The experiment may involve more than one drift opening so that temperatures around and between drifts more nearly represent those expected in the repository.

Constraints and zones of influence

Flexibility in location and orientation of the experiment is a constraint necessary to ensure that the geologic conditions (rock quality, joint orientation, etc.) are representative of and consistent with those expected in the repository block. Because it will be approximately 2 to 3 years after heating begins before data are available, the test should begin as soon as possible. Special doors and thermal barriers may be required to control the ventilation and heat flow from the area.

Estimates of the potential zone of influence of the experiment were taken from preliminary design calculations (Bauer et al., 1988) that assumed the drifts were separated by 65 ft (20 m) center to center with the test drift being 20 ft (6.1 m) wide and the access drifts being 13 ft (4 m) wide. For a 50 kW heat load and a 3-yr test duration, the thermal zone resulting from this experiment will extend approximately 90 ft (28 m) laterally from the central drift. Although the thermal zone extends slightly above and over the access drifts, the extent of the thermal zone is effectively limited by the presence of the two access drifts. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses are predicted to be less than 10 percent above the initial in situ stress (Bauer et al., 1988). The 100°C isotherm will attain a maximum distance of approximately 7 m horizontally and 10 m vertically from the center of the line of heaters on each side of the central drift (Bauer et al., 1988). Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm boundary. Hence, a zone of saturation is likely to occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone extending a maximum of approximately 33 ft (10 m) beyond the 100° C isotherm (Martinez, 1988). The heated region, however, is bounded by the two access drifts, which are ventilated. Thus, the region of potential hydrologic alteration will likely not extend beyond the access drifts. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Therefore, both the zones of potential chemical and hydrological alteration are expected to be contained within the zone of thermal alteration. The stress-altered region resulting from the mining of the drifts will extend laterally approximately 100 ft (31 m) from the centerline of the central experiment drift (i.e., out to two drift diameters from the outside access drifts) and 20 ft (6.1 m) (one drift diameter) from the end of the central drift. Possible changes in orientation were not considered. If the experiment continues longer than 40 months, additional standoff distance may be required. The layout should provide standoff distances of 150 ft (45 m) laterally from the centerline of the central drift and 50 ft (15 m) longitudinally from the end of the central drift.

Activity 4.4.6: Development and demonstration of required equipment (Section 8.3.2.5.6)

Purpose and operations

The purpose of this activity is to drill, line, and instrument (for convergence monitoring) two waste emplacement-size holes to evaluate the horizontal boring technology and equipment performance in the TS welded unit.

A development prototype boring machine (DPBM) has been designed for demonstration in underground testing. The DPBM would be capable of drilling and installing a metal lining in long, horizontal boreholes. Tests currently under consideration in the ESF involve the drilling and lining of two 250-ft (76.2-m) long horizontal holes in the dedicated test area and/or the upper DBR. The drilling of these holes will be highly instrumented so that data on drill performance can be obtained for use in predicting drill performance in the repository. Substantial uncertainty exists about whether this test will be conducted. The uncertainty is because the DPBM will be developed only if the long, horizontal borehole concept is selected as the preferred option for waste emplacement. Ongoing engineering studies are evaluating the relative advantages of both the vertical emplacement option and numerous horizontal emplacement options. The test may also evaluate the proposed liner emplacement technique. Because of the possibility that the test may be canceled, no specific area has been set aside in the current design for this testing.

Constraints and zones of influence

The prototype boring machine has been designed to excavate long holes for waste emplacement. The process of boring will not use water. Thus, the principal constraints on the ESF design resulting from this test are the requirements to provide adequate area and utilities (electric power and compressed air) if the test is conducted. Dust and noise must also be carefully controlled. Because of the dry excavation method used in the test, no significant hydrological or geochemical alteration is expected from the excavation. The stress-altered region that will result from the excavation is estimated to be approximately two borehole diameters from the liner.

Activity: Plate loading tests (Section 8.3.1.15.1.7.1)

Purpose and operations

Plate-loading experiments will be performed at selected locations in the upper DBR, MTL DBR, and in other locations on the MTL to measure the rock-mass deformation modulus and evaluate the fracture zone adjacent to the mined openings. Rock deformations will be measured with a multipoint borehole extensometer oriented parallel to the load axis in the center of the plate area. Deformation of the loading column will be monitored with rod extensometers. Values of the rock deformation moduli will be calculated by using the rock-deformation and the applied stresses. Moduli from different stations will be compared to evaluate spatial variability within unit TSw2 (low lithophysal TS). These data primarily will be applicable to the material around an opening that has been affected by the presence of the opening and by the excavation process. As such, the moduli will represent lower bounds on the modulus of the undistributed rock mass.

Constraints and zones of influence

This test will be conducted at several locations to help evaluate values of rock-mass modulus of deformation. Because the test is short (approximately 2 weeks at each location) and stresses only a small amount of rock (approximately 1 m^3), no special constraints are specified other than ensuring that the tests are not conducted in regions altered by other testing. No permanent alteration to the local hydrological, chemical, or thermal conditions will result from this test.

Activity: Rock-mass strength experiment (Section 8.3.1.15.1.7.2)

Purpose and operations

The objective of this activity is to evaluate the mechanical behavior of the rock mass or its components. Experiments will be performed to obtain information with regards to the mechanical response of single joints and multiply jointed volumes of rock. It is envisaged that this experiment will be conducted in several areas that are representative of the range of conditions encountered in the ESF. The information will be used to evaluate potential scale effects between laboratory and in situ conditions, to provide data to evaluate empirical design criteria, and to provide data to evaluate and validate jointed-rock models.

Experiments will be conducted in several areas on the MTL chosen to be representative of the geologic conditions expected in most of the repository. The experiments will be conducted in stages. The joint shear-strength stage will be performed on samples of field-scale size, where field-scale is considered the expected in situ joint length (up to a few meters is possible). If random jointing is encountered, then the compressive strength stage of the experiment will be performed in which a volume of randomly jointed rock will be loaded to a point beyond its maximum support capacity. The final stage of this experiment will require a block of jointed rock (1 to 3 m^3) to be carefully characterized as to joint spacing, aperture, properties, etc., and then loaded to predetermined stress levels. This stage of the experiment will provide information on joint loading and closure characteristics for evaluating and validating a jointed-rock model.

Constraints and zones of influence

This test can be conducted in any drift on the MTL where suitable rock conditions exist. Thus, no special constraints exist other than ensuring that the tests are not conducted in regions that have been altered by other testing. The location of the test will be determined after the drifts in the dedicated test area are mined.

The experiment will be similar to the plate loading test in that only a small region of rock (approximately 1 to 3 m^3) will be directly loaded and the effects of the loading will likely extend only a distance of a few times the width of the area over which the load is applied. No permanent alteration to the local hydrological, chemical, or thermal conditions will result from this test. No significant zone of influence will result from the rock-mass loading imposed in this activity.

Activity: Evaluation of mining methods (Section 8.3.1.15.1.8.1)

Purpose and operations

These tests will monitor and evaluate mining methods for ramps and exploratory drifts, with emphasis on rock responses in a variety of lithologic and structural settings that may be encountered in the long exploratory drifts. This activity will be to develop recommendations for mining in the repository. Mining methods in ramps and in the long exploratory drifts will be monitored. Mining investigations will be concentrated in the widened (repository-size) portions of the long drifts.

Constraints and zones of influence

This activity is primarily observational and will be conducted in the long exploratory drifts and ramps where a variety of geologic conditions are expected. Because the activity is primarily observational, no special constraints are required to include it in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from it.

Activity: Evaluation of ground-support systems (Section 8.3.1.15.1.8.2)

Purpose and operations

The purpose of this activity is to develop recommendations for a ground-support methodology to be used in drifts in the repository, based on evaluations of the ground-support techniques used in the underground excavations, and on experimentation with other ground-support configurations. This activity will be carried out on the MTL. The selection, installation, and performance of the support systems used will be monitored. Experimentation with ground supports will include pull tests on rock bolts, observation of unsupported rock, strength measurements on shotcrete cores, and trials of alternate ground-support configurations from those prescribed for the ESF. The effects of heat on ground support will be considered in the heated room experiment.

Constraints and zones of influence

These activities will be conducted in the MTL where a variety of geologic conditions are expected. Because this activity is observational, no special constraints are required to include it in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity other than that created by excavating the opening.

Activity: Monitoring drift stability (Section 8.3.1.15.1.8.3)

Purpose and operations

The purpose of these tests is to monitor drift convergence throughout the ESF to understand potential instabilities and provide data for empirical evaluations. This activity involves monitoring drift convergences and drift maintenance activities around the MTL. Instrumentation will be concentrated in the long drifts, although convergence measurement stations may be set up anywhere in the MTL drifts. In the long drifts, convergence measurements will be taken in a continuous manner, if practical. Rock-mass relaxation will be investigated in the repository-scale portions of the long drifts using multiple-point borehole extensometers. Rock falls and maintenance activities will be documented through observations and with photographs.

Constraints and zones of influence

This activity will be conducted in the MTL where a variety of geologic conditions are expected. Because this activity is observational, no special constraints are required to include this activity in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity (i.e., no significant zone of influence).

Activity: Air quality and ventilation experiment (Section 8.3.1.15.1.8.4)

Purpose and operations

The purpose of these tests is to assess the impact of site characteristics on ventilation requirements to ensure a safe working environment. This activity consists of (1) measurements of radon emanation; (2) surveys of air-flow and pressure, temperature, and humidity; (3) determinations of air resistance factors; and (4) dust characterization. The radon emanation measurements will be made in a dead-end drift that has been sealed with a bulkhead at equilibrium conditions and at various rates of airflow. Radon concentrations might also be measured in a borehole. Activities 8.3.1.15.1.8.1 through 8.3.1.15.1.8.3 (discussed earlier) will be performed with portable instruments over periods of a few days each. They are not expected to interfere significantly with other underground activities.

Constraints and zones of influence

This experiment will measure the rate of radon emanation from the TSw2 formation and will be conducted on the MTL. Because this requires only periodic air sampling, no special constraints are required to include this activity in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity.

Activity: In situ testing of seal components (Section 8.3.3.2.3)

Purpose and operations

As described in more detail in Section 8.3.3.2.2.3, additional evaluations will be required before defining appropriate field tests for seal components. The most important needs will be the characterization of the repository environment and results of laboratory studies on seal material properties. Specifically, the occurrence or non-occurrence of water at the repository horizon will be essential to define an appropriate seal test. Much of the information will be obtained from other testing (primarily hydrologic) programs conducted in the ESF. Some laboratory testing can also aid in developing the details of a field test, for example, (1) laboratory or bench-scale testing to determine the rate of movement of fines into fractures as a function of flow volume and (2) laboratory testing to determine index properties for the emplacement of grout, earthen, or cementitious materials.

Once this and other additional information is obtained, the need for the following categories of field tests will be evaluated:

1. Verification of emplacement techniques.

2. Saturation or infiltration tests, including the effects of fines on drainage potential.

3. Seal behavior under in situ hydrogeological conditions.

The methodology for selecting needed in situ seals tests is given in Section 8.3.3.2.2.3.

Constraints and zones of influence

While particular experiments are not defined yet, the three general categories of field-test operations are expected to provide some constraints on the test location. For example, if testing is performed to verify emplacement techniques, this operation may involve a significant amount of equipment, as well as construction operations that may require physical separation from other more sensitive tests.

The mechanical zone of influence from sealing tests is likely to be within the zone created as a result of the related excavation. Initial tests would most likely be done without heating so that no thermal zone of influence is expected. Hydrologic considerations may, however, be significant. If testing of sealing systems is needed under simulated flooding scenarios, then a significant amount of water may be required. If this is required, then a hydrologic zone of influence may result. If this zone of influence were to become unacceptably large or the test were to significantly increase uncertainties relative to postclosure performance, an alternative test could possibly be conducted either in the laboratory or in an alternate field location removed from the ESF. The geochemically altered zone would depend on the types of materials tested and upon the total amount of water used in each test. When these tests are defined, test and associated constraints and performance related impacts will be described in semiannual progress reports.

Activity: Overcore stress experiments in the Exploratory Studies Facility (Section 8.3.1.15.2.1.2)

Purpose and operations

The overcore stress experiments will be performed to determine the in situ state of stress above and within the repository horizon, to determine the extent of excavation-induced stress changes, and to relate stress parameters to rock-mass heterogeneities.

After access is available, small-diameter holes will be drilled to prescribed orientations and lengths (longer than three drift diameters). A stress sensor will then be installed, and the instrumented center hole will be overcored in stages. Stress data will be taken as the instrumentation of each stage is overcored.

Constraints and zones of influence

Flexibility in location of the tests within the upper and lower DBRs is required because intact segments of core are required. Thus, the location, distribution, orientation, and apertures of fractures need to be examined before tests are conducted. No mining, testing, or construction should take place in such a way as to influence the in situ stresses at the bottom of the test holes. Test holes should not be drilled near other instrument holes. Tests will be conducted within the approximately 50-ft-long boreholes extending downward and horizontally from the end of the DBR. Small volumes (approximately 1 to 2 gal) of water may be injected in the vertical test holes for low-volume hydraulic fracture stress tests, but the quantities of fluid used will be carefully limited. Thus, this activity is not expected to result in significant hydrological, chemical, or thermal disturbance to the rock mass.

Activity: Matrix hydrologic properties testing (Section 8.3.1.2.2.3.1)

Purpose and operations

The purpose of the matrix hydrologic properties tests is to develop a comprehensive data base on matrix flux properties in the unsaturated-zone tuffs at Yucca Mountain. This activity includes collecting bulk and core samples, taken during ramp and drift construction and from core holes. The collected samples will be packaged, labeled, and sent to a laboratory for analyses as described in Section 8.3.1.2.2.3.

Constraints and zones of influence

Rock-matrix hydraulic properties of large rock samples taken from selected horizons during ESF construction will be measured. Because of the nature (sample collection) and location of the test, no special constraint beyond the planned control and tagging of construction water will be imposed on the layout or operation of the ESF, and no additional perturbation to the natural conditions will result from this activity.

Activity: Intact-fracture test in the exploratory shaft facility (Section 8.3.1.2.2.4.1)

Purpose and operations

The intact-fracture test will be used to evaluate fluid-flow and chemical transport properties and mechanisms in relatively undisturbed and variably stressed fractures to enhance understanding of physics of flow and for flow modeling.

Fracture-sampling locations will be selected at the TS and CH levels on the basis of detailed fracture maps. At about 12 locations (TBD), a small pilot hole will be drilled across a fracture, a rock bolt anchor will be installed, the pilot hole will be overcored, and the sample will be withdrawn. The sample will be packaged, labeled, and transported to an onsite field laboratory for intact-fracture analyses as described in Section 8.3.1.2.2.4.1.

Constraints and zones of influence

Flexibility in sampling location is required to locate suitable fractures. Because only sample collection will be conducted in the ESF, no other special constraints on the layout are required. No hydrological, chemical, or thermal disturbance is expected from this activity.

Activity: Percolation tests in the Exploratory Studies Facility (Section 8.3.1.2.2.4.2)

Purpose and operations

This test will be used to observe and measure fluid flow through a network of fractures under controlled in situ conditions in order to characterize and quantify important flow processes in fractured welded tuff. The percolation test design is not completely finalized. The test is planned to use a large, isolated block of rock 6 ft (2 m) on a side. The block will be instrumented to detect fluid flow under physical conditions that can be mechanically controlled and systematically varied. Tracer-tagged water will be introduced from a trickle system/sand bed on the surface of the block.

Constraints and zones of influence

Flexibility in location of the block excavation is required because of the need to have a high fracture density spacing in the block. Orientation is not considered critical. Mining disturbances should be limited so that the rock mass is not excessively damaged during excavation and preparation. Hence, the zone of hydrologic or geochemical influence will not extend beyond the isolated test block. Stress redistribution around the experiment drift will extend approximately two drift diameters from the drift boundaries.

Activity: Bulk-permeability test in the Exploratory Studies Facility (Section 8.3.1.2.2.4.3)

Purpose and operations

The purpose of the bulk-permeability test activity is to assess the fluid transport properties in relatively large volumes of minimally disturbed TS welded tuff and nonwelded CH tuff. Tests are planned at multiple locations in the MTL and at the CH level, selected on the basis of detailed fracture maps. At each location, a small-diameter hole 100 to 200 ft (30 to 60 m) deep, will be air-cored and logged. Air permeability will then be measured in packed-off intervals. If the rock is deemed suitable for the test based on the preliminary results, three additional holes subparallel (frustrum configuration) to the first, will be air-cored, logged, and instrumented.

Cross-hole air permeability (injection) tests will be conducted in the formation. Pressure, temperature, and humidity sensors will be installed in experiment boreholes. Selected holes will then be pressurized, and the air movement outward to sensors in the other holes will be monitored. The measurements will be repeated as required by using positive or negative pressures in the boreholes.

Constraints and zones of influence

Constraints relative to flexibility of location and orientation are required because fracture geometry and orientation relative to the test holes are important. Test areas must be outside the hydrologic zones of influence of other tests or mining activities. The feasibility of and possible need for nearly "dry" mining in the vicinity of this test are being investigated.

Test holes for each test will be dry-drilled deep enough (approximately 150 ft (46 m)) into the rock mass so that the cross-hole permeabilities will be measured in undisturbed rock (outside the stress-altered zone of the excavations). Gas-phase pressure pulses may occur as much as 100 ft (30 m) away from centerline of the cross-hole frustum configuration. Test holes may penetrate the rock mass to 150 ft (46 m). Thus, a zone of influence extends along the frustum out to 150 ft (46 m) longitudinally and radially to approximately 100 ft. The air injected for this test will contain a tracer to allow discrimination between the natural gas in pore spaces and the injected air. Hence, no interference caused by air injection between this test and any other test is expected. No significant mechanical, hydrological, thermal, or chemical alteration to the rock mass is expected to result from this activity, that is, there is no zone of influence.

Activity: Radial borehole tests in the Exploratory Studies Facility (Section 8.3.1.2.2.4.4)

Purpose and operations

The radial borehole tests will investigate vertical and lateral movement of gas, water, and vapor on and across hydrogeologic contacts and within the TS unit, and evaluate near-field excavation effects on hydrologic properties.

Radial boreholes will be drilled at various depths. At each depth location, two 4- to 8-in. (10.2- to 20.3-cm) diameter, 30-ft (9.1-m) long coreholes will be drilled using air as the drilling fluid. Orientation of the radial boreholes at each depth location will be determined by analyzing fracture data collected during geologic mapping of the ramps and drifts (see Activity 8.3.1.4.2.2.4 for mapping details). Core will be collected, packaged, labeled, and transported to an onsite laboratory for hydrologic analyses (fracture and matrix properties). The holes will be logged and surveyed for fracture and moisture data. Nitrogen injection tests in packed-off intervals will be conducted to obtain gas permeability data. Across stratigraphic contacts, crosshole permeability tests will be run with both gas and water. Short-term monitoring for moisture resulting from ramp mining will be done periodically when mining resumes. Long-term monitoring of matrix water potential, pressure, and temperature will also be conducted; formation gases will be sampled periodically.

Constraints and zones of influence

The radial boreholes will be drilled deep enough to be beyond the expected zone of mechanical and hydrologic influence of ramp and drift construction. The holes will be used to monitor the movement of construction water to measure the hydrologic zone of influence resulting from ramp construction. These monitoring activities require no special constraints, nor do they alter the hydrologic or geochemical state of the rock mass. However, at the stratigraphic contacts between the Tiva Canyon welded unit and the Paintbrush non-welded unit and between the Paintbrush non-welded unit and the TS welded unit, crosshole permeability tests will be run with both gas and water. The water injected under low pressure is estimated to influence a zone extending 10 m from the test location (Martinez, 1988). Further, the hydrologic zone of influence is expected to be localized in a vertical sense near the top 10 m of the TS welded unit. The calculations of Peters (1988) indicate that the vertical movement of the test water will be very slow and will not be expected to cause significant disturbance at the main ESF test level. Geochemical effects are not expected to extend beyond the zone of influence resulting from water movement. The air injected for this test will contain a tracer to allow discrimination between the natural gas in pore spaces and the injected air. Since a portion of the hydrochemistry testing is expected to be performed at the same location as the radial borehole test, the use of an air tracer will control the potential interference between these tests. No thermal or mechanical alterations to the rock mass will result from this test.

Activity: Excavation effects test in the Exploratory Studies Facility (Section 8.3.1.2.2.4.5)

The excavation effects test is to be deferred until after construction and other prioritized ESF testing activities have been completed. The status and scope of the test is currently being addressed for ESF ramp accesses to be consistent with the reference ESF design concept. The following discussion provides information on the excavation effects test as planned for the original ESF configuration with two shafts in close proximity.

Purpose and operations

The excavation effects tests will measure stress changes in the near-field wall-rock as the shaft is mined and lined, and measure air-permeability changes that result from the stress redistribution.

Tests are planned at two breakout zones. At each breakout horizon, multiple small-diameter holes will be drilled parallel or subparallel to the unexcavated shaft wall but set back selected distances from it. All holes are planned to be air drilled/cored, logged, and surveyed; some of the holes will be instrumented to monitor stress changes and some to monitor permeability changes as the shaft is advanced. Stress and permeability data will be taken in drillholes extended below the bottom of the shaft from the upper breakout zone. Long-term permeability measurements will be made and temperature and moisture data collected. Additional holes may be drilled to handle the instrumentation packages if they are determined to be necessary during prototype testing.

Constraints and zones of influence

Flexibility is the only significant constraint identified for this test. It is required for locating drill holes for tests at the two breakout horizons. The instrument holes will be drilled from the upper breakout zone at distances up to 49 ft from the shaft. They will extend as much as 100 ft below each breakout creating a zone of potential mechanical interference. No thermal, chemical, or hydrological alteration of the rock mass is expected as a result of this activity.

Activity: Perched-water test in the Exploratory Studies Facility (Section 8.3.1.2.2.4.7) (Contingency test)

Purpose and operations

The purpose of the perched-water test is to detect the occurrence, and delineate the lateral and vertical extent, of perched-water zones (if encountered) during ramp construction, drifting, and testing to identify perching mechanism(s), and to sample the water for chemical analyses. Because there is significant uncertainty regarding the likelihood of encountering perched water, the perched-water test is categorized as a "contingency test."

If perched water is encountered, one or more small-diameter hole(s) will be drilled to enhance drainage, facilitate collection of water samples, and allow flow and/or pressure measurements to be made. The hole(s) will also be instrumented and sealed during testing to obtain data on hydraulic pressure and water potential over time.

Constraints and zones of influence

This test will be conducted if perched-water zones are encountered. If perched water is encountered, small-diameter holes will be drilled into the walls for testing and sampling. Because of its nature and location, no special constraints on the layout or operation of the ESF are imposed by this experiment.

Because this activity only involves sampling and drilling of small-diameter holes only, no mechanical, chemical or thermal alteration of the rock mass is expected.

Activity: Hydrochemistry tests in the Exploratory Studies Facility (Section 8.3.1.3.3.4.8)

Purpose and operations

The hydrochemistry tests will determine the chemical composition, reactive mechanisms, and age of water and gas in pores, fractures, and perched-water zones within the unsaturated tuffs accessible from the ESF and/or affiliated core holes.

During ramp construction and drifting, large block (>6 in. (16 cm) diameter if possible) samples of rubble will be collected at selected locations, packaged, labeled, and transported to a surface laboratory for analysis of pore and fracture-fluid chemistry. Core from selected ramp, drift, and test alcove drillholes will also be collected and analyzed as described in Section 8.3.1.2.2.4.8.

Constraints and zones of influence

Bulk-rock samples taken at various depths during construction are required for this experiment. Because sample collection is the only activity taking place in the ESF related to this experiment, no special constraints on the layout or operation of the ESF are imposed by this experiment, and no additional perturbation to the natural conditions is expected to result from this activity. The methods developed during prototype testing to control both influences of construction and water use (including tracer tagging) are expected to be sufficient to ensure that the geochemical analysis conducted under this activity will not be adversely affected by construction operations. Studies are in progress to assess the effect of by-products of blasting materials and the tracer-tagged water on the type of geochemical analysis proposed for this test. One of the results of this effort will be to define the construction controls to be used in the ESF needed to successfully complete this test.

Study: Diffusion tests in the Exploratory Studies Facility (Section 8.3.1.2.2.5)

Purpose and operations

The purpose of these tests is to determine in situ diffusivity coefficients for nonsorbing ions in the TS welded tuff and the CH nonwelded tuff. At four locations to be selected on both the MTL and the CH level, small-diameter holes will be air-drilled to a vertical (or horizontal) depth of 33 ft (10 m), a suitable nonsorbing tracer will be deposited at the bottom in a packed-off zone, then the holes will be capped and left undisturbed for periods of 3 to 12 months. Finally, the test intervals will be overcored, and the core will be removed to a laboratory for analysis of tracer diffusivity.

Constraints and zones of influence

Flexibility in experiment locations is a necessary constraint. Excessively fractured rock should be avoided. The test will be conducted at the end of the approximately 33 ft (10 m) vertical or horizontal boreholes. The region around the end of the boreholes must not be affected by stress changes due to mining or other construction or by alterations in the in situ water saturation.

The mechanical zone of influence is expected to extend about 33 ft (10 m) beyond or below the alcove due to test hole drilling. The lateral extent of influence around the test holes is approximately 0.3 ft (at the end of the boreholes) which is estimated from the extent of movement of the tracer species placed in the borehole. This estimate was taken from previous field work using a similar technique (Birgersson and Neretnieks, 1982). No thermal or hydrological effects are expected from this test.

Activity: Chloride and chlorine-36 measurements of percolation at Yucca Mountain (Section 8.3.1.2.2.2.1)

Purpose and operations

These measurements will be made at various depths to determine the rate of water movement downward through the unsaturated-zone tuffs using the chlorine-36/chloride concentration ratio. As the ramps, drifts, and test areas are being excavated, large bulk samples (from up to 30 locations) will be periodically collected, packaged, and labeled for laboratory analysis as described in Section 8.3.1.2.2.2.1. Because of the requirement to extract pore water to conduct the chlorine-36 test, several hundred pounds of rubble may be needed at each sampling location.

Constraints and zones of influence

Because rock samples will be collected from rubble at several depths for laboratory analysis under this activity, no special constraints on the layout or operation of the ESF are imposed by this experiment. The methods developed to control both the influences of construction and use of water (including tracer tagging) are expected to be sufficient to ensure that the geochemical analysis conducted under this activity will not be adversely affected by construction operations. Studies are in progress to assess the effect of explosion by-products and the tracer-tagged water on the type of geochemical analysis proposed for this test. One of the results of this effort will be to define the construction controls to be used in the ESF that will allow these tests to be successfully completed.

Study: Engineered barrier system field tests (Section 8.3.4.2.4.4)

Purpose and operations

The EBS field tests will determine the in situ hydrologic transport properties in rock at the repository horizon and determine the effect on water chemistry of near-field thermal perturbation. These waste package environment tests will provide thermal, hydrologic, mechanical, and limited chemical alteration information during an abbreviated thermal cycle (of at least 1 year duration) in the very near-field emplacement environment. In test alcoves in the dedicated test area, horizontal and vertical heater emplacement holes and small-diameter parallel and perpendicular instrumentation holes will be typically drilled as shown in Figure 8.4.2-11. Heater canisters and associated instrumentation packages will be inserted to monitor thermal, moisture, and stress and strain parameters during a thermal cycle (heating and subsequent cooling) in each test. In selected tests, water will be injected during heating and cooling stages while monitoring takes place. Core from the rock mass adjacent to the heater hole will be recovered and petrologic, petrographic, mineralogic, and related laboratory analyses will be performed to identify thermally induced alterations.

Constraints and zones of influence

Isolation from mining operations and mine traffic is an essential constraint for this set of experiments. Isolation from mining is required to ensure that the stress state near the heater boreholes is not influenced by excavation of other drifts once the test has begun. Also, the experiment drifts for this area cannot tolerate significant drying of the rock mass or temperature changes from sources other than the experiment heaters. A 40 ft (12 m) standoff around the heater holes is required to allow for monitoring of condensation from the heaters. Some flexibility of orientation of the experiment drifts is desired to ensure that fracture or joint sets are not parallel to the axis of the horizontal boreholes. Recent evaluations have indicated that drift separation of approximately 75 ft may be needed to ensure isolation of the individual tests.

At 24 months, the zone of thermally disturbed rock around either vertical or horizontal heater holes is calculated to extend approximately 10 m (33 ft) radially from the heater centerline (based on the expectation of 6 months of heating at maximum power, 6 months of rampdown from the maximum power level to zero, and 12 months with no heat (Buscheck and Nitao, 1988)). Within the thermally altered zone, the 100°C isotherm will be a maximum of approximately 2 m radially from the centerline of the heater. Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm boundary. Hence, a zone of saturation may occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone that may extend to a maximum of about 10 m beyond the 100°C isotherm (Martinez, 1988). Thus, a hydrologically altered region that may extend to a maximum of 12 m from the heater is created. Because of the small volume of rock dehydrated, the hydrologically altered zone is likely to be less than the estimated 12 m maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Therefore, the zones of potential chemical and hydrological alteration are approximately coincident with the zone of thermal alteration. Thermally induced stresses are also expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses should not be more than 10 percent above the initial in situ stress (Butkovich and Yow, 1986). The stressaltered region, due to mining of the test rooms, will extend two drift diameters from the outer drifts. The thermal, chemical, and hydrologic zones of influence are anticipated to be contained well within the mechanical zone resulting from drift construction.

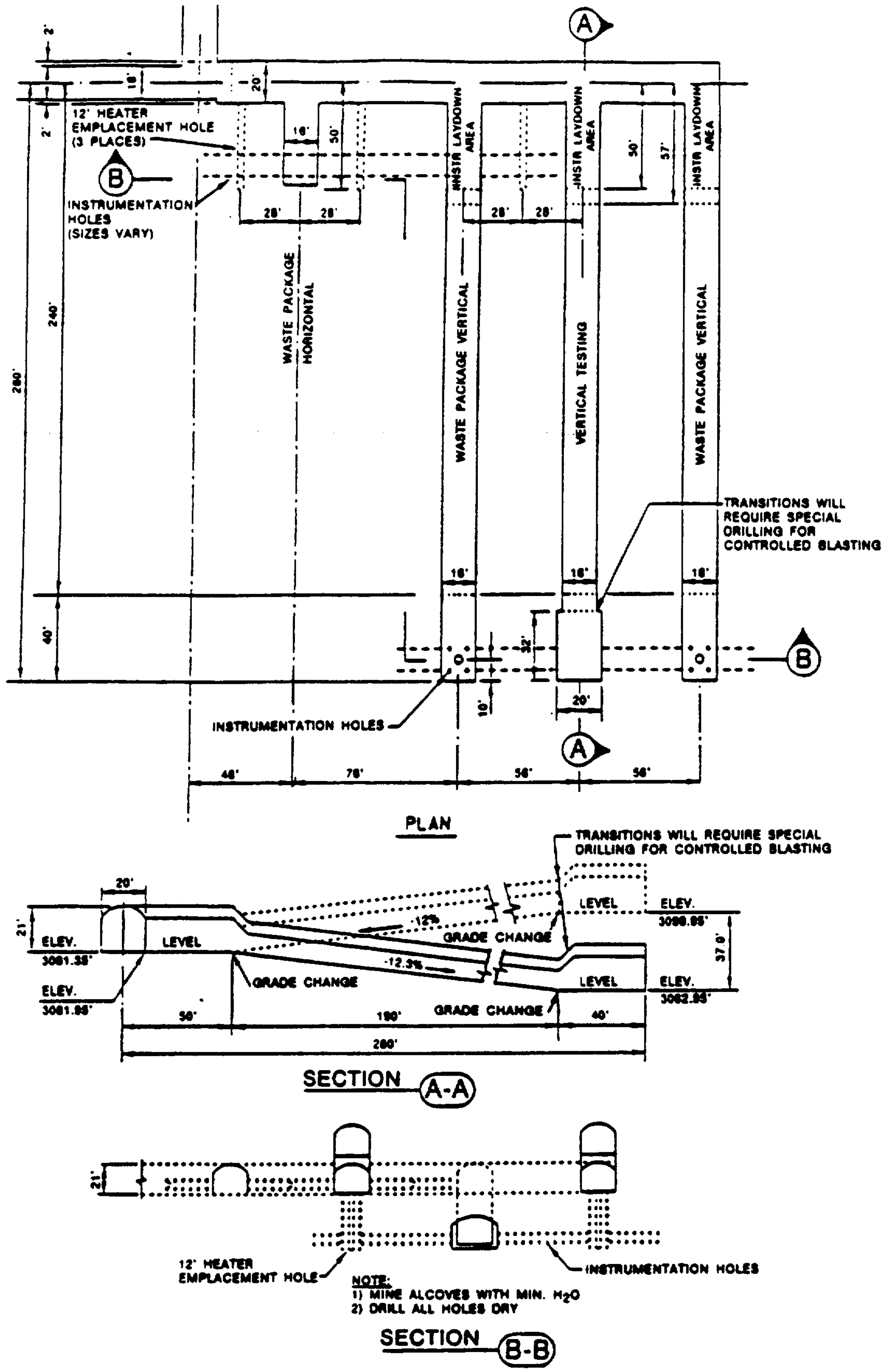


Figure 8.4.2-11. Repository horizon near-field hydrologic properties (waste package environment) typical test arrangement (from Title I 100% design).

Activity: Laboratory tests (thermal and mechanical) using samples obtained from the Exploratory Studies Facility (Activity 8.3.1.15.1)

Purpose and operations

The laboratory geoengineering properties tests will provide bulk, thermal, and mechanical properties data for evaluations of opening stability and related design and performance studies and/or modeling. Data from the laboratory tests will also support analyses of the geomechanical and thermomechanical field tests planned in the ESF. The ESF activities are basically the collection, packaging, and labeling of the selected bulk samples taken from the ramps or drifts. The laboratory test activities are described individually in Section 8.3.1.15.1.

Constraints and zones of influence

This activity involves collection of rock and core samples from the MTL for use in laboratory testing. Because only sample collection is to take place in the ESF, no special constraints are imposed by this activity, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity.

Activity: Hydrologic properties of major faults encountered in the main test level of the Exploratory Studies Facility (Activity 8.3.1.2.2.4.10)

Purpose and operations

This activity is designed to provide hydrologic information in parallel with a portion of Activity 8.3.1.4.2.2.4, geologic mapping of the ESF. All faults encountered in the access ramps and in the long exploratory drifts on the MTL will be characterized geologically under the geologic mapping activity. Hydraulic properties of the major faults encountered in the ramps and on the MTL will be determined by this activity. The major faults or fault zones expected to be tested are the Ghost Dance fault, a suspected fault in Drill Hole Wash, and the imbricate fault zone.

Based on major fault identification determined by the geologic mapping activity, a hydrologic testing program will be implemented. This program will consist primarily of tests conducted in boreholes drilled from drifts constructed through the fault zones and tests on core collected from the boreholes. All boreholes will be drilled using air to minimize changes in ambient moisture conditions. Onsite core examination will be conducted for preliminary determinations of fracture frequency, orientation, location and characteristics. This information will be used in conjunction with geophysical and television camera logs to select test intervals. In selected test intervals, air permeability tests will be conducted between boreholes. Other sets of boreholes will be used for cross-hole water-injection tests. All water will be tagged with a tracer. In addition, some boreholes will be instrumented to determine in situ conditions of the rock mass and monitored to determine any changes with time in these conditions. Core recovered from the boreholes will be tested to provide a water-content profile across the fault zone. This profile may provide information relative to any recent moisture occurrence in the fault zone.

Constraints and zones of influence

Constraints related to the drilling method used near the test area and the location of test holes have been identified. Both exploration and test holes must be dry cored through the fault zone. Some flexibility in the location of the holes is required so that the portion of the hole that intersects the fault zone will be far enough from the drift wall to preclude interference from drift construction (two drift diameters minimum). The exact number of holes to be drilled and their location cannot be determined before construction of the drift through the fault zone.

Instrumented drillholes may extend more than 50 ft (15.4 m) beyond the perimeter of the drift. Because the details of this activity are still being planned, the volumes of air or water to be injected into the fault region have not yet been determined. The injected air or water is expected to be confined to the fault and not to permeate the surrounding region of more competent rock because of the greater permeability in the fault zone. No estimates of the potential travel distances along the faults for injected fluids have been made on which to base a zone of influence, but the potential impacts and zones of influence of fluid injection will be assessed before testing. Because the testing will be done only in the extremities of the long exploratory drifts, this activity is not expected to interfere with tests being conducted in the dedicated test area.

Activity: Multipurpose borehole testing (Activity 8.3.1.2.2.4.9)

The following summary descriptions of the MPBH tests are provided here with the ESF testing because of the potential interrelationship between the MPBH and the ESF activities. In actuality, the MPBH is a surface-based test that would be conducted within boreholes drilled on the ESF pad.

The MPBH test plans are being evaluated to determine if it is feasible to conduct such tests within the reference ESF design configuration. The current plans for the MPBH test are tied to the original ESF design configuration with two shafts in close proximity. The test would include two 6-in. (15-cm) boreholes, air-drilled (with intermittent coring) to the total depth of the ESF shafts. The boreholes can be located 46 to 60 ft (14 to 18 m) to the south-southeast (down dip) of each shaft. The purpose of the MPBH test would be to (1) investigate for perched water (either natural or from existing exploratory hole USW-G4), (2) obtain stratigraphic and rock quality information before shaft construction, (3) establish baseline data on hydrologic properties before shaft construction, and (4) monitor for changes in baseline hydrological conditions during construction of the exploratory shafts. Present plans include long-term monitoring of the proposed MPBHs, in conjunction with other ESF hydrologic testing activities, to determine the actual behavior of the rock mass between the proposed MPBHs and the shafts for comparison with the design assumption that rock mass effects are limited to the zone of influence (two shaft diameters) around the shafts. If the MPBHs are not drilled as currently planned, and if the information is still considered necessary, then equivalent information will be acquired by alternative testing strategies or thorough analyses of available information. More information about the tests is provided in Section 8.3.1.2.2.4.9.

The MP-1 borehole would be near ES-1, and the MP-2 would be near ES-2. The holes are planned to be located in a pillar at the MTL, thereby complying with the 10 CFR 60.15 requirement that, to the extent practical, shafts and boreholes be located where large, unexcavated pillars are planned. The holes would be at least two drift diameters away from any mined openings in the dedicated test area in the ESF. These boreholes would be periodically accessed from the surface for purposes of logging or instrument maintenance while the shafts are under construction.

A third MPBH could be drilled between ES-1 and ES-2. This borehole would be used to evaluate the effects of fluids used during construction of ES-2 on hydrologic tests to be conducted in ES-1. A decision on the need for a third MPBH would be made on the basis of additional analysis before constructing ES-2.

Constraints and zones of influence

Location requirements for the proposed MPBHs include the requirement for long-term surface access for monitoring, the requirement to locate the boreholes at least two drift diameters away from any underground openings, and the requirement to not penetrate the mechanical zone of influence expected to occur around the shafts. A standoff of approximately 60 ft (18.5 m) from the shaft centerline is required to accomplish this. The standoff would be based on the assumption that the MPBH can be drilled with a maximum deviation of 1.5°, which translates to a 28 ft maximum horizontal deviation at 1,050 ft (323 m) depth. The mechanical zone of influence of both shafts would be approximately 1.5 to 2.0 shaft diameters from the shaft centerline (Section 8.4.2.3.6.2). Thus, the shaft zone of influence could reach a maximum of 28 ft (18.5 m) from the shaft. A 56-ft (17.2-m) minimum separation distance between the centerlines of the shafts and the corresponding MPBH would be required to preclude the MPBH from entering the zone of influence of the shaft. The assumption of maximum drillhole deviation would be reviewed and revised as necessary when a drilling method is successfully prototyped. In addition, the hole would be surveyed as drilling proceeds and the option to cease drilling could be invoked if insufficient separation from the proposed shaft location were observed.

Because the testing in the boreholes would involve only monitoring activities (no fluid injection), no additional perturbation to the natural conditions (stress, temperature, moisture, etc.) would result from this activity. However, because of the uncertainty in the location of the drillhole relative to the shaft caused by the potential for deviation during drilling, a zone of mechanical influence would be established to account for the maximum potential deviation of the hole. Thus, a 28-ft radius around the hole would be used as a standoff zone resulting from uncertainty in final location of the hole at any depth.

Summary

These brief descriptions of the ESF testing are based on current test concepts and plans. Design modifications and more detailed planning will undoubtedly result in changes before the tests are actually conducted in the ESF. The study plans for each activity will provide much more detailed information about all the planned ESF tests.

It is recognized that 10 CFR 60.140(b) requires that a performance confirmation program shall have been started during site characterization. However, Section 8.3.5.16 (performance confirmation) describes the DOE's current approach to performance confirmation and explains that certain tests will likely continue after the submittal of the license application. Therefore, performance confirmation must be considered now in ESF design, test planning, and repository design. Specifically, allowance for continued access to the dedicated test area during repository operations and operational flexibility necessary to support follow-on performance-confirmation testing have been considered.

8.4.2.3.2.2 Intentionally Omitted

8.4.2.3.3 Description of Exploratory Studies Facility

8.4.2.3.3.1 Introduction

This section describes the ESF. The general arrangement of the surface facilities is presented first. Then, the configuration of the ramps and optional shaft is described. Finally, the general arrangement of the MTL and lateral exploratory drifts is presented. Before this discussion, two related topics are presented to provide some background information on the process used by the DOE to control the design of the ESF and on how the current ESF location and configuration were chosen.

Control of the design for the Exploratory Studies Facility

The design of the ESF must incorporate the necessary features to support the tests to be performed in it, and it must complement the repository design, including provisions for controls and features to avoid a significant impact on site integrity. Consequently, the DOE has instituted a design-control process to ensure that the design appropriately considers these factors. This design-control process is part of the application of the quality assurance program (SCP Section 8.6). Requirements and procedures are developed and implemented in accordance with the Office of Civilian Radioactive Waste Management (OCRWM) Quality Assurance Requirements Document (DOE/RW-0214) (DOE, 1990a) and Quality Assurance Program Description (DOE/RW-0215) (DOE, 1990b), specifically under ANSI NQA-1 Element #3--design control.

The requirements that pertain to the design of the ESF are contained in a set of requirements documents. The requirements flow down in a systematic manner from the OCRWM Waste Management System Requirements through a series of intermediate, more detailed documents, down to the ESFDR. While 10 CFR 60 provides the primary requirements for the design, DOE orders, policies, other applicable federal regulations and mining laws, codes, and safety regulations from the States of Nevada and California are also considered.

The ESFDR guides the design activities as they proceed. Typically, the design consists of two major elements: (1) the development of the facility configuration and associated studies to define that configuration and (2) supporting analyses to evaluate the design with respect to the requirements. Specific examples of these analyses are presented in Sections 8.4.2.3.6 and 8.4.3 to evaluate test interferences and impact on the 10 CFR Part 60 requirements to meet the postclosure performance objectives. The design is developed using data, principally parameters defining rock characteristics, design conditions, and other site-related information. These data are contained in a controlled data base designated the reference information base. The contents are maintained by a change control process to reflect the current status of knowledge from site characterization activities.

At various times in the design, formal reviews will be conducted to evaluate the adequacy of the design in meeting the requirements. These independent reviews are conducted during Title I preliminary design and Title II detailed design, which are the major design phases, with the participation of various program reviewers. The reviews are open to observation by the NRC and the State of Nevada. Each major design phase results in products, principally a design report, engineering drawings, a cost estimate report, and construction specifications. These products are supported by reports of related analyses and numerous quality assurance records. The products of Title I design, including engineering drawings for underground excavation, surface facilities, and support systems have been used as the basis for the discussion in Section 8.4.

The process just described is controlled by baseline control of major elements, such as the requirements documents, including interface control on the contents of the documents. Examples of interface control include defining the relationship of the ESF configuration to that of the potential repository and defining the test requirements for each in situ test.

The ESF test requirements are established by the principal investigators (PIs) for each test. The PIs identify standoff distance, space, drilling requirements, utilities, test instrumentation and data acquisition requirements, special construction and operational control criteria, and other special or general test-support requirements to limit test interference and potential impacts on postclosure performance. These requirements, once reviewed and approved by the DOE, become the fundamental bases for the ESF design and are incorporated into Appendix B or C of the ESFDR.

Application of this design control process, with specific emphasis on incorporation of testing requirements and constraints and the requirements of 10 CFR Part 60, ensures a comprehensive design that is consistent with the DOE's objectives of conducting an effective site characterization program and not adversely affecting site integrity.

8.4.2.3.3.2 General arrangement of surface facilities

At this time, existing surface facilities consist of an access road to the ESF site that is paved on the NTS except in washed-out areas and a water line and 69 kV overhead power line extending to the NTS boundary. The water is from well J-13 and the power is from the Canyon Substation; both are located in Area 25. In addition, there is a transformer to change the 69 kV power, which is underbuilt on the same power poles. Figure 8.4.2-13 graphically illustrates the conceptual plan for the general arrangements for the surface facilities for the potential repository. Surface facilities intended to provide full and independent service to the underground test work are shown in Figure 8.4.2-14. A new 138 kV power line will provide power for the tunnel boring machines (TBMs) which will excavate the ESF ramps.

The major surface facilities consist of pads and roads, buildings, electrical facilities, water, waste water, including mine water and sewer, communication and data management systems, ESF plant and support facilities, muck storage, batch plant, ramp portals, shaft collar (optional), and hoists and headframes (optional). The facilities are designed to provide adequate space for construction and testing for the site characterization.

Pads and roads

The pads and roads will be prepared using earth moving equipment such as rippers, scrappers, and dozers. Blasting will be required to remove the hard rock, and controlled blasting techniques will be used to control damage to the rocks surrounding the blasting operations. Such control blasting requires strict control on the use of explosives (e.g., type of explosive to be used might be specified), the amount of explosive to be used, the type of initiation system, and stemming and delays. In addition, special techniques such as angle drilling, cushion blasting, or presplitting or preshearing can be used to minimize potential damages to the surrounding rocks. More discussion of the expected extent of fracturing of the rock during pad construction is provided in topic 12 of Section 8.4.3.2.3.

The blasting controls will be instituted through construction specifications. This can be accomplished by specifying threshold limit of peak particle velocity and frequency. The actual blast will be verified by testing and monitored when the pads and roads are excavated

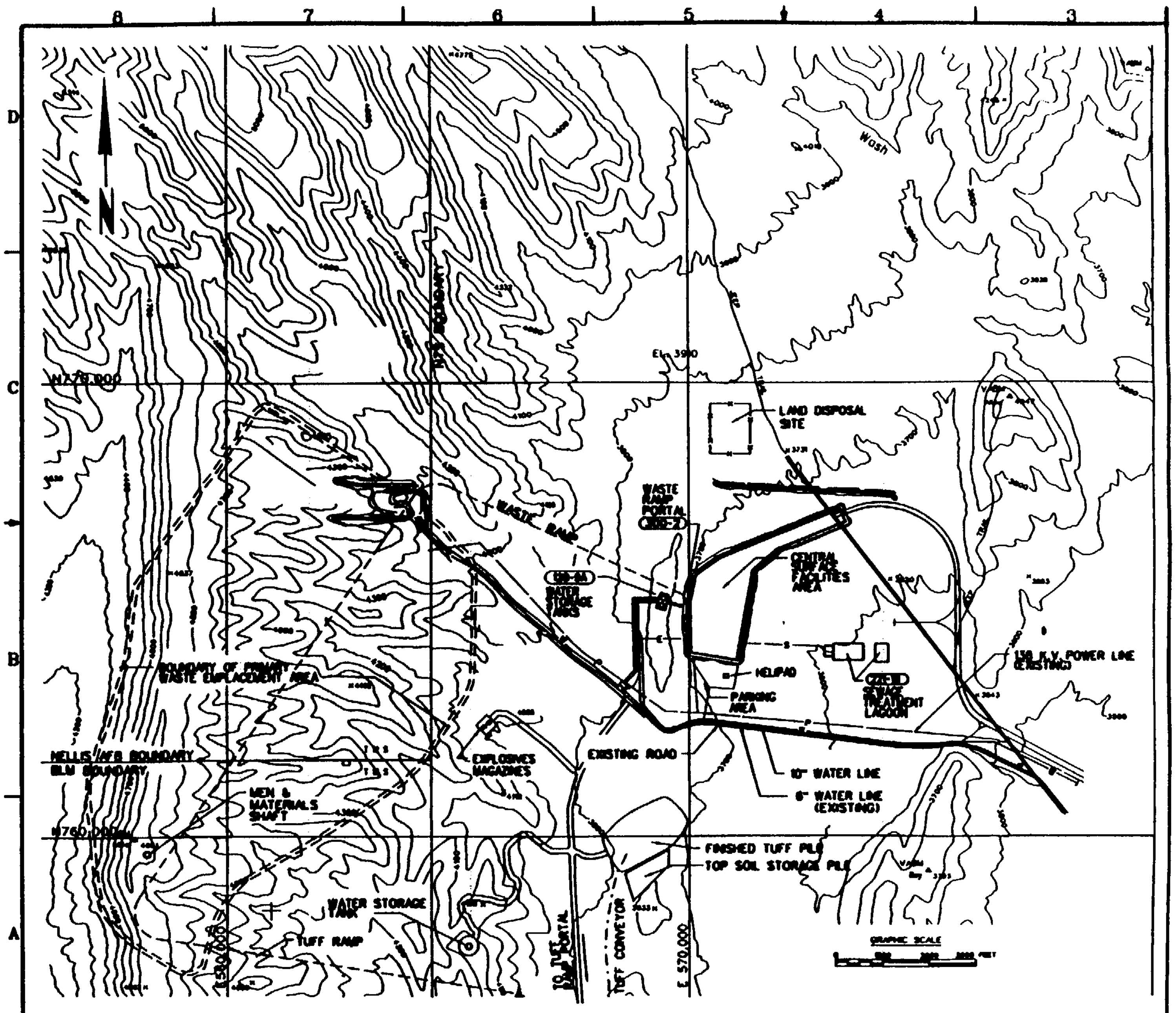
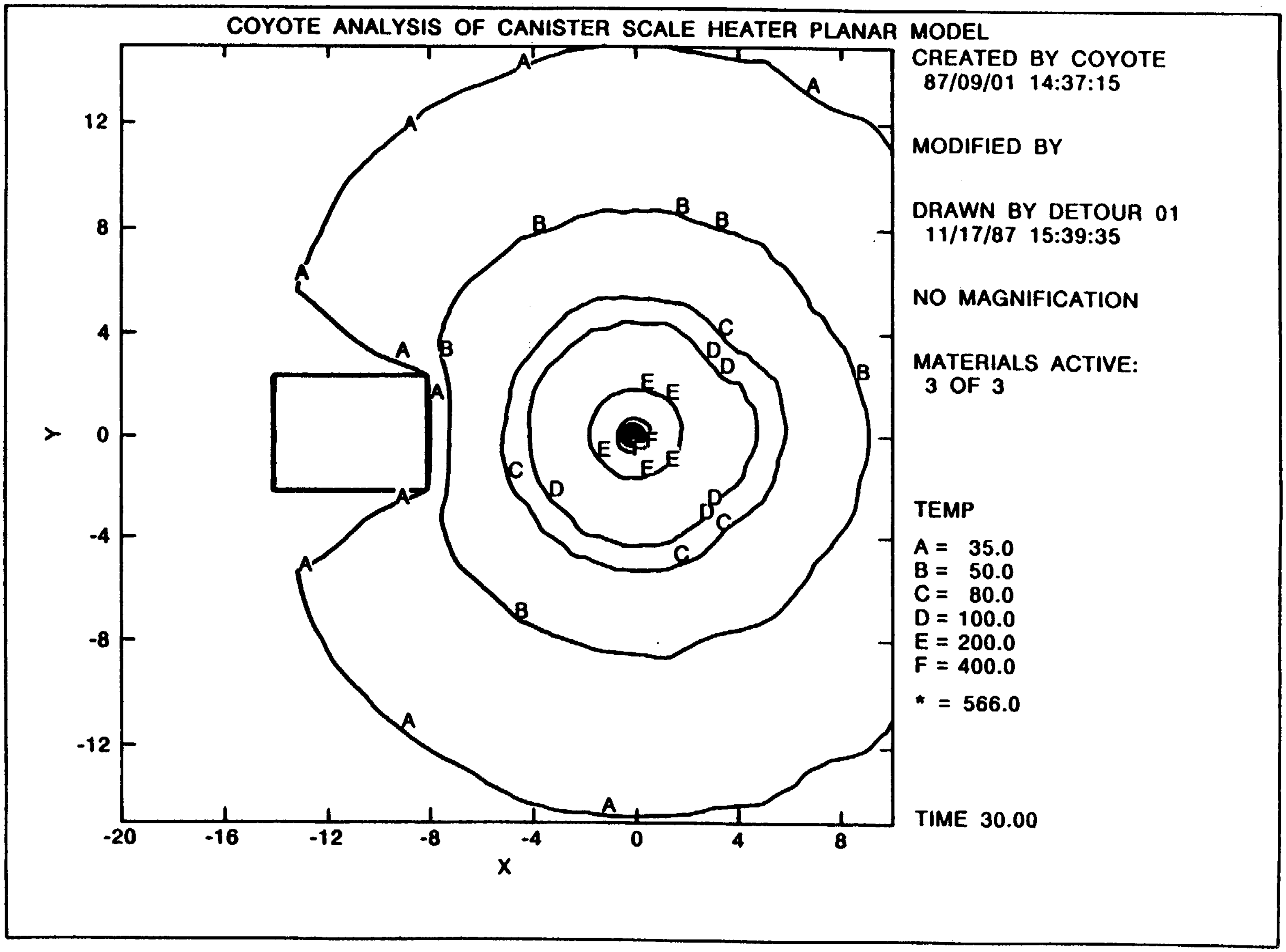


Figure 8.4.2-13. General arrangement of surface facilities.



PLANAR MODEL TEMPERATURE CONTOURS AT 30 MONTHS

Figure 8.4.2-14. Thermal analysis of canister scale heater test planar model.

Several leveled pads will be required to accommodate the various surface facilities needed for ESF construction and operations. The existing access road from Jackass Flats to the NTS boundary is 24 ft (7 m) wide with a double oil-and-chip surface pavement. This road will eventually be extended to the ESF location. Other roads within the ESF location will be graded dirt or gravel access routes subject to periodic surface maintenance. Access will be controlled using fences and gates as necessary on the roadways.

Buildings

Buildings on or in proximity to the ESF pads include space provisions for the YMP participants and other related functions. A change house, shop, and an IDS building are provided. Provisions were made to accommodate mining personnel in the change house, which will also be the location of the first aid station, the Reynolds Electrical and Engineering Company training room, lamp battery room, and the life-safety systems panels. A shop will be provided to support the ESF minor shop functions and responsibilities.

Surface data will be collected in a dedicated building. The building will be a pre-engineered metal building with appropriate fire protection. The building will be designed to accommodate and protect the data records.

Warehouse facilities will be located on one of the auxiliary pads. This will consist of a building and protected storage on the pad. Other building requirements include an explosives storage area with bunkers and a pump house to boost the water supply. Again, all buildings will be pre-engineered metal and appropriately sized to the use intended.

Temporary buildings will be assembled or moved onto the ESF site as they are needed during the construction and operations phases. The pads will accommodate only a limited number of buildings, and, as one construction phase is complete, buildings may be converted for different use or removed from the site. Trailers will be located on the ESF pads and used for office and sample preparation space, and a first aid station. Most functions not directly supporting construction will be conducted from offices and laboratories in the Architect and Engineering (A&E) building, the Sample Management Facility, or laboratories in other existing buildings located in Jackass Flats. The A&E building will also serve as a visitors' center.

Electrical facilities

A surface substation to be constructed at the ESF site will provide the above ground electrical supply and power for the underground distribution system. The existing 69 kV power line will be replaced with a new 138 kV power line from Canyon Substation to a new Yucca Mountain Substation. The substation will be equipped with transformers (138 kV to 12.47 kV) to supply power to the Portal Facilities distribution system, water pumping stations, and batch plant facilities.

Standby diesel generators will provide electrical power to critical life-safety and data-collection systems. The generators will be sized to the use and be on a demand start. Further backup to the critical systems will be provided with uninterruptable power supplies. These will be put on the lines supplying the data-collection equipment as determined by the PIs.

A new 138 kV power line from Nevada Power Co. Northwest Substation, Las Vegas will terminate at Mercury Substation, providing additional power to the NTS power transmission system. Modifications to the NTS system will be made to improve capacity and reliability.

Water

According to current plans, the water supply will be distributed from well J-13 on the NTS through an existing 6-mile-long, 6-in.-diameter polyvinyl-chloride pipe buried about 2 ft below grade. The pipeline, which has been constructed in the bed of the old access road to the NTS boundary, is adjacent to the new paved road and will be extended to the ESF site. Well J-13 is located approximately 3 miles east of the potential repository boundary. One pump station is at well J-13, and a booster pump station is about halfway (based on elevation) to the site. Water will be pumped to a 150,000-gal water tank, which will be located west of and above the site at an elevation of approximately 4,330 ft (1,320 m). The water distribution system from the tank will supply water for all needs at the ESF, including fire protection. The fire protection system is designed to meet all applicable codes. The water supply system will be designed to accommodate reasonable changes in the surface and underground facilities. Drinking water will be separately provided to the underground workers. The water used will be tagged. Water controls will be installed to ensure that failure of the distribution system will not be critical. The types of control planned are

1. Pressure reducing valves utilized to reduce the high pressure head present in the ramp/shaft piping.

2. Line break valves placed at strategic locations to automatically shut in the event of excess flow due to damaged or severed water main piping.

3. Pressure relief valves located downstream of pressure regulators for safety. These relief valves will drain to the waste water system if ever used.

4. Manual shutoff valves located as required to provide isolation of piping sections for maintenance or component inspection.

5. Water hammer arrestors used to minimize hydraulic shock caused by sudden reduction of flow in a piping system.

Waste water

The disposal of the waste water is divided into two systems. Sanitary waste from about an expected 200 persons will be disposed of in a septic tank leach field system. The disposal point will be offsite and downhill from the ESF, well away from the water supply and all personnel activity. The other system is the mine waste water, which it will be processed through a separator to remove oils and disposed of in a settling pond. This system will handle the capacities of both mining water and naturally occurring water expected from the ramp/shaft. Permits will be required for both systems and the disposal systems will be built to code.

The settling and evaporation pond for mine waste water will be used to contain all the waste fluids pumped from the underground facility. The unlined mine waste-water settling pond will be located east of the ESF 2,000 ft beyond the repository block boundary. Drilling fluids that will be used underground, including air-water mist, bentonitic mud with water control agents, and polymer foam, and any other no-sewage water used for construction, will be pumped from the underground facility to this pond. The mine waste water will be tagged with a tracer, and treated before being discharged into the tail end of Coyote Wash. To support this design, an analysis will be performed to ensure all concerned parties that this system will not impact site characterization. The design life for the pond will be a minimum of 25 years, and it will be able to hold approximately 375,000 gal (1.4 x

10^6 L) of waste water. Top soil removed during construction of the pond will be placed in a topsoil storage area and saved for eventual reclamation of the area once the pond is no longer used.

Communications and data management system

The ESF communications system provides telephone communications to the outside world, a life-safety warning system, an underground paging system, intercoms, and a hoist operators communication system. The system is designed as a unified system to provide the maximum flexibility to the operation. The life safety system will be centered around the supervisor's office, which will house the annunciators and response controls. Both audio and visual warning will be provided. If the optional shaft is constructed, the hoist operator will have verbal communication, the traditional bell system, and a closed circuit TV system to provide visual indication of the landing areas. The system is being designed as state of the art in all respects using proven equipment built to the most stringent of the applicable codes. The data produced by various tests described in Section 8.3.1 will be collected by an IDS.

Shaft collar

The reference ESF design concept includes the option of constructing a shaft in the north. The shaft collar is a structure that (1) provides a stable foundation for the headframe assembly and hoisting sheave wheel assembly and conveyance system over the entire range of hoisting system functions, operations, and requirements; and (2) accommodates penetrations and structural mountings for the conveyance system, utilities, instrumentation, and ventilation used for the underground facility. The shaft collar would be located in bedrock, and the initial excavation will be accomplished by controlled drill and blast techniques. The broken rock will be removed mechanically using a crane with clam-shell bucket.

Exploratory Studies Facility plant and support facilities

The ESF plant and support facilities provide the aboveground equipment and systems to support the subsurface construction. Major equipment provided in the plant includes ventilation fans with ductwork through the ramp/shaft; air compressors and supply lines to the ramp/shaft; water-supply piping to the ramp/shaft; and waste-water piping from the ramp/shaft to the mine waste-water pond. Other equipment may also be required. Major construction support facilities in the Title I design include the concrete batch plant, muck-storage area, mine waste-water storage pond, laydown areas for supplies and equipment, explosive magazines, shops, warehouses, hoists, and headframes (optional).

Intake, exhaust, and distribution facilities will supply and exhaust required quantities of air to and from underground working areas for personnel health and safety. Systems will be provided to continuously monitor the underground facilities for radon, methane, oxygen, carbon monoxide, temperature, humidity, and air speed.

A concrete batch plant will provide for the storage and mixing of materials for concrete and grout during the ESF construction activities. Concrete will be used for building foundations and for ramp portals, shaft collars and liners (optional). Approximately 1 acre will be used for the batch plant at a location beyond the potential repository boundary. Crushed rock, sand, and cement will be temporarily stored in this area while the ESF is being constructed.

Hoists and headframes

The hoists, hoist house, and headframe for the optional shaft will be installed and erected following the construction of the shaft collar. The hoist will provide the necessary hoisting capacity for muck removal and for personnel and material transport to and from the surface. The hoist will be outfitted with standard controls, brakes, and other safety systems. If the hoist is not functional, the ladderway provided in the shaft can also be used for emergency egress.

Ramp Portals

The ESF will contain two ramps, one in the north and one in the south (Figure 8.4.2-14). The ramp portal is a structure that provides a stable foundation for entry into the ramp. The portal structure is constructed of reinforced concrete and extends into the ramp for about 50 feet or that distance deemed necessary for near-portal rock support. The outside structure is essentially a building complete with controlled entry, doors, utilities, and special construction to accommodate ventilation and rock removal equipment. The underground portion of the portal consists of an approximately 1-foot thick reinforced concrete liner with concrete invert. This is installed only to the depth where it is field-determined that a stable subsurface rock mass has been reached and it is no longer necessary to control a fractured rock mass associated with the portal entrance. Beyond this area regularly scheduled ground support is installed in the form of rockbolts and/or other methods as required.

Muck storage

The muck-storage area location is indicated in Figure 8.4.2-14. The rock debris, removed during the construction of the ESF will be brought to the surface and hauled to the muck-storage area. Dust from the handling and storage operation will be controlled using appropriate dust suppression techniques.

8.4.2.3.3.3 General arrangement of ramps and shaft

In preparing the arrangement for the two ramps and optional shaft, as well as the subsurface facility, adequate consideration has been given to the design and layout of a facility that will allow for the characterization of the site to provide needed data and information. Various regulatory concerns and the requirements of DOE orders have been incorporated into the facility design, and the design meets NRC 10 CFR 60 requirements, Mine Safety and Health Administration (MSHA) requirements, and State of Nevada mining rules and requirements.

The north ramp (which may eventually be incorporated into the potential repository as the waste ramp) and the south ramp (future tuff ramp) will provide access to the TS, where the MTL dedicated testing area will be located. Both of these ramps will have turnouts to two additional ramps leading to the CH level.

The north ramp has been designated as the scientific ramp. The excavation cycle in the ramp will consider the needs of the investigators to ensure that the expected data from the planned tests are procured. As discussed in Section 8.4.2.3, only limited testing will be conducted in the south ramp.

Both the north and south ramps are oriented to enter the ESF MTL from the east. These ramps are expected to be approximately 25 ft. (7.6 m) in diameter, with the north ramp extending with a slope length approximately 6,467 ft. (1,978 m) to the TS level and the south ramp having a slope length of approximately 9,142 ft. (2,796 m). The north ramp leading down to the CH level is expected to be approximately 18 ft. (5.5 m) in diameter and have a slope length of 6,738 ft. (2,060 m). The south ramp to CH is expected to be the same diameter as the north ramp and have a slope length of approximately 7,379 ft. (2,257 m). These dimensions are discussed in DOE (1992). These details are subject to change pending Title II design decisions.

As indicated in Section 8.4.2.3, the ESF design will include an optional shaft, which would be constructed in the north, extending from the surface to the TS level near the MTL dedicated testing area. This shaft, if constructed, may eventually be incorporated in the potential repository as the emplacement exhaust shaft. While the general arrangement for this shaft is presently being developed, it is expected that it would be approximately 25 ft. (7.6 m) in diameter and be similar to one of the two shafts in the previous ESF configuration described in Section 8.4.2.3.3.3 of the SCP (DOE, 1988g).

The following industrial safety related considerations are important in developing the general arrangements for the ramps/shaft:

1. Locate the accesses to provide rapid emergency egress from the testing area.

2. Separate the accesses so that the refuge chamber shall be readily accessible from all accesses.

3. Provide at least 100 ft. (30 m) of standoff distance at the surface from the accesses to flammable materials, including vegetation above the high wall.

4. Locate the accesses to minimize the size of the high walls and potential mechanical interference between the accesses.

5. Separate the accesses so that an adequate pillar will be available.

6. Locate the accesses such that safe terrain conditions are maintained.

8.4.2.3.3.4 General arrangement of the exploratory drifts in the Topopah Spring and Calico Hills levels

The excavations at the TS and CH levels consist of long drifts that connect the north and south ramps. From these drifts, lateral drifts would be constructed to features of special interest (e.g., Imbricate normal fault zone, Ghost Dance fault, Solitario Canyon fault). The drifts in the TS level also include the MTL dedicated testing area, in the north. Planned underground excavations for the TS level are illustrated in Figure 8.4.2-14a.

The main drift within the TS level is expected to be approximately 25 ft. (7.6 m) in diameter. The TS east and west drifts are planned to be 20 ft. (6.1 m) wide and 12 ft. (3.7 m) high. The TS imbricate drift is planned to be 18 ft. (5.5 m) in diameter. Approximately 20,000 ft. (6,096 m) of drifting is planned for this level of the ESF (not including the MTL dedicated testing area). The main

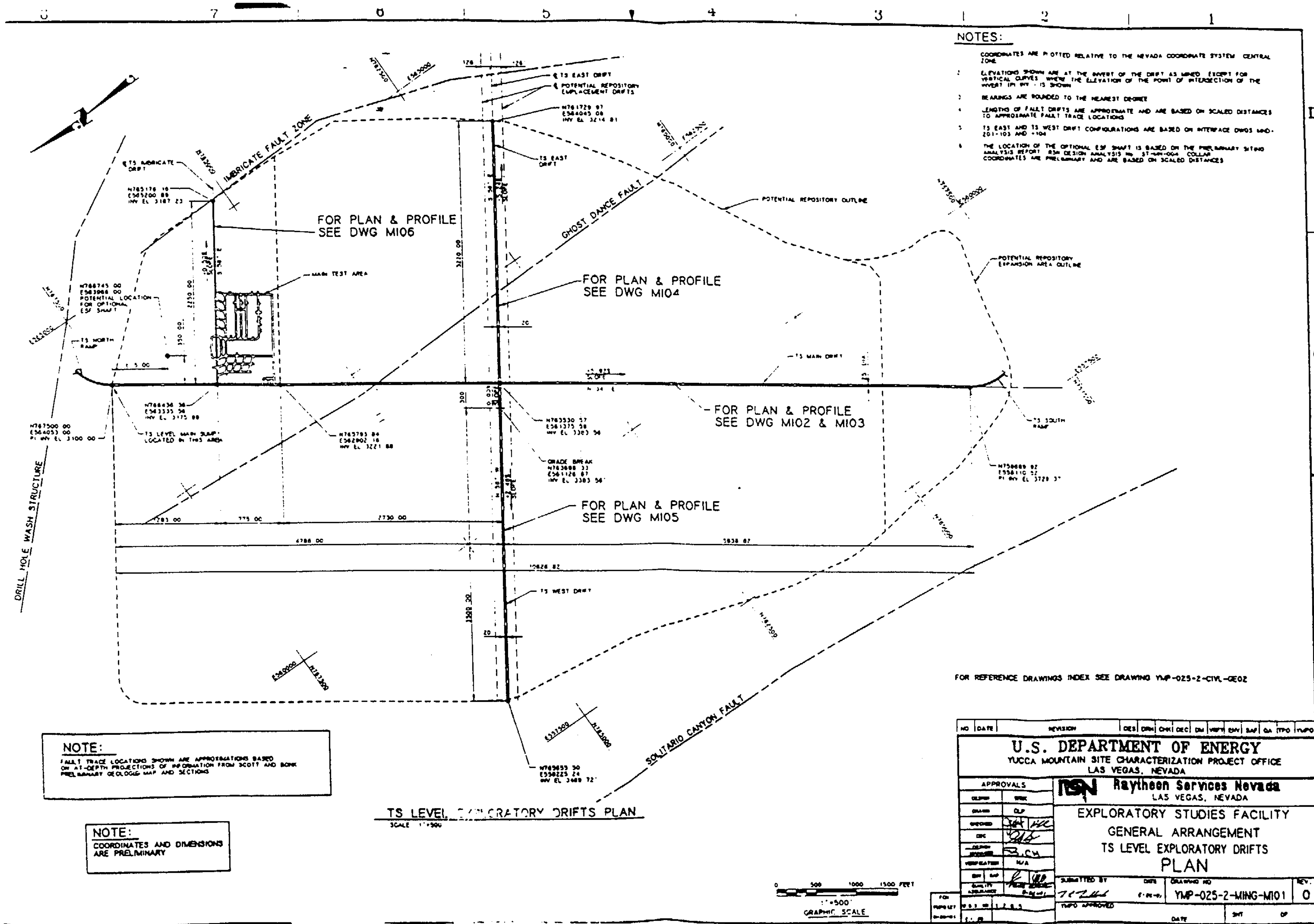


Figure 8.4.2-14d. Exploratory Studies Facility General Arrangement TS Level Exploratory Drifts Plan.

drift within the CH level is expected to be approximately 18 ft. (5.5 m) in diameter. All other drifts on the CH level are planned to be 16 ft. wide and 9 feet high. Drifting on the CH level is estimated to total approximately 19,000 ft. (5,790 m).

The MTL dedicated testing area will contain space for the different tests identified in Table 8.4.2-12, shops (including a science shop), a refuge area, power center, and sump. The area set aside for this is expected to be approximately 4,200,000 ft^2 (390,193 m^2), with an expansion capacity of approximately another 3,300,000 ft^2 (306,580 m^2), if needed. The general arrangements for the various drifts, as well as the MTL dedicated testing area, are presently under development.

The following considerations are important in developing the general arrangements for the underground excavations:

1. Need to separate testing from shops, training, and operations areas.

2. Flexibility for experiments.

    a. Required areas for expansion for future testing.

    b. Location of test drifts and alcoves depend on rock conditions and joint orientation that are uncertain until those areas are mined. Flexibility is required for experiment locations and, in some instances, drift orientations.

3. MTL requirements--provide adequate isolation of tests and provide access for continued mining and construction activities. The MTL provides facilities for the excavation of test areas.

    a. Develop MTL as necessary to provide adequate separation of experiments.

    b. Certain tests, such as the infiltration test, require separation from any wet mining or drilling activities.

    c. A minimum of two drift diameter standoff distance from mains and repository drifts along the ESF boundary is required.

    d. Test-to-test separation requirements include considerations of possible thermal zones, stress-altered zones, hydrologically altered zones, extent of instrumentation beyond the drift or alcove, and requirements to be isolated from mining or construction activities.

4. Operational schedule: operational areas and facilities need to be mined first before experiment drifts. Limited amount of mining is allowed before ramps are connected.

5. Ventilation requirements affect room layout and main drift locations.

8.4.2.3.4 Description of Exploratory Studies Facility construction operations

This section briefly describes the various stages of construction operations for the ESF. The construction sequence essentially consists of preparing the site and ramp portals, constructing the ramps, and developing the exploratory drifts at the TS and CH levels. If the optional shaft is constructed, the activities will also include constructing the shaft collar, sinking the shaft, and erecting the headframe and hoist. As described in Section 8.4.1.1, a phased approach to implementing site characterization in the ESF is being used by the DOE to continually evaluate the adequacy of the testing configuration and the impacts of the testing activities. Similarly, controls, such as those identified in Section 8.4.2.3.3.1, will be in place to ensure that conditions encountered during ESF construction are adequately reviewed and factored into the experimental program and the remaining construction. These reviews and evaluations will also allow the opportunity to provide information to the NRC, the State of Nevada, and other interested parties.

A summary of the construction of the site pads, ESF surface facilities and utilities; a description of ramp portal and shaft collar construction; and a description of ESF underground construction and operations are discussed in the following sections. The details of the construction activities will be developed as Title II design proceeds.

8.4.2.3.4.1 Site pads

The ESF surface pads will be constructed using standard cut and fill methods. If a particular pad site requires controlled blasting to develop the necessary cut area, the resulting rubble will be used for fill to build up the pad downslope. Any additional fill material will be brought to the pad from designated borrow areas nearby. The pad surfaces are designed to slope away from the ramp portals and shaft collar for runoff control. All the access roads to and from the ESF site are designed with appropriate grade elevations, berms, and/or culverts to handle normal expected runoff and not restrict water flow under conditions of a major flood event.

Exposures created by controlled blasting to develop surface pads will be examined and mapped for indications of potentially adverse structures.

8.4.2.3.4.2 Exploratory Studies Facility surface facilities and utilities

Once the site pads and roads are completed, the ramp portals, shaft collars (if optional shaft is constructed), mine plant, support buildings, and utilities will be constructed or installed.

8.4.2.3.4.3 Ramp portal and shaft collar construction

The ramp portals (Figures 8.4.2-15 and 8.4.2-16) will be constructed first by excavating the area around where the portal will be located. The portal structure is constructed of reinforced concrete and extends into the ramp for about 50 feet or that distance deemed necessary for near-portal rock support. The outside structure is essentially a building complete with controlled entry, doors, utilities, and special construction to accommodate ventilation and rock removal equipment. The underground

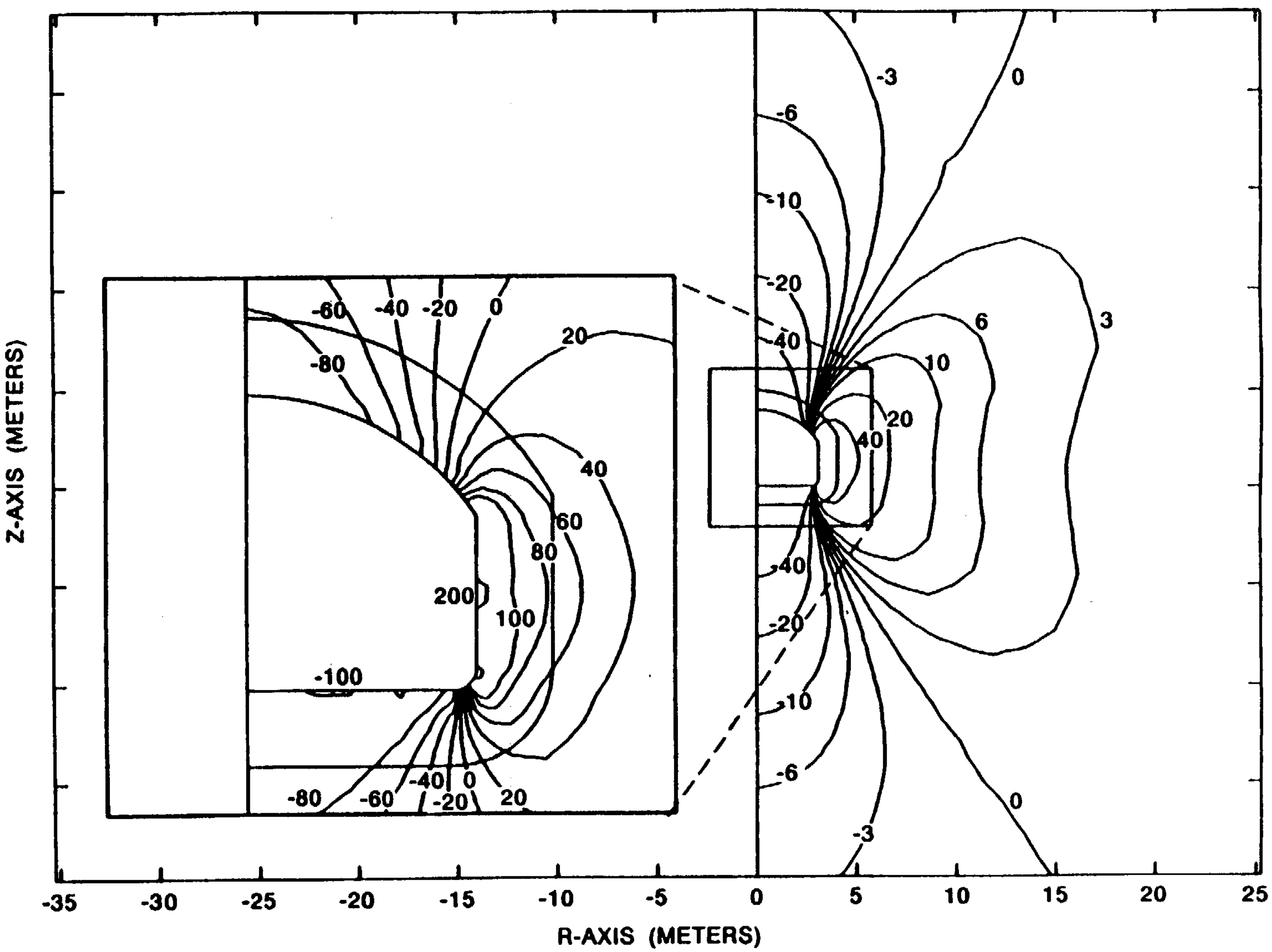


Figure 8.4.2-15. Analysis of demonstration breakout room--percentage change fr... in situ vertical stress.

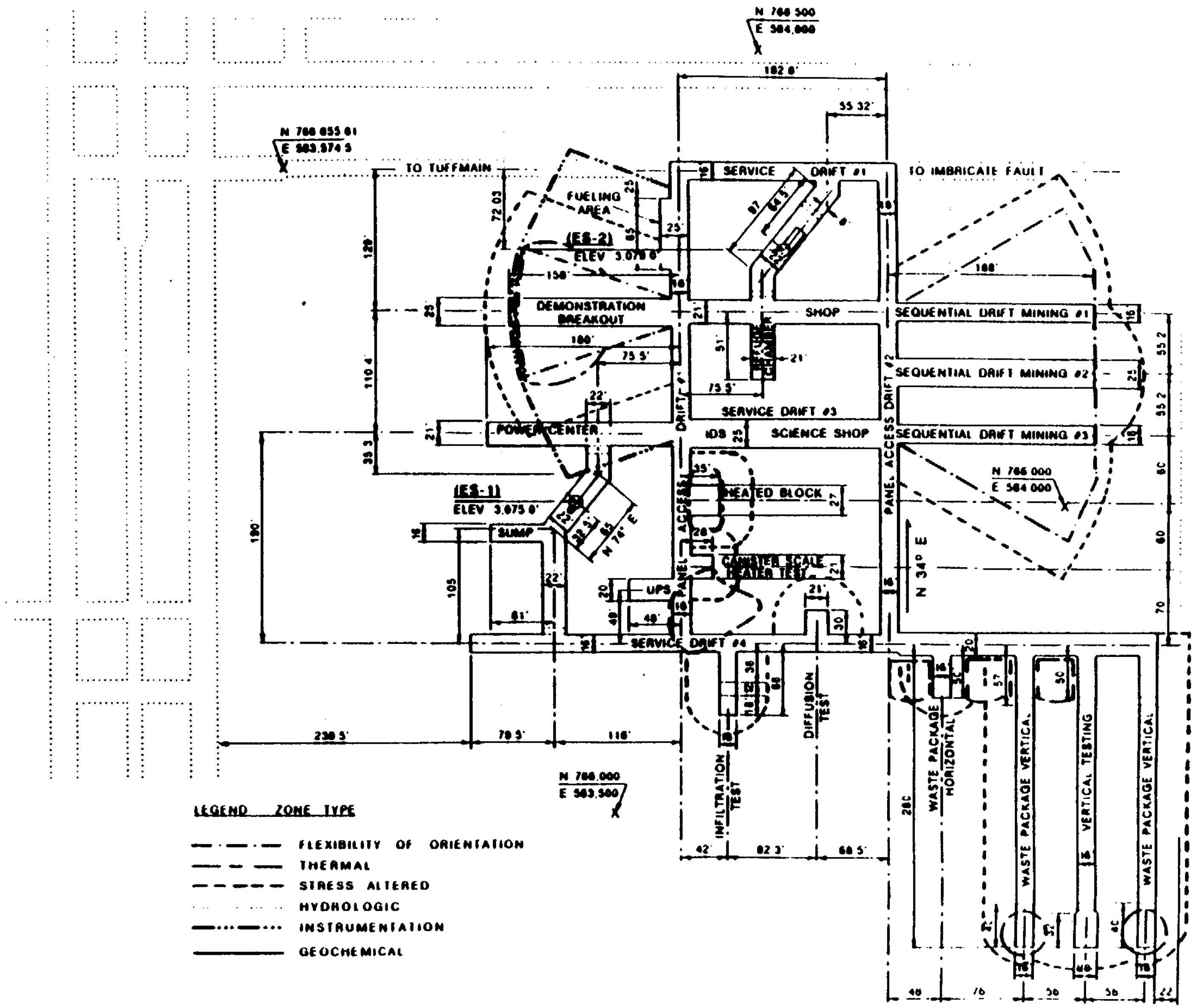


Figure 8.4.2-16. Zones of influence from main test level experiments on dedicated test area layout.

portion of the portal consists of an approximately 1-foot thick reinforced concrete liner with concrete invert. This is installed only to the depth where it is field-determined that a stable subsurface rock mass has been reached and it is no longer necessary to control a fractured rock mass associated with the portal entrance. Beyond this area regularly scheduled ground support is installed in the form of rockbolts and/or other methods as required.

If the optional shaft is constructed, the shaft collar will be constructed by first excavating a square foundation several feet below the finish grade. At the center of this excavation, a circular subfoundation will be excavated. Should ground support be required at this depth, a liner plate with ring beams will be placed and grouted; once the foundation excavation is stabilized, the isolation joint excavation can take place. The isolation joint will provide a structural discontinuity between the collar/ headframe and the shaft liner. A liner plate with ring beam stiffeners, will be centered on the future shaft. Cement grout will be placed in the bottom of the annulus between the excavation and the plate to hold the liner plate in place. The remainder of the annulus will be filled with gravel to complete the isolation joint. Once the joint is completed, forms can be installed for the vertical shaft penetration, through the collar structure and the horizontal intersection of the utility tunnel. Reinforcing steel, embedded items, and any required bulkheads or blockouts are placed and secured and the collar structure can be completed in a continuous pour.

8.4.2.3.4.4 Exploratory Studies Facility underground construction and operations

This section generally describes the various steps involved in constructing the underground portion of the ESF.

The underground portion of the ESF will be constructed using mechanical mining equipment. TBMs will be used to construct the north and south ramps from the surface to the TS level. TBMs will also be used to construct the two ramps from the north and south ramp turnouts to the CH level. The two ramps at the CH level will be connected by a long exploratory drift, also constructed with a TBM. The lateral drifts to the Imbricate normal fault zone, Ghost Dance fault, and Solitario Canyon fault will then be constructed. These drifts may be constructed with a TBM, but most likely with a mobile miner or road header.

As in the CH level, the two ramps leading to the TS level will be connected by a long drift, constructed with a TBM. The lateral drifts to the Ghost Dance fault and Imbricate normal fault zone will most likely be constructed with a mobile miner or road header. This is also true for the individual excavations to be constructed in the dedicated test area in the MTL on the TS level.

The last phase of construction involves the optional shaft from the surface to the TS level. If such a shaft is constructed, it would most likely be done using a shaft boring machine, v-mole, or blind bore.

More details regarding the construction of the underground portion of the ESF will be available as Title II design evolves.

8.4.2.3.5 General description of underground support systems

The following subsections describe the ESF underground support systems. These systems, which all relate to the underground mine environment, are mine ventilation, rock support, life safety systems, fire protection, health and safety, and mine evacuation and rescue.

Mine ventilation

The ventilation system will supply and exhaust adequate air quantities of acceptable quality to and from underground working areas, to provide personnel safety, health and productivity in accordance with applicable Federal, State and Local regulations.

Active drifts away from the primary airways are ventilated by appropriate auxiliary fans and ducting to satisfy the required airflow in the drifts.

Airborne dust from roadways, muck transfer points, drilling, bolting, and blasting (if done) will be controlled and limited to concentrations below the threshold limit values. Dust suppressants consisting of water and biodegradable/nontoxic chemical additives will be applied regularly to subsurface roadways. These dust suppressants are not expected to adversely affect mine waste water discharges. Where applicable, plain water spray or other wetting agents will be used to suppress dust, in amounts consistent with goals to minimize water use to levels required for health and safety. Appropriate stationary or mobile dust collection systems provide the means to further enhance dust control.

A typical dust collection system consists of a series of cyclones and filters that will remove 99 percent of particles greater than 3 micrometers, and 96 percent of particles down to 1 micrometer. Stationary dust collection units will be applicable to permanent muck transfer points such as loading and unloading pockets and dump stations. Mobile dust collection units mounted on wheels will be used during drilling and bolting and after blasting (if done) and mucking.

Rock support

Rock support needs are determined using several available methods. These methods include both analytical and empirical approaches, which are supported by historical experience with underground construction. Results of these analyses serve as a basis for developing the flexible systems for reinforcement capable of accommodating various rock conditions anticipated underground.

Ground support requirements for each segment of a drift may vary over relatively short distances, depending on the local geologic conditions. Based on the visual inspection by a qualified professional, the local ground conditions are classified in terms of rock-mass categories. In turn, the rock-mass category is assigned a specific rock-support system, including the procedures and the hardware necessary for its proper implementation. Thus, the rock-support system is adaptable to local conditions.

Depending on the rock-mass class, the rock-support system may include rock bolts, wire mesh, shotcrete, or the combination of those as specified for each system.

Analytical methods

Analytical methods use the analyses of stresses and deformations around openings and include numerical modeling techniques, such as the finite-element method. These methods are very useful in strata control because they enable comparisons of various underground excavation systems and serve as a design process. They are also very useful in forecasting the possible performance of underground openings over extended periods of time, where such aspects as the influence of temperature and/or time-dependent properties of rock (e.g., creep) are to be assessed.

Finite-element codes, such as VISCOT, will be used to evaluate the stability of underground openings. Several studies in which this code was used have been reported in the literature, and the code certification process is currently well under way. Once the certification process is completed, the code will serve as one of the design tools acceptable from the quality assurance point of view.

There are a number of other codes currently available, each appropriate for analysis of certain types of problems. Other code(s) may be used to analyze the stability of underground openings.

Empirical methods

Sophisticated computer analyses inherently incorporate a number of assumptions related to the properties of the rock mass, the state of stress anticipated in a particular underground situation, the geometry of the opening(s), etc. As pointed out by Hoek and Brown (1980), the combined effect of all the factors and processes contributing to the stability of underground openings can seldom be determined. Invariably, the designer is faced with the need to arrive at a number of design decisions in which his engineering judgment and practical experience must play an important part.

To provide a link between the results of analytical studies as well as to incorporate practical experience gained from operations performed under similar underground conditions at other sites, some form of classification system is needed. Such a system allows the results obtained from analytical studies and experience to be translated into a series of engineering drawings, specifications, and procedures leading to a successful implementation of the design concepts.

Hoek and Brown (1980) recommend two common classification methods for use in the preliminary design of underground excavations, namely, the classification of joint rock masses (South African Council for Scientific and Industrial Research) proposed by Bieniawski (1974), and the tunneling quality index (Norwegian Geotechnical Institute) proposed by Barton et al. (1974a).

These two methods will serve as a point of departure for the development of a site-specific rock-mass classification appropriate for the tuff formations at Yucca Mountain. As a result, a set of procedures, along with detailed drawings showing various rock-support systems, will be developed. These will be simple enough to use under field conditions and will contain specific information to help select a suitable rock support system for particular rock conditions encountered underground.

<u>Life safety</u>

The function of the life safety system is to provide systems to alert on-site personnel of danger, ensure a timely response to emergency conditions, provide safe shutdown and evacuation if necessary and limit interruption to the site characterization program.

Life Safety is a broad concept that includes other major system components. Some of these components are

1. Fire protection.
2. Alarm warning system.
3. Emergency communication systems.
4. Evacuation plans.
5. Atmospheric monitoring and control systems.

Each of these systems is engineered separately to maintain its individual integrity. In addition, all systems are designed to function in a coordinated capacity by interfacing shared responsibilities for overall program effectiveness.

Fire protection

The fire protection system is a part of the life safety system. Its development is based on the anticipated fire hazards, and the use and occupancy of each area. The fire protection system will include

1. Automatic extinguishing systems using water sprinklers, halon, and foam.

2. Manual extinguishing systems such as portable dry chemical units, factory-equipped rolling extinguisher systems, fire doors, fire dampers, and ventilation controls.

3. Automatic detection system for smoke and heat (flame).

Each component of the fire protection system is designed considering credible accident scenarios that may be attributed to various ESF functions. Fire protection for these events is part of the total consideration given to safety, and the system interfaces with other life safety systems involved.

Health and safety

The DOE has an established health and safety program. The following policies are followed by the YMP management:

1. Accident prevention.

2. Safety promotion and training.

3. Supervisors' health and safety inspections and reports.

4. Resolving safety and health complaints.

5. Accident and injury reporting system.

6. Safety awards for outstanding injury and illness prevention achievement.

7. Job safety analysis program.

8. Construction and occupational safety standards.

Evacuation and rescue

The ESF organization has emergency evacuation and rescue procedures developed to respond to fire, flood, and other catastrophic events. These procedures detail the proper response and sequence of action to be taken by subsurface personnel to various emergency calls.

A well-planned and well-rehearsed program of evacuation and rescue for ESF personnel will be followed. Adequate training and drilling of personnel and management in this program will be provided, including these topics:

1. Early warning and alarm systems.
2. Use of self rescuers.
3. Basic ventilation circuitry.
4. Direction to emergency exits.
5. Use of emergency hoist (if optional shaft is constructed).
6. Use of refuge chambers.
7. Survival techniques.
8. Barricading.

Equipment that is important to life safety is designed with redundancy so that back-up systems are available during an emergency.

A designated person in each shift will be responsible for initially coordinating the emergency response until relieved by the head of the Emergency Coordinating Committee. Initial rescue response such as mobilization of mine rescue team, planning to establish underground fresh air base, and actual rescue and recovery work will be started as soon as possible after an emergency occurs. The head of the Emergency Coordinating Committee may solicit the help from various organizations to carry on the rescue and recovery work.

8.4.2.3.6 Evaluation of Exploratory Studies Facility layout and operations

This section evaluates the ESF layout and operations with respect to interferences that could affect the experimental program, coordination with the geologic repository operations area design as required in 10 CFR 60.15(c), design flexibility as required in 10 CFR 60.133(b), and operational safety. This section is divided into five subsections. The first three subsections discuss various aspects of the interference concerns regarding construction and operation of the ESF, the experimental program, and the repository. The fourth subsection examines the flexibility of the ESF design and layout in handling variable geologic conditions, in incorporating additional testing within the dedicated test area, in exploring other areas, and in reorienting or relocating certain experiments. The final section deals with operational safety concerns addressed in the design and their consistency with the governing regulations.

[NOTE: The interference evaluations contained in Sections 8.4.2.3.6.1 and 8.4.2.3.6.2 were conducted for the ESF configuration, construction method, and testing layout described in the SCP. This evaluation still needs to be conducted for the reference ESF design concept shown in Figure 8.4.2-16a. These sections will be revised when that evaluation is available. These sections are being included unchanged because, while the details of the evaluation will be different for the new design concept, the overall methodology and considerations for conducting the evaluation will be similar.]

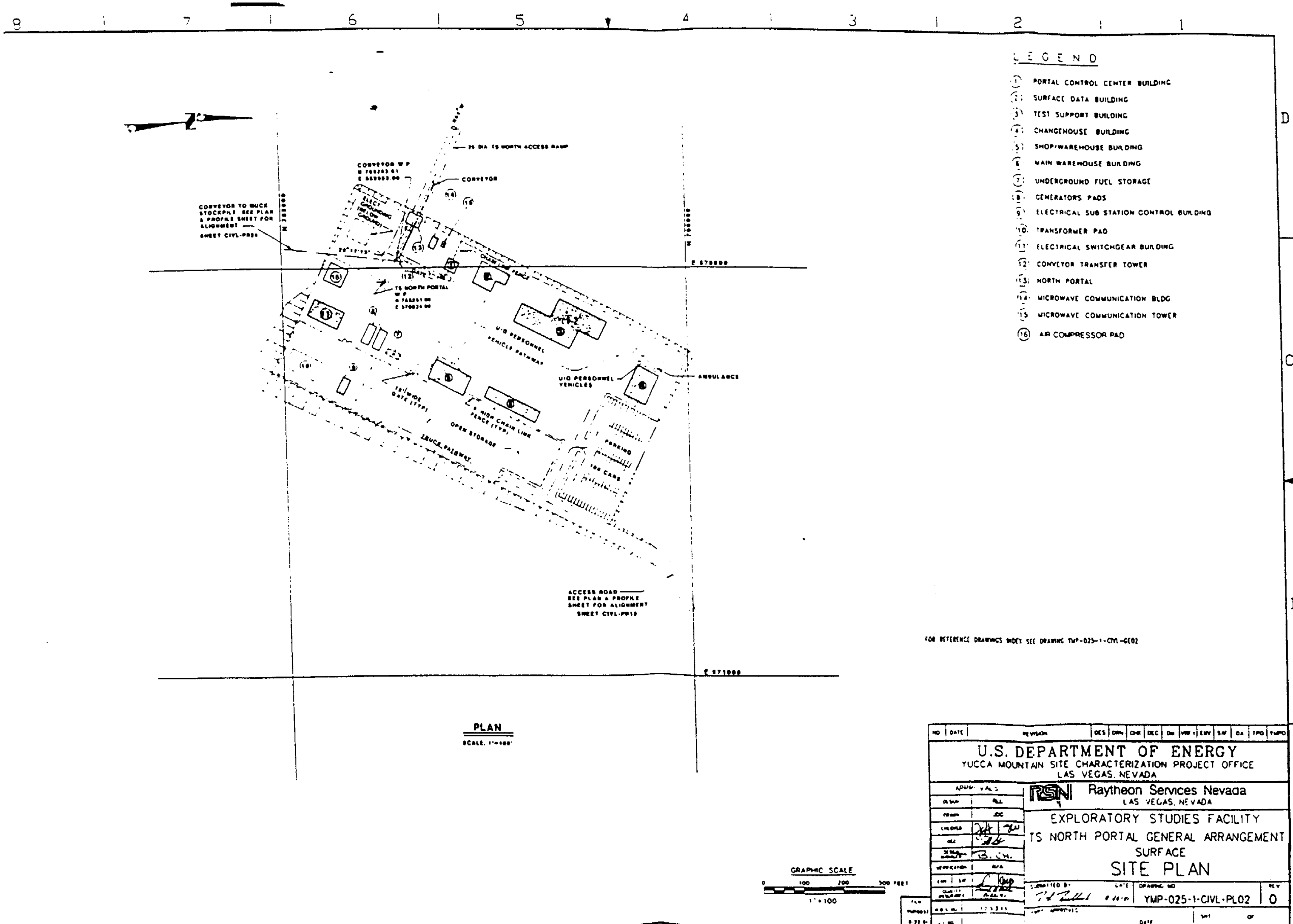


Figure 8.4.2-16a. Exploratory Studies Facility General Arrangement TS Main Test Area Preliminary Test Locations Plan.

Three categories of potential interference concerns affecting the underground design and testing are discussed in the first three sections. In Section 8.4.2.3.6.1, the approach used to analyze the potential for test-to-test interference is described and applied to the current design layout. In the following section (8.4.2.3.6.2), test and construction/operations interferences are discussed, along with the means used to mitigate those concerns. The approach used to plan and coordinate the ESF layout and construction with that of the repository is discussed in Section 8.4.2.3.6.3. Within each of these sections, several mechanisms of potential interference were considered, principally those due to hydrologic, thermal, mechanical, and geochemical activity associated with the experiments (Table 8.4.2-14). Other potential sources of interference among tests or between the tests and the ESF construction and operations, such as ventilation, blast vibration, instrumentation, and traffic (including vibration), were also considered. The means used to limit interferences are discussed and analyzed relative to the current design. In general, potential interference problems can be limited through the use of physical separation (including orientation of tests), but other means are also used and their applications discussed. These include the sequencing of operations and testing to limit interference, control of operations such as blasting and fluid usage to limit the extent of changes induced in the rock mass, and monitoring and observation before accepting the location for testing. The application of these methods to the interference problem are discussed in the appropriate sections.

8.4.2.3.6.1 Potential for interference between tests

Purpose and background

This section describes the general approach used to evaluate the potential for test-to-test interference among the experiments planned for the ESF and the use of this methodology in evaluating the current design layout of the ESF with respect to test-to-test interference. Each test proposed for the ESF is briefly described in Section 8.4.2.3.1. This section also discusses the constraints imposed on the underground layout by each experiment and the estimated zone of influence of each experiment. The design requirements generally arise from the requirement that the in situ conditions, such as stress state, degree of saturation, and temperature in the region where the experiment is to be conducted, not be altered by other activities in the ESF. Flexibility in choosing the final location and orientation of an experiment may also be an important constraint because of local variations in geology and fracture orientation. The zone of influence is intended to describe the extent to which each experiment alters or influences the surrounding region. In the conduct of each test, it is vital to ensure that the data derived from the test is not corrupted by the influence of other experiments that may be underway at the same time. The combination of experiment descriptions, design constraints, and zones of influence for each test, given in Sections 8.3.1 and 8.4.2.3.1, provides sufficient information to evaluate the current ESF layout with regard to addressing concerns regarding test-to-test interference.

Approach

The approach taken to assess the potential for interference among the ESF experiments consisted of three basic steps. First, each experiment was evaluated with regard to potential interferences and zones of influence (Section 8.4.2.3.1). Several mechanisms for zones of influence and other potential interference sources were considered. For example, regions of material potentially affected or altered by an experiment due to heating, hydrologic alteration, geochemical reactions, and mechanical changes (excavation of drifts or thermally induced stress changes) were determined. Next, these four interference considerations and zones of influence for each test were combined and the one that gave the maximum zone of influence was translated into a physical area (standoff) requirement that represents the maximum extent of the rock zone affected by the test given the expected rock properties. These regions were then superimposed onto the design layout of the ESF test area. Finally, the overlay of zones of influence on the test locations was examined for potential interferences among the experiments.

The criteria for determining if a potential interference existed was to determine if the zone of influence of one experiment impinged on another experimental area to such a degree that the results of the experiment could be affected. To ensure conservatism in this approach, the potential for interference was considered high if the zones of influence of two experiments overlapped. Where the zones of interference for two or more experiments overlapped, the timing of the experiments and the type of interference (i.e., effect) resulting from the individual experiments were reviewed. If the tests were separated sufficiently in time to preclude an interference problem (i.e., one test may have been completed, with no unacceptable alteration of the rock, before the second was begun), the tests were considered to be independent of interference effects. If potential interference effects were found during the analysis, then adjustments to the timing or the layout of the experiments were considered.

The test-to-test interference concerns were completely evaluated using this methodology only for the experiments proposed for the MTL. Experiments and observational activities planned for the underground excavations were evaluated with regard to potential zones of influence (Section 8.4.2.3.1). Further evaluation was not, however, considered necessary because the tests involved primarily observational and sample collection, affected a limited amount of rock (see Section 8.4.2.3.1), or had large physical separations between them and other tests.

The principal mechanisms for creating zones of influence were considered to be thermal (for experiments using heat sources), mechanical (for experiments requiring extensive excavation), hydrologic (for experiments that introduced fluids to the environment) and geochemical (for experiments that altered the local in situ geochemistry). Other potential sources of interference, such as the location and extent of instrumentation (included in the mechanical category in Table 8.4.2-14), were also considered on a test-by-test basis. In general, most tests will have several zones of influence summarized in Table 8.4.2-14 resulting from different mechanisms. The effect of some coupling of mechanisms was also considered. For example, heating the rock mass also affects the local hydrological and stress conditions. Analyses of these coupling effects are quite complex but generally depend on the gradient of the principal driving force. That is, hydrological and stress changes are a function of the thermal gradient. Therefore, the approach taken to account for these effects was to extend the zone of influence of the principal mechanism far enough so that gradients were low and secondary coupling effects would likely be contained within the zone defined by the principal mechanism. Thus, thermal zones of influence were extended to include all material surrounding an experiment whose temperature changed by more than 5°C.

The coupling of thermal and hydrologic zones of influence is also considered by Nitao (1988). In this investigation of thermal and hydrological behavior in the vicinity of the waste package, the region of condensed water vapor extends to approximately the same location (within 4 m) as the 80°C isotherm (approximately 50°C above ambient). As this water condenses, it is rapidly imbibed into the matrix (Martinez, 1988) where it remains relatively immobile (Peters, 1988). Since the 80°C isotherm is contained within the 5°C above ambient isotherm, the assignment of the 5°C isotherm as the boundary for the experimental zone of influence provides a conservative zone that addresses coupled thermal and hydrologic effects.

Geochemical and hydrological zones of influence were conservatively assumed to be identical where elevated temperatures are not encountered. At elevated temperatures (approximately 100°C), some geochemical alteration of tuff may occur (Smyth and Caporuscio, 1981; Smyth, 1982). However, beyond the boundary of the thermal zones of influence the temperature is assumed to be less than 5°C above ambient. This distinction between geochemical and hydrologic zones of influence need not be made.

Thermal zones of influence were estimated from preliminary thermal analyses performed in support of the experiment designs (for example, Bauer et al., 1988). The thermal zone of influence was taken to be the maximum extent of the isotherm that was 5°C above ambient temperature because temperature changes of less than 5°C are unlikely to have any measurable thermomechanical effect on the host rock. Thus, material outside the zone of influence was subjected to less than a 5°C temperature change. Figure 8.4.2-17 gives an example of such a thermal analysis for the canister-scale heater experiment. The view shown is looking along the axis of the heater with the instrument access drift shown 8 m to the left. After 30 months of operation, the 35°C isotherm (31°C is ambient) has extended approximately 12 m from the heater. The effect of the ventilated drift on heat conduction away from the heater is also evident. The effects of nearby drifts were factored into the estimation of thermal zones of influence where necessary.

Hydrologic zones of influence were estimated from pretest analyses, if available, or from generic studies such as those reviewed by West (1988) and are summarized in Section 8.4.3.2. The rock surrounding an experiment was considered to have been hydrologically altered if the in situ saturation change was more than 0.01. Changes in saturation of less than 0.01 are not considered appreciable and are difficult to measure with standard instrumentation.

Mechanical interferences from stress-altered regions around drifts and alcoves were estimated from preliminary structural analyses of the experiments (summarized in Section 8.4.3.2) such as those in Costin and Bauer (1988). Figure 8.4.2-18 gives an example of the expected alteration in stresses around the demonstration breakout drift (Costin and Bauer, 1988). In the figure, lines of constant vertical stress are shown as a percentage of the initial in situ stress. The figure shows that stresses differ by less than 10 percent from the in situ stress in the region beyond approximately one drift diameter from the wall of the drift. For tests where such analyses were not available, the results of generic analyses of repository size drifts were used. In general, structural analyses of underground openings using linear elastic (Hill, 1985; Johnson and Bauer, 1987; St. John, 1987 a,b,c) or nonlinear jointed rock mass models (Thomas, 1987) show that beyond one drift diameter (in a horizontal direction) from the wall of a long drift, the stresses are within 10 percent of the initial in situ stresses. Thus, a two-drift-diameter standoff around openings was maintained to account for the stress-altered zone around the opening.

Most of the structural analysis calculations performed to support the design of the ESF underground excavations and the thermomechanical testing used a linear elastic material model to simulate the rock mass. In many of these calculations, the elastic moduli are reduced from the measured values taken from intact rock samples in an attempt to account for the effect of joints and other discontinuities on the stiffness of the rock mass. But even when such efforts to account for the discontinuous nature of jointed rock are included in the analyses, the results from linear elastic calculations may not completely represent the behavior of the rock mass, especially in regions very close to the excavations. Very near the opening (usually within 1 to 3 meters), rock is loosened by the excavation process and stresses are reduced so that joints previously held intact by high normal forces may open or shear, resulting in displacements larger than predicted from elastic theory. The severity of this nonlinear rock response near mined openings depends on the nature of the rock mass. For example, Cording (1974) found that for openings where extensive rock loosening did not take place, the tunnel closure displacements predicted from elastic calculations were within a factor of two of the

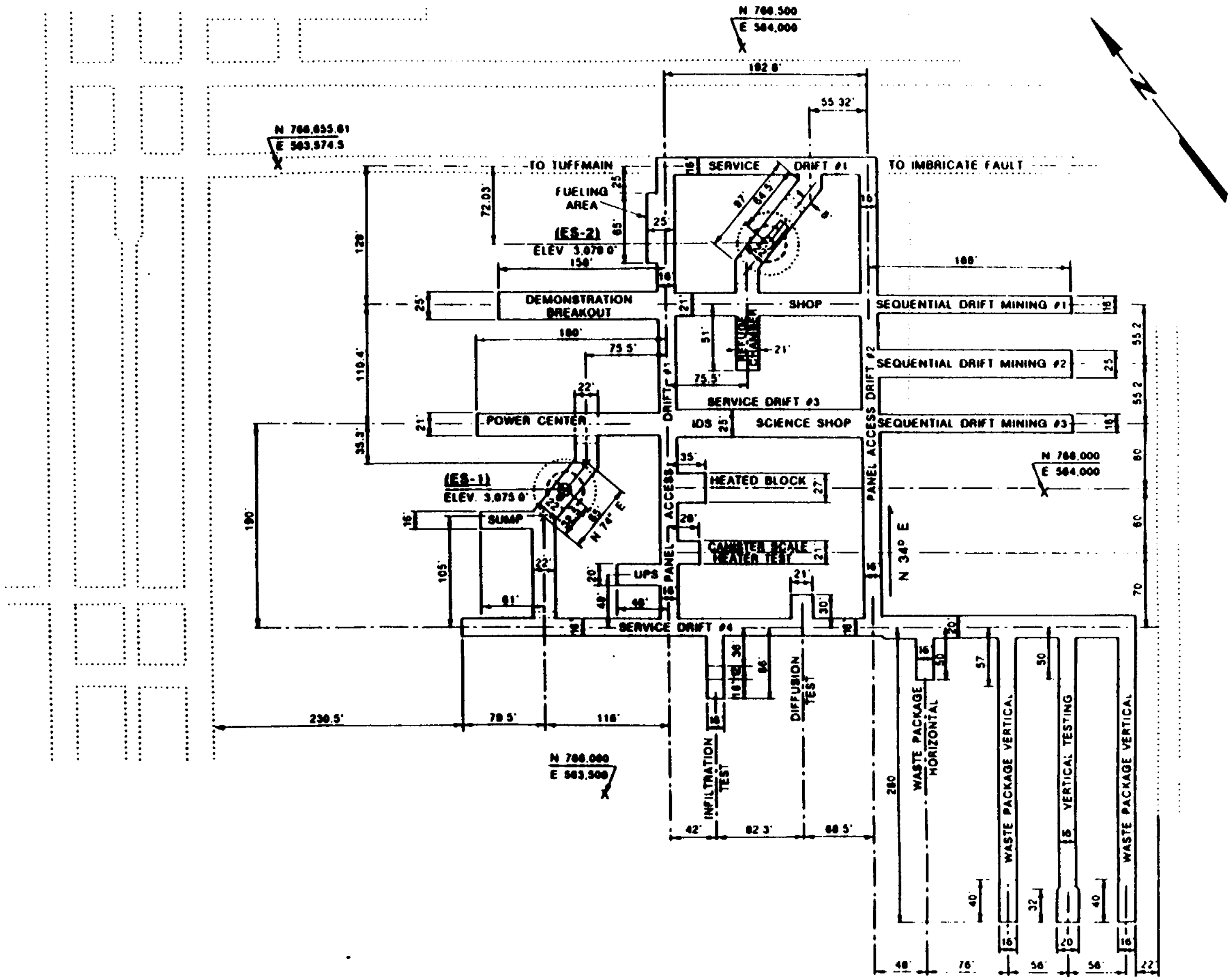


Figure 8.4.2-17. Hydrologic and mechanical zones of influence of exploratory shafts 1 and 2.

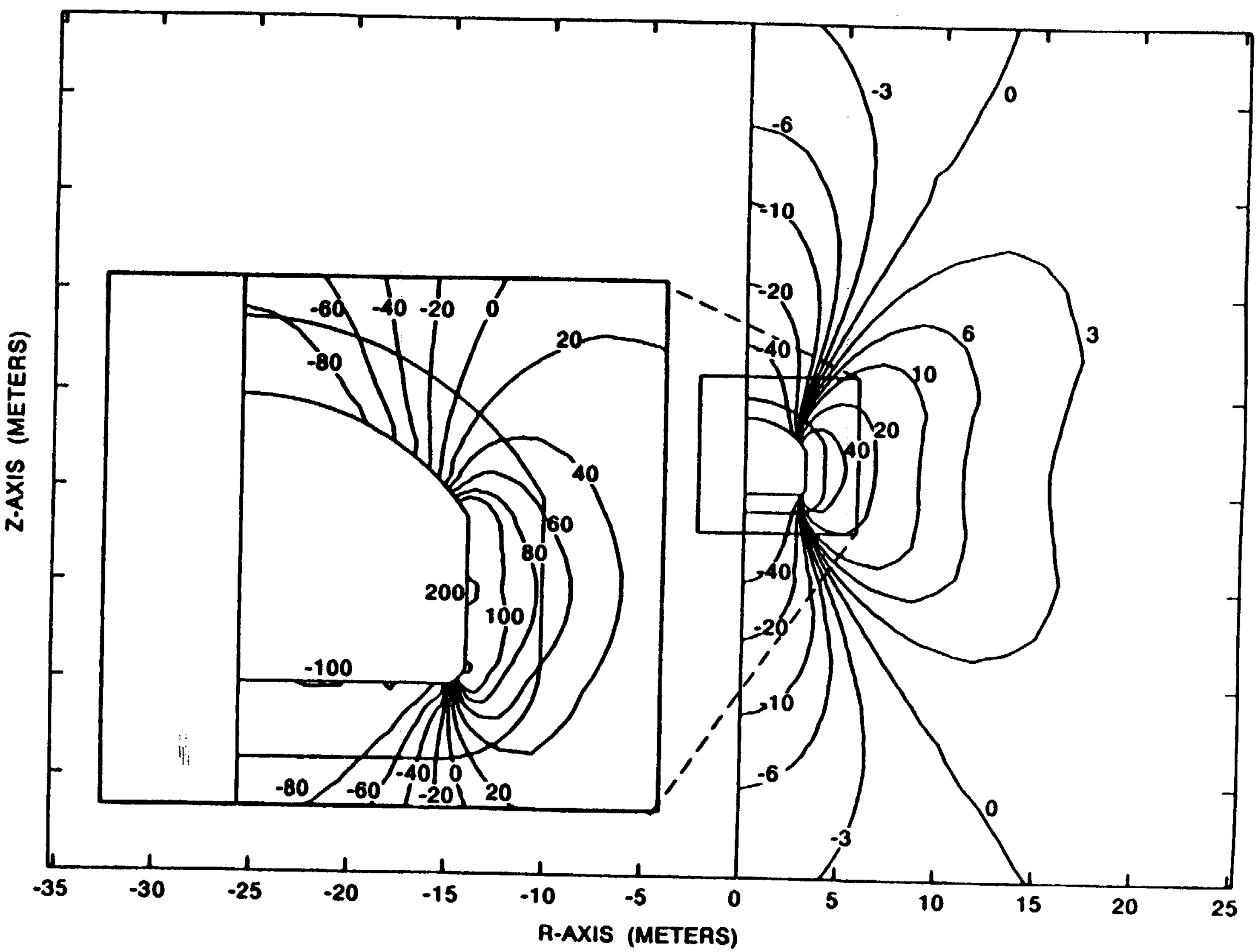


Figure 8.4.2-18 Analysis of demonstration breakout room--percentage change from in situ vertical stress.

measured values. Where rock movement and loosening along joints was evident, measured displacements ranged from 3 to 10 times the predicted elastic displacements. Farther away from the opening, where stress gradients resulting from the excavation are low, the elastic analysis is generally accurate in predicting both the trend and magnitude of displacements.

Based on preliminary testing, the rock is expected to be relatively competent at the repository level. Although the rock is known to be fractured, elastic analyses will provide good estimates of rock behavior near excavations. However, before and during site characterization, several actions are being taken to ensure that the standoff requirements and drift stability estimates (based on elastic analyses) are conservative and to substantiate that the results of previous analyses of the underground excavations and experiments are reasonable. One ongoing effort is to look carefully at the existing mining experience in welded tuff. Prototype testing of excavation methods and instrumentation has been conducted in G-Tunnel on the NTS. Zimmerman et al. (1988) reported the results of a mining experiment conducted in welded tuff. Careful measurements of rock motion and permeability were made before mining the drift, during mining, and after an experimental drift (6.1 m wide by 4.0 m high, with an arched roof) was mined. Measurements of rock motion around the drift using MPBX gages that extended 15 m into the rock around the drift indicated that the measurable disturbance to the rock extended approximately 6 m laterally from the drift. As would be expected, the disturbance into the floor and ceiling were somewhat greater. Injection tests were also conducted to measure the hydraulic quotient of the rock in several boreholes. The hydraulic quotient is a measure of the apertures of fractures that are connected with the borehole in the region tested. From this testing, the fractures were found to be tighter after excavation than before, in most places near the excavation. Near a large fault through which the drift was mined, some rock loosening was noted. However, the measured hydraulic quotient only increased from the pre-mining value for 2 to 3 m into the drift wall. In addition, displacements predicted from an elastic analysis were generally found to be within a factor of 2 of the measured displacements, except near the fault, which was not taken into account in the calculations.

This preliminary evidence suggests that the results of the elastic analyses conducted so far should reasonably predict the structural response of the ESF underground excavations. An assumption of the acceptability of a two-drift-diameter standoff for precluding significant interference between test drifts and other mined areas seems conservative. Both analyses and preliminary measurements indicate that the stress-altered region around a drift will extend only approximately one drift diameter into the rocks.

With the exception of the diffusion test, geochemical alteration was not found to be sufficiently extensive as a primary mechanism to require a standoff region. The zone of influence due to diffusion of tracers in the diffusion test was estimated to be 0.3 m at the bottom of the borehole. This estimation was taken from previous field work using a similar technique (Birgersson and Neretnieks, 1982).

Other possible interference mechanisms were considered on a test-by-test basis. The extent of instrumentation for excavation deformation analyses was the most common reason for other mechanical zones of influence. Deformation gauges, such as multiple point borehole extensometers (MPBXs), extend 15 m into the rock surrounding an instrumented drift. For proper interpretation of the displacement measurements made from such gages, the bottom anchor should remain fixed, or move only as a result of displacements induced by the instrumented drift. If other drifts are constructed close to the bottom anchor during the period when measurements are being made, the bottom anchor may move and make interpretation of the displacement data more difficult. To preclude this, interference standoff zones for such instrumentation were included in the design so that no drifts would be constructed closer than two drift diameters from the bottom of the gages.

In defining the constraint and estimating the zones of influence for each test it was assumed that strict controls over water usage and blasting methods would be applied during construction of the test area. Therefore, the zone of hydrologically or chemically disturbed material created by these construction activities was not included in the zone of influence estimation for each test but rather is included in a general way in Section 8.4.2.3.6.2. Hydrological or chemical zones of influence were determined only on the basis of the fluids and chemicals used in the test itself.

The zones of influence estimated for each experiment are based primarily on results of numerical analyses, results of prototype tests, and assumptions regarding the physical nature of the rock mass. One purpose of the early testing in the ramp and on the MTL is to provide some data that may be used to confirm or adjust the estimated zone of influence resulting from the mechanisms described above. Specifically, radial boreholes experiments will provide data on water transport and allow for monitoring of a hydrologic zone of influence. Similarly, the DBRs and the heater test in TSw1 will provide thermal and mechanical data for comparison with current analyses. If estimated disturbed zones are found to be inadequate on the basis of early test results, needed adjustments and redesign can be completed before the experiments are set in place on the MTL.

Current assessment

The drifts for DBR and the sequential drift mining tests require flexibility of orientation of the drifts. The flexibility requirement results in having to set aside an area larger than would be required if the orientation of the drifts could be fixed at the present time. For other experiments, the flexibility requirement is satisfied by providing additional areas where the experiment could be conducted. This is discussed further in Section 8.4.2.3.6.4.

The DBR experiment is intended to provide early data on rock response that will be used in the development of later experiments. Therefore, measurements in the DBR should be completed before any further construction takes place, and no interference with construction or other testing is expected. Additional area for instrumentation is not required for other excavation experiments such as the sequential drift mining experiment because the instrumentation is confined between the two outer access drifts.

The canister-scale heater, the heated block, the thermal stress test, and the waste package environment tests are sufficiently separated that thermal effects will not pose a problem to other test areas. The canister-scale heater test provides the most severe thermal loading. The heater is located in the pillar formed by the intersection of two drifts, which not only provides instrumentation access from two directions, but also helps contain the region of elevated temperatures to near the intersection. The drift ventilation helps block the thermal load from conducting across the drifts. This produces the nonsymmetric shape of the thermal front shown in Figure 8.4.2-17. However, in the near field of the heater, where the principal thermal and mechanical measurements are to be made, the thermal field is axisymmetric about the canister (Bauer et al., 1988). The waste package tests will be quite isolated and have small zones of influence so test-to-test interference should not be a problem. Preliminary thermal and structural analyses have been completed for the heated room test (Bauer et al., 1988), and zones of influence have been estimated for the proposed design. With this information, designers can locate the experiment with due consideration for interference concerns.

The zone of influence for the infiltration test is small relative to the alcove where it will be conducted. Thus, this test should not affect other nearby experiments or potential experiments that may be fielded in the dedicated test area. Similarly, the diffusion test affects only a narrow region near the borehole drilled from the diffusion test alcove. The central portion of the pillar containing the test should not be affected by the thermal experiments located in the northwest section of the pillar. The bulk permeability test areas have not been agreed upon yet. Because this test potentially could affect large areas with gas-phase pressure pulses, location relative to the longer-term, more sensitive tests is of concern and will be addressed.

Like the heated room test the seal-component tests are still in the early stages of design definition.

This discussion indicates that the layout design is a dynamic and evolving process of refining and modifying the design. Thus, the information represents a snapshot of the current state in this evolutionary process. New tests may be added and perhaps some of the currently defined tests may be changed, all of which will have some effect on the planned layout. These changes will be documented in the semiannual progress reports. Also, as the planned layout changes, the interference analysis (described earlier) will be updated as needed and used to ensure that changes will not produce unacceptable interference problems.

8.4.2.3.6.2 Potential for construction and operations interference with testing

Introduction and background

The ESF design is currently being revised. When the preliminary design is completed the potential effects of construction and operation of the underground excavations on the conduct of the experimental program will be evaluated. In this section, the process that will be used to evaluate the current layout and planned operations for potential interference with the testing program is described. Such assessments will continue to be an ongoing process and subject to frequent review as the design evolves and more data become available. The assessments are expected to be refined during the final preconstruction phase, during ramp construction when site-specific data become available, and during mining of the MTL when data for test locations and orientations become more specific.

Approach

The approach, which consists of both a forward and a backward evaluation method, will be taken to evaluate the potential impact of construction and operations on the testing program. The forward evaluation will look in detail at the description of planned operations. It specifically will look at controls placed on those operations to reduce the effect of construction and operations on the testing environment and to determine whether those controls are sufficient to satisfy the constraints to the design imposed by the experiment plans (discussed in Section 8.4.2.3.1). Operational controls include such things as plans for blast control (if blasting is used) to limit damage to surrounding rock; control of fluids introduced in the shafts and MTL from mining or other sources; control of dust, vibration, and traffic near sensitive experimental areas; use of phased construction and testing; and inclusion of sufficient separation distances between experiments to reduce the potential for interference.

The backward evaluation will consist of looking at each constraint placed on the design by the experiment plans (Section 8.4.2.3.1) and determining whether ESF operations will satisfy that constraint. This part of the assessment will include an evaluation of the sensitivity of each experiment to changes in the environment that may occur due to ESF operations. The experiments will be evaluated with regard to their sensitivity to such operational considerations as ventilation changes; traffic; potential of excess water from surface flooding; and vibration, overpressure, and dust from nearby mining.

Current assessment

The assessment will be done when the design is finalized for the ramps and the ESF.

8.4.2.3.6.3 Integration of the Exploratory Studies Facility with the repository design

This section describes the general objectives and specific actions taken to plan and coordinate the ESF design and layout with the repository design in a manner consistent with the governing regulations (10 CFR 60.15(c)(3) and (4)). The specific intent of this effort is to ensure compatibility between the ESF and the repository designs and to limit potential interference between the ESF and the repository. The repository conceptual design was described in detail in Chapter 6 of the SCP and supported by detailed evaluations presented in the SCP Conceptual Design Report (SNL, 1987). The ESF testing, layout and operations are described in Sections 8.4.2.3.1 through 8.4.2.3.5.

The ESF Alternatives Study recently completed by the DOE evaluated 34 different ESF/repository configurations. In that study, a configuration was defined as the combination of an ESF configuration and associated construction methods integrated with a repository configuration so as to provide compatible interfaces between the ESF and potential repository. That is, for each configuration the accesses and other ESF interfaces with a potential repository were defined in the context of a total ESF/repository system so that ESF accesses were compatible with and had integral functions in the repository.

In the initial part of the study, all previous ESF and potential repository conceptual configurations (including the one described in Chapter 6 of the SCP) were reviewed and new ESF/repository configurations were generated. The current reference ESF design concept, shown in Figure 8.4.2-18a, is different from the configuration discussed in the SCP. However, the potential repository underground layout is quite similar to the layout shown in Chapter 6 of the SCP. The current plan for the general layout of the potential repository is shown in Figure 8.4.2-18b.

The general approach taken to limit ESF and repository interference focused on two compatibility concerns. First, the ESF was designed to maintain compatibility with the repository layout and operations. Particular attention was paid to ensuring that repository preclosure performance objectives (10 CFR 60.111), retrievability, and radiological health and safety were not compromised by any component of the ESF design. Second, steps were taken to ensure that the ESF design was compatible with postclosure considerations, particularly with the repository sealing objectives. Specific steps taken in the design to meet these two compatibility objectives are discussed below.

Compatibility with the preclosure performance objectives was addressed primarily by establishing the experiment drifts within the dedicated testing area at the repository level. Because it

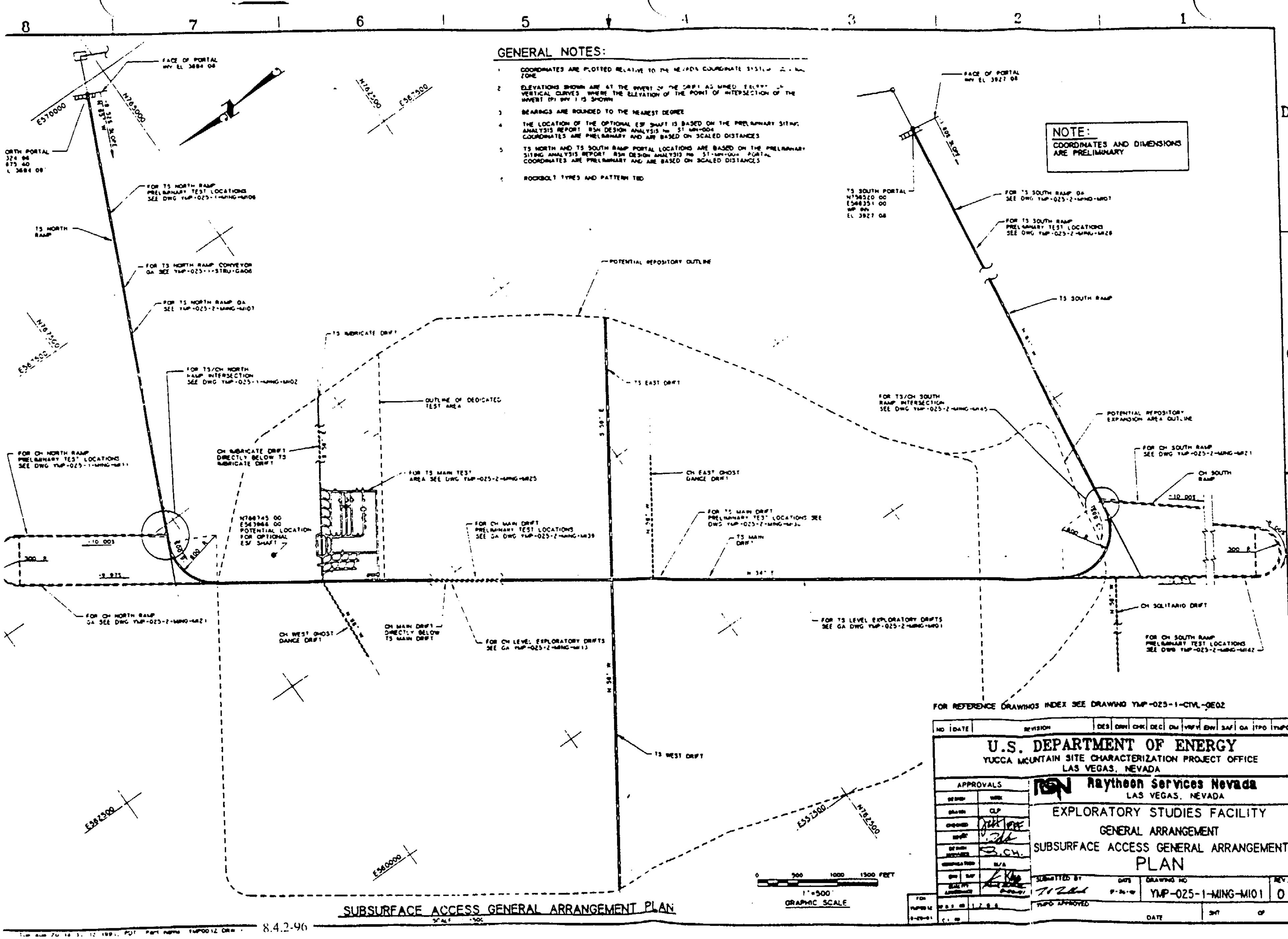
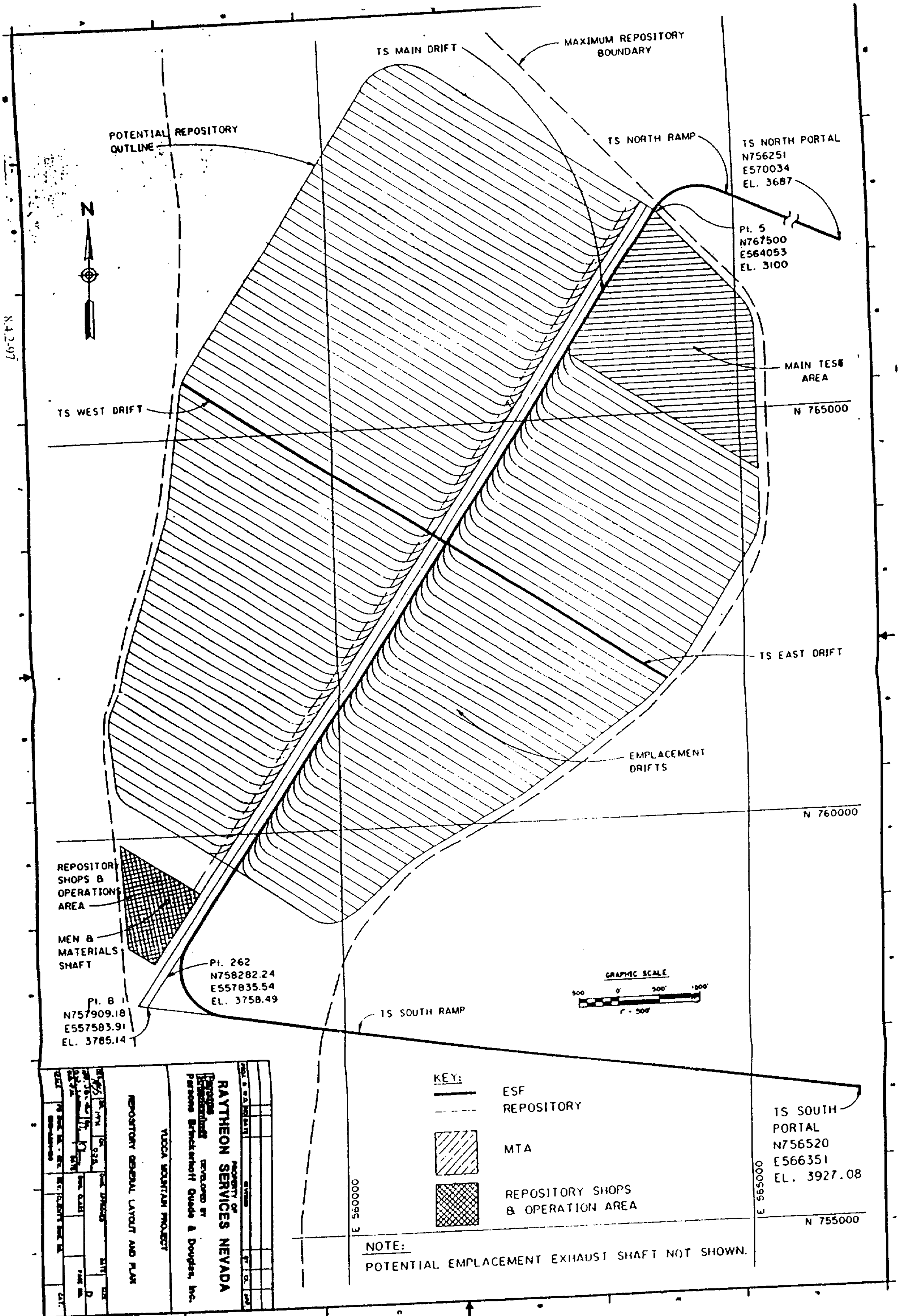


Figure 8.4.2-18a. Exploratory Studies Facility General Arrangement Subsurface Access General Arrangement.



| Figure 8.4.2-18b. Repository General Layout and Plan

is a dedicated area, no waste is planned to be stored in the test area. A minimum of a two-drift-diameter standoff from repository drifts (resulting in an even greater standoff from waste emplacement areas) is also maintained to isolate the dedicated test area and reduce the probability that testing activities would interfere with or alter any part of the repository area. The dedicated test area was planned to support both site characterization and performance confirmation testing and to locate both close to support facilities. In addition, requirements were set to incorporate the test area within the repository block but near the boundary. This was so the test area would have a limited impact on the usable repository area and still retain the flexibility to expand without affecting the planned repository mains or panel access drifts (Section 8.4.2.3.3). Also, to limit the disturbance to the repository area, the long exploratory drifts were planned to be coincident with repository drifts (and at repository grade). These drifts will also be mined using methods and controls similar to those planned for the repository. Indeed, experience gained in mining these drifts will provide important input to the mining procedures used in the repository.

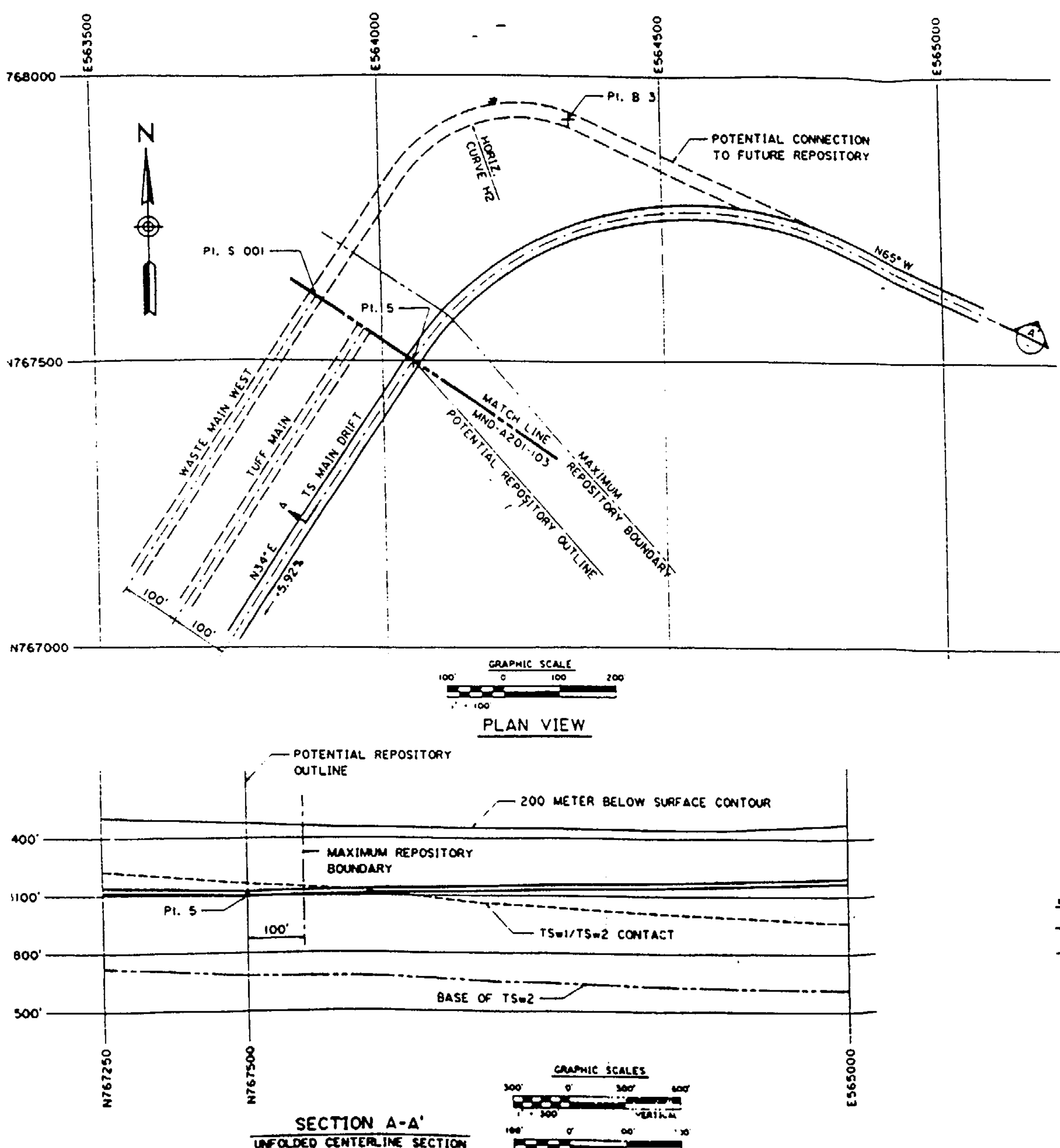
The ESF would support a potential repository in several ways: (1) the TS north and TS south ramps provide access to the underground levels; (2) the TS north and TS south ramps and the TS main drift provide the conduit for ventilation air to support waste emplacement operations; and (3) the exploratory drifts on the TS level penetrate waste emplacement areas. Pictorial representations that depict how the ESF and potential repository interface are shown in Figures 8.4.2-18b, 8.4.2-18c, and 8.4.2-18d. Tolerances at the interfaces will be established during Title II design based on generally accepted mining practices. If the site has been determined suitable, the NRC has licensed the construction of a repository, and all other pre-construction obligations have been met, the TS north and TS south ramps and underground drifts could represent the initial construction phase of a potential repository.

The various surface facilities shown in Figure 8.4.2-14 provide for worker comfort, surface and underground utilities, storage of excavated materials from underground, communications, and scientific test data collection facilities. The underground facilities shown in Figure 8.4.2-18a provide shop facilities, drifts for scientific testing, and paths for ventilation air. The most important underground activity is conducting the scientific tests and experiments. This is true for both the TS level and the CH level.

If Yucca Mountain is licensed by the NRC for use as a repository, the ESF shops will be used to support initial development of the repository until the permanent repository shops are commissioned. The utility systems used for the TS level development will be used for initial repository development until the permanent repository utilities are installed. The dedicated main test area will be modified to provide space as a training area for waste emplacement, emergency, and mine rescue activities.

The ESF may also include an optional shaft. Whether the vertical shaft will be included in the ESF design will not be determined until scientific data from the ramps are available. The optional shaft would not be considered a permanent item in the proposed repository, but as a pilot shaft to be enlarged later. The 16-foot diameter presently planned is not adequate for use in a repository.

Permanent items are items or facilities constructed or installed as part of the ESF that are converted for operational use by the repository. The majority of the excavations between the surface and the TS level would become permanent items in the proposed repository. These items would include the TS north and TS south ramps and all openings and drifts at the TS



KEY:

ESF

REPOSITORY

NOTES

1. THE GRID SYSTEM SHOWN ON THESE DRAWINGS IS THE NEVADA COORDINATE CENTRAL SYSTEM. THE POINT NUMBERS ARE BASED ON PB DEVELOPED REPOSITORY NUMBERING SYSTEM.
2. DIMENSIONS AND ELEVATIONS ARE IN FEET UNLESS OTHERWISE SPECIFIED. DIMENSIONS, ELEVATIONS AND GRADES ARE ROUNDED OFF TO THE NEAREST TWO DECIMAL PLACES.
3. THE CONTOUR OF THE BASE OF THE TSw2 FORMATION WAS DERIVED FROM SNL DRAWING CAL0304.
4. THE CONTOUR OF THE TSw1/TSw2 FORMATION CONTACT WAS DETERMINED FROM SNL DRAWING CAL0302.
5. THE 200 METER BELOW THE SURFACE CONTOUR WAS DEVELOPED FROM A 1 INCH = 500 FEET SCALE TOPOGRAPHIC MAP WITH A 10 FOOT CONTOUR INTERVAL.
6. THE 100' CENTER TO CENTER DISTANCE BETWEEN MAIN DRIFTS IS FOR ILLUSTRATION PURPOSES ONLY AND MAY BE ALTERED AFTER FURTHER EVALUATION.
7. ELEVATIONS SHOWN ARE AT THE INVERT OF THE DRIFT WITH NO FILL, LINING OR CONCRETE.
8. ALTHOUGH THERE ARE ONLY THREE MAIN DRIFTS SHOWN, A FOURTH MAIN MAY BE REQUIRED FOR ADDITIONAL VENTILATION.
9. COORDINATES CANNOT BE SCALED OFF THE UNFOLDED CENTERLINE SECTION A-A.
10. PI 5 IS THE POINT OF INTERSECTION OF THE TS NORTH RAMP AND THE REPOSITORY.
11. THE TS NORTH RAMP WILL NOT EXCEED A GRADE OF 10%.
12. ALL DRIFTS ON THIS DRAWING ARE ASSUMED TO BE 25.0 FOOT DIAMETER AND DRIVEN BY TUNNEL BORING MACHINES, EXCEPT FOR THE CONVEYOR DRIFTS.

CURVE DATA

POINT	RADIUS OF CURVE	TANGENT LENGTH	CURVE LENGTH	ANGLE
H2	250	213.52	353.43	81.00

POINT	NORTHING	EASTING	ELEVATION
5	767500.00	564053.00	3100.00
B 3	767924.84	564339.56	3069.65
S 001	767665.81	563941.16	3100.00

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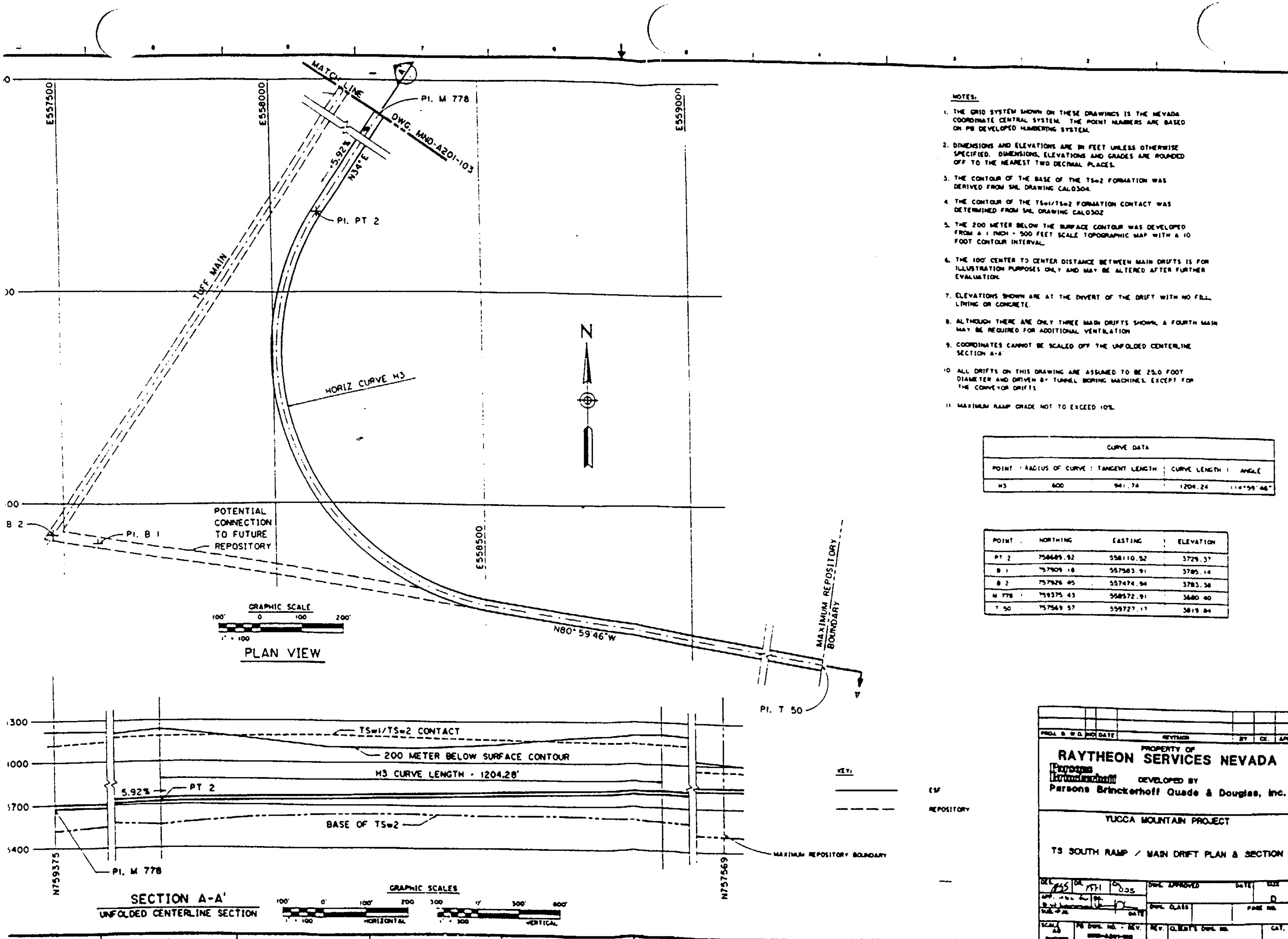
RAYTHEON SERVICES NEVADA
Parsons Brinckerhoff DEVELOPED BY
Parsons Brinckerhoff Quade & Douglas, Inc.

YUCCA MOUNTAIN PROJECT

TS NORTH RAMP / MAIN DRIFT PLAN & SECTION

SIZE D

Figure 8.4.2-18. TS North Ramp/Main Drift Plan and Section.



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4. THE CONTOUR OF THE TSw1/TSw2 FORMATION CONTACT WAS DETERMINED FROM SNL DRAWING CAL0302
5. THE 200 METER BELOW THE SURFACE CONTOUR WAS DEVELOPED FROM A 1 INCH = 500 FEET SCALE TOPOGRAPHIC MAP WITH A 10 FOOT CONTOUR INTERVAL.
6. THE 100' CENTER TO CENTER DISTANCE BETWEEN MAIN DRIFTS IS FOR ILLUSTRATION PURPOSES ONLY AND MAY BE ALTERED AFTER FURTHER EVALUATION.
7. ELEVATIONS SHOWN ARE AT THE INVERT OF THE DRIFT WITH NO FILL, LINING OR CONCRETE.
8. ALTHOUGH THERE ARE ONLY THREE MAIN DRIFTS SHOWN, A FOURTH MAIN MAY BE REQUIRED FOR ADDITIONAL VENTILATION
9. COORDINATES CANNOT BE SCALED OFF THE UNFOLDED CENTERLINE SECTION A-A'
10. ALL DRIFTS ON THIS DRAWING ARE ASSUMED TO BE 25.0 FOOT DIAMETER AND DRIVEN BY TUNNEL BORING MACHINES EXCEPT FOR THE CONVEYOR DRIFTS
11. MAXIMUM RAMP GRADE NOT TO EXCEED 10%.

CURVE DATA

POINT	RADIUS OF CURVE	TANGENT LENGTH	CURVE LENGTH	ANGLE
H3	600	941.74	1204.24	114°59'46"

POINT	NORTHING	EASTING	ELEVATION
PT 2	758685.92	558110.52	3729.37
B 1	757909.18	557583.91	3785.14
B 2	757926.45	557474.94	3783.38
M 778	759375.43	558572.91	3680.40
T 50	757569.57	559727.17	3819.84

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TS SOUTH RAMP / MAIN DRIFT PLAN & SECTION

Figure 8.4.2-18d. TS South Ramp/Main Drift Plan and Section.

level. The exception is any lateral exploratory drifts excavated undersized. All undersized drifts would need to be reworked to be made adequate for repository use and are therefore not considered permanent items.

Permanent items would also include: ground support items used to reinforce rock and/or control the movement of rock, except for items of support which may be removed or replaced if the ESF is incorporated into the repository; and operational seals, which may be defined as any engineered structure including the material placed in an underground opening and/or the peripheral rock for the purpose of controlling the flow of water and/or gas during the life of the ESF and through the preclosure phase of the repository if the site is approved.

Consistent with the design criteria in 10 CFR 60.134(b)(2) that require that seals not become pathways that compromise meeting the postclosure objectives, compatibility with repository sealing requirements was addressed in several ways. First, only a limited number of interconnections of the dedicated test area with the repository were allowed. These interconnections include long exploratory drifts, which will be used as repository drifts, and other drifts needed for ventilation. The standoff area between the dedicated test area and the repository area also provides a degree of isolation between the dedicated test area and the repository so that postclosure sealing questions are limited to the few interconnections. Additionally, any boreholes penetrating the repository horizon will be located in pillars to the extent practicable. Finally, a drainage plan was established that was compatible with repository operations and postclosure sealing concerns. Specifically, excess water entering the dedicated test area either through ramp/shaft flooding or encountering perched water zones will be expected to remain in the area and drain into the formation. The long exploratory drifts are graded to repository grades so that if repository construction proceeds they will be consistent with the repository drainage plan (drifts will slope away from the rooms in which waste is emplaced). The drainage features of the ESF layout and standoff between the testing and waste emplacement areas are consistent with meeting the additional design criteria of 10 CFR 60.133, particularly criteria (a)(1), (a)(2), (d), and (h).

8.4.2.3.6.4 Design flexibility

One of the design criteria in 10 CFR 60.133 is the requirement for flexibility of design (10 CFR 60.133(b)). That criterion requires the underground facility to have sufficient design flexibility to allow for necessary adjustments to accommodate specific site conditions. And since the ESF construction is exploratory, significant flexibility is necessary. A major aspect in the ESF design is to include sufficient flexibility (1) to provide alternative locations and orientations for the various experimental areas to ensure that geologic, hydrologic, and other constraint conditions or acceptance criteria on the location of the test can be met; (2) to incorporate additional tests within the dedicated test area; (3) to open additional areas to exploration and testing without significant impact on the repository; (4) to accommodate uncertainties or unusual site-specific conditions that may be encountered; and (5) to incorporate schedule changes allowing the more rapid development of some areas or the suspension of some activities while tests are performed. This section discusses the features of the design and layout of the ESF that address these flexibility concerns. The design and operations of the ESF are described in Sections 8.4.2.3.2 through 8.4.2.3.5, and test constraints and flexibility requirements are presented in Section 8.4.2.3.1.

Tests to be conducted in the ramps have flexibility in location. Specific depths at which each test will be performed will not be determined until construction of the ramp reaches the depths where testing is planned. Because experiments, such as the perched-water test, will be conducted only if specific conditions (such as perched-water zones) are encountered in the ramp, flexibility in scheduling of activities is necessary.

The design also provides ample space for additional testing within the boundary of the dedicated test area. While the specific location of tests have not yet been determined, the space available within the dedicated test area is much larger than the space provided in the ESF configuration described in the SCP. If necessary, areas proposed for shops and training could be converted to provide additional space for the experimental program. The shops and storage areas could then be relocated, possibly by developing the planned repository shops area that is nearby. Larger scale experiments can be incorporated by additional drifting within the dedicated test area. This is an option for incorporating the heated room experiment into the test plans.

Sufficient flexibility in the construction and operations plans to extend the scope of many of the planned activities and open additional regions for exploration or testing was included in the design. If deemed necessary, shaft sinking and mining operations could continue into the CH horizon or additional areas in the TPn could be explored by mining along planned repository drifts (at repository grade) as far as the planned repository boundary. Ventilation, utilities, and other support facilities are designed to support additional mining capability (drilling jumbos, muck haulers, etc.) so that additional mining could be done without greatly compromising the schedule.

Uncertainties in ground conditions and water flow are always part of any mining operation. The underground design for the ESF, therefore, provides for flexibility in ground support to ensure stable drifts for all areas. The ground support design is based on rock quality determinations and, thus, is tailored to the specific ground conditions encountered. Additional ground support may be required in experimental areas where severe environmental conditions may be imposed on the rock mass. In addition, poor rock conditions or excessive water may be encountered in planned test areas requiring the relocation of some tests. As discussed previously, additional area is provided for this contingency.

In conclusion, evaluations indicate that the current design layout has a great deal of inherent flexibility for arranging test activities. In addition, flexibility relative to changes in design, construction schedule, and experiment requirements have been considered. Finally, provisions or contingencies for handling changes that may be necessary during construction and experiment fielding have been considered.

8.4.2.3.6.5 Design and operational safety

Introduction and background

This section discusses the impact of safety considerations on the design and operation of the surface facility and the underground excavations of the ESF. Safety concerns and regulations are a critical factor in the design process. All applicable codes and regulations regarding health and safety, as defined in DOE Order 5480.4, were followed in the design of the ESF. These include (1) the MSHA code 30 CFR 57, (2) the State of Nevada Revised Statutes Title 46, (3) the California Administrative Code Tunnel Safety Order Title 8, (4) the California Administrative Code Mine Safety Order Title 8, and (5) the Occupational Safety and Health Administration code 29 CFR 1926. The surface facilities, the underground layout, and the ESF operations are reviewed in Sections 8.4.2.3.2 through 8.4.2.3.5. This section reviews those features of the ESF design most relevant to safety.

Discussion

The design of the surface plan includes sufficient pad size and a general arrangement of features to ensure compliance with the applicable regulations. Surface noise regulations are considered in the design of the ventilation fan systems. Finally, the road system was limited to 6 percent grades for heavy truck traffic and 10 percent grades for other traffic to limit safety hazards associated with the grades.

The underground excavation was designed so that adequate ground-support control could be maintained. This is accomplished by limiting the size and shapes of the drifts and the intersections to ensure that ground support can be designed to limit rock fall. Two independent means of egress are required to be available at all times while personnel are underground, except during the limited period before the ramps are connected. For safe equipment operation, drifts and rooms are generally limited to less than 10 percent grade.

Consideration of safety concerns is evident in the design of the support and operations systems. Support systems include ground support, ventilation, utilities (water, electrical, and compressed air), communications, and emergency escape systems. These are discussed in the following paragraphs.

The ground support system is based on a rock quality rating method and rock mechanics analyses. The requirements for support vary with the observed rock quality to ensure that all drifts will have the support necessary to maintain stability and limit the probability of rock fall in the area.

The ventilation system is designed with an overcapacity, primarily to allow for flexibility in the underground design. This overcapacity, however, also includes a margin of safety for controlling dust and maintaining air quality in the ESF. The ventilation fans are reversible and ventilation control is provided so that in the event of a fire underground, the spread of the fire and the resulting smoke and fumes can be controlled with the ventilation system.

The utility substations for electrical distribution are isolated in separate alcoves to keep them out of the main traffic patterns and to limit exposure of personnel to high voltage equipment. In addition, an uninterruptable power supply is used, with backup generators to ensure that in the event of loss of power to the site, critical facilities and equipment will have backup power.

Besides the ramps and optional shaft for emergency egress, the underground design also includes a refuge chamber. This chamber is centrally located to the operations on the MTL so personnel will have a safe, controlled area to wait for evacuation if needed. As the long lateral drifts are extended away from the dedicated test area, additional refuge areas may be included for personnel working in areas remote from the ramps. The refuge chambers are equipped with emergency utilities and communications and are airlocked to provide a controlled atmosphere.

Operational aspects of the ESF related to safety include (1) the control of the traffic patterns to limit areas where personnel and heavy equipment must work at the same time, (2) the control and isolation of potentially hazardous areas such as the shops and equipment handling areas, and (3) the isolation of the shaft stations where dumping and mucking operations are concentrated.

As just discussed, the design process for both the surface and underground operations has considered safety as a paramount issue both through enforcement of codes and regulations in the design and through additional design constraints imposed to enhance safety of the YMP.