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Site Characterization
Plan

Yucca Mountain Site, Nevada Research
and Development Area, Nevada

Volume VII

January 1988

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Nuclear Waste Policy Act
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Section 8.3.5.10

Consultation Draft

**ENGINEERED BARRIER
SYSTEM RELEASE RATES**

Site Characterization Plan

***Yucca Mountain Site, Nevada Research
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8.3.5.10 Issue resolution strategy for Issue 1.5: Will the waste package and repository engineered barrier systems meet the performance objective for radionuclide release rates as required by 10 CFR 60.113?

Regulatory basis for the issue

The NRC regulations set a performance objective for control of the release rate of radionuclides from the engineered barrier system for the time period following the end of the containment period. The draft amendments to 10 CFR Part 60, intended to incorporate the requirements of 40 CFR Part 191, state that the release rate control period will end at 10,000 yr after closure.

The portion of 10 CFR Part 60 that sets the performance objective for control of radionuclide release rate is Section 60.113(a)(1)(ii), and it states, in part, the following:

the engineered barrier system shall be designed, assuming anticipated processes and events, so that... (B) The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided that this requirement does not apply to any radionuclide which is released at a rate less than 0.1 percent of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay.

This issue is specifically restricted to showing that the engineered barrier system is designed in conformance with the statement quoted in the preceding paragraph; however, there are other needs for release rate information to support resolution of other issues. To simplify the presentation of the plans and to minimize redundancy in the discussion, the information needs under this issue will include plans to gather data to support resolution of the following issues:

1. Issue 1.1: This issue requires source term data for use in the system analysis calculations. Data on the release rate of radionuclides from the engineered barrier system for a period of 10,000 yr under anticipated processes and events to support these calculations will be provided. Data on release rates of radionuclides under lower probability scenarios (unanticipated processes and events) for 10,000 yr will also be provided. Plans for collection of the data will be given in Information Needs 1.5.4 and 1.5.5 (Sections 8.3.5.10.4 and 8.3.5.10.5).
2. Issue 1.4: This issue requires information on the rate of cladding failure and radionuclide release rate data from failed containers during the 1,000-yr containment period--plans for collection of the

data will be given in Information Needs 1.5.1 through 1.5.4 (Section 8.3.5.10.1 through 8.3.5.10.4).

3. Issue 1.9: This issue deals with the higher level findings required under 10 CFR Part 960. In particular, 10 CFR 960.3-1-5 requires calculation of the cumulative releases to the accessible environment during 100,000 yr. The data gathered in Issue 1.5 will be used to support resolution of Issue 1.9.

These issues are addressed in Sections 8.3.5.13 (Issue 1.1), 8.3.5.9 (Issue 1.4), and 8.3.5.18 (Issue 1.9).

Approach to resolving the issue

The overall waste package compliance strategy was shown in Figure 8.3.4-1 with further details in Section 8.3.4. The essence of the waste package strategy lies in an iterative process of performance allocation, performance assessment, and testing to determine if the goals are met. If not, changes are made in design, materials, models, etc., and the process is repeated until the design objectives are met with reasonable assurance. Within this overall waste package compliance strategy, the strategy for resolution of Issue 1.5 is based on present knowledge of the repository emplacement environment, the data gathered on waste form performance in environments that can be related to the projected repository environment, and the use of models to assess the performance of various system elements.

Figure 8.3.5.10-1 shows the hierarchy of models. The highlighted portion is used in the resolution of Issue 1.5 and to provide input to Issues 1.1, 1.4, and 1.9. The lower levels of detailed models support the higher levels of aggregated models. The system model and the flow and transport model are used to assess the net performance with respect to regulatory issues. The experimental studies and activities (not shown in the figure) support the detailed models by explaining mechanisms and processes, guiding model development, examining processes to make sure that no important phenomena are being overlooked, providing data for models, and validating models.

Principal input parameters for the highlighted models are presented in Table 8.3.5.10-1. Other models that support the resolution of Issue 1.5 are found in Sections 8.3.4.2 and 8.3.5.9.

The data presented in Section 7.4.3 indicate that it is very likely that the performance objective for control of release rate from the engineered barrier system can be met by the waste form in an unprotected condition, provided that the analysis is done using the conditions of the expected case. For lower probability conditions (bounding case), it may be necessary to include other system elements in the analysis. Some of the components and processes available for allocation of performance, if needed, are identified in topic E of this section.

Figures 8.3.5.10-2 and 8.3.5.10-3 show the overall outline for the reference and alternative approaches to be used in the resolution of this issue. The reference approach includes branches for both the expected case, in which the amount of water contacting the container is negligible, and a

Figure 8.3.5.10-1. Model hierarchy for Issue 1.5 (engineered barrier system release rates).

Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates
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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

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Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates
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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

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Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates
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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
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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

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Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates
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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

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Table 8.3.5.10-1. Input to predictive models for Issue 1.5, engineered barrier system release rates
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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	8.3.4.2.4.3

8.3.5.10-10

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Figure 8.3.5.10-2. Reference approach to resolving Issue 1.5 (engineered barrier system performance).

Figure 8.3.5.10-3. Alternative approaches to resolving Issue 1.5 (engineered barrier system performance), assuming case of maximum water flux per package (20 liters per year).

bounding case, in which 20 L/yr is allowed to contact each container. Although for most of the containers no liquid water is expected to be able to contact the waste, some fraction of the containers could experience up to the maximum flux of water. The actual ensemble liquid release from all packages will be calculated taking this into account. The bounding case for the reference approach allows for the possibility that all containers experience the maximum water flux, even though this is not expected to occur. The integrated liquid release mechanism referred to in Figure 8.3.5.10-2 is the combination of release-rate and solubility controls on release for both exposed spent fuel and glass still contained in breached containers.

Because the repository horizon is in the unsaturated zone, release into the gas phase must be considered. For the expected case, negligible flux of liquid water, this may be the dominant release mechanism. Because of its long half-life, carbon-14 is the only significant radionuclide available for gas-phase release during the controlled release period. Because of the lower gamma fluxes and temperatures in the controlled release period, present data suggest that the release rate will be sufficiently low to meet the requirements of 10 CFR 60.113.

Figure 8.3.5.10-3 outlines the various alternatives to be used if the reference approach proves inadequate to resolve the issue. The principal concerns are for carbon-14 on the exterior of cladding and assembly components and the readily soluble radionuclides present in the pellet cladding gap and grain boundaries that are available for rapid release.

Currently, there is considerable uncertainty in the release rates, mechanisms, and locations of carbon-14; because of this, two alternative approaches to carbon-14 control are given in Figure 8.3.5.10-3. These will be used if the carbon-14 release rates are found to exceed the 10 CFR 60.113(a) limits. Because of the small number of curies of carbon-14 present, the first alternative would be to request a new allowed release rate for carbon-14 under the provisions of 10 CFR 60.113(b), provided that it can be shown that such a release rate does not compromise the overall system performance. The second alternative would be to remove carbon-14 from the exterior of the cladding and assembly components by heating (and oxidizing the carbon to carbon dioxide) before emplacement. The carbon-14 could then be dealt with separately from the spent fuel or solidified as calcium carbonate and disposed of in standard containers.

Two alternatives are shown in the event that liquid release from bare waste is not low enough to meet the requirements of 10 CFR 60.113. The first is to take into account other components and processes to limit access of water to the spent fuel.

There are limited quantities of three readily soluble radionuclides that are present in the gap and grain boundary inventory at 1,000 yr after closure. These isotopes, Tc-99, I-129, and Cs-135, account for about 0.8 percent of the total inventory. Under the expected case of the reference approach (no liquid water), these nuclides would not be released from the engineered barrier system because there is no aqueous medium for dissolution and transport. Under the bounding case, in which bare spent fuel is contacted by as much as 20 L of liquid water per container per year, high solubility and availability of the nuclides will result in an annual release

rate that exceeds the performance objective. Therefore, it would be necessary to rely on additional components of the waste package to inhibit the access of liquid water.

The existing information is not sufficient to allow selection of the components and to allocate quantitative performance goals. Several components and processes are available to provide additional barriers to the release of gap and grain boundary radionuclides. These include

1. The rate of failure of the containers that are intact at the end of the containment period.
2. The rate of failure of fuel cladding during the entire period following closure.
3. The fraction of water that contacts and enters failed containers.
4. Dilution of concentration of radionuclides in solution within failed containers before release.

Tests and analyses to provide a basis for allocating performance to these potential barriers are described under Information Needs 1.4.2 through 1.4.4 (Sections 8.3.5.9.2 through 8.3.5.9.4) and 1.5.2 through 1.5.4 in this section.

The second alternative (which applies to both waste forms) would be to include a portion of the host rock as part of the engineered barrier system. This rock is expected to significantly limit the release rate.

In the event of failure to demonstrate all the previous approaches, an alternative container with considerably greater expected lifetime before breach would be used. This alternative has been kept as the final fallback position because of the current confidence that the requirements of 10 CFR 60.113 can be met with the existing waste package concept. An activity to examine alternative containers is being maintained so that a longer-lived container could be developed if required. This activity is described in Section 8.3.5.9.1.3.

The strategy for meeting the controlled release requirements of 10 CFR 60.113 is based on the bounding assumption that there are less than 20 L of water available per package per year. This value was obtained by multiplying the cross sectional area of a vertical borehole by 80 times the maximum anticipated flux passing downward through the cross sectional area. This value of 20 liters per year per package is consistent with the requirements placed on the repository seals. Any greater flux is not considered credible and is not designed for. The strategy applies only to an unsaturated repository.

For the reference approach, a performance allocation has been made to system elements on the basis of the bounding case (see Figure 8.3.5.10-2). The performance measures and goals associated with the reference approach are listed in Table 8.3.5.10-2. Control of the quantity of water contacting the container to less than 20 L/yr requires that the engineered environment have several performance measures and related goals. These are further discussed

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	Needed confidence
Engineered environment	Quantity of liquid water that can contact the container	<20 L per pkg per yr	High
	Water quality	Constrain water chemistry to acceptable levels for waste form performance	High
Waste form	Release rate from bare waste form inside failed containers	<1 part in 100,000 (of 1,000 year inventory) per year for each radionuclide	High

in Issue 1.10 (Section 8.3.4.2) and are not addressed in detail here. There are three performance goals and measures in the reference case. These are for the quantity and quality of water contacting waste and the release rate from bare waste forms inside failed containers. The performance parameters needed to evaluate these performance measures are listed in Table 8.3.5.10-3. The table also lists parameters that are consistent with meeting the performance goals of Table 8.3.5.10-2.

The first set of parameters (Table 8.3.5.10-3a) refers to the quality of the water contacting the waste. The goals for the constituents of the water are set so that they are consistent with the composition of well J-13 water (Chapter 4), and are used as a basis for setting goals for the other parameters. The information needs to establish both the quantity and quality of the water are discussed in Section 8.3.4.2.

The second and third sets of parameters are given in Table 8.3.5.10-3b. The second set of parameters is a list of the maximum concentrations of radionuclides permissible in effluent solutions exiting a waste package containing spent fuel. The values given for the goals are the concentrations necessary to meet the design objectives of the controlled-release period. The third set of parameters is the analogous information for the glass waste form.

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

^aNot 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).

^bTBD = to be determined.

^cNA = 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 7)

Performance measure	Performance parameter	Performance goal (Concentration of radionuclide in effluent water)		Needed confidence	Current estimated range (mg/L)	Current confidence
		(mg/L) (see note a)	(Ci/L) (see note b)			
SPENT FUEL WASTE FORM (see note c)						
	(see note d)				(see note e)	
Release rate from bare waste form inside failed container	C-14 ^f	0.206	1.80E-06 ^g	High	<40	Low
	Cl-36	5.61E-02	1.80E-06	High	To be determined	Low
	Ca-41	1.65E-02	1.80E-06	High	<20	Medium
	Ni-59	12.7	5.28E-06	High	<4	Medium
	Ni-63		1.80E-06	High		
	Se-79	8.55E-02	1.80E-06	High	<6.0E-3	Low
	Zr-93	190	1.99E-06	High	<1	High
	Nb-93m		1.89E-06	High		
	Nb-94	0.732	1.80E-06	High	<1	High
	Mo-93	289	1.80E-06	High	To be determined	Low
	Tc-99	0.798	1.34E-05	High	<0.8	Low
	Pd-107	22.0	1.80E-06	High	<10	Low
	Sn-126	8.81	1.80E-06	High	<.010	High
	I-129	11.0	1.80E-06	High	<0.2	Low
	Cs-135	7.93	1.80E-06	High	<1.6	Low
	Sm-151	9.49	1.80E-06	High	<1	High
	Ho-166m	1.00E-03	1.80E-06	High	<1	Low
	Pb-210	2.22E-05	1.80E-06	High	<4.0E-8	Medium
	Ra-226	1.82E-03	1.80E-06	High	<8.0E-2	Low
	Ac-227	2.47E-05	1.80E-06	High	To be determined	Low
	Th-230	8.91E-02	1.80E-06	High	<1.0E 08	High

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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 7)

Performance measure	Performance parameter	Performance goal (Concentration of radionuclide in effluent water)		Needed confidence	Current estimated range (mg/L)	Current confidence
		(mg/L) (see note a)	(Ci/L) (see note b)			
SPENT FUEL WASTE FORM (continued)						
	U-233		1.80E-06			
	U-234		2.10E-06			
	U-235	997	1.80E-06	High	<10	High
	U-236		1.80E-06			
	U-238		1.80E-06			
	Np-237	2.55	1.80E-06	High	To be determined	Medium
	Pu-238		1.80E-06			
	Pu-239		3.15E-04			
	Pu-240	7.78	4.94E-04	High	<5.0E-3	High
	Pu-241		1.80E-06			
	Pu-242		1.80E-06			
	Am-242m		1.80E-06			
	Am-243	8.08E-02	1.61E-05	High	<1.0E-2	High
	Cm-245		1.80E-06			
	Cm-246	1.28E-02	1.80E-06	High	<1.0E-3	Medium
	Activity of ¹⁴ CO ₂ released as a gas (gaseous release)	(see note f)		High	To be determined	Low

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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 7)

Performance measure	Performance parameter	Performance goal (Concentration of radionuclide in effluent water)		Needed confidence	Current estimated range (mg/L)	Current confidence
		(mg/L)	(Ci/L)			
		(see note h)	(see note b)			
GLASS WASTE FORM (see note i)						
Release rate from bare waste form inside failed containers	Ni-59	1.4E-02	1.09E-06	High	3.3E-04 to 4.9E-03 ^j	Medium
	Ni-63		8.78E-08			
	Se-79	8.1E-04	5.62E-08	High	1.9E-05 to 2.9E-04 ^j	Medium
	Rb-87	2.1E+02	1.76E-08	Low	1.1E-03 to 1.6E-02 ^k	Medium
	Zr-93	2.4E-01	6.22E-07	High	5.8E-03 to 8.8E-02 ^j	High
	Nb-93m	9.5E-05	6.22E-07	High	2.3E-06 to 3.4E-05 ^k	Medium
	Nb-94		1.76E-08			
	Tc-99	6.1E-02	1.03E-06	High	1.5E-03 to 2.2E-02 ^k	Low
	Pd-107	3.4E-02	1.76E-08	Medium	2.4E-04 to 3.6E-03 ^k	Medium
	Sn-126	2.9E-03	8.22E-08	High	7.0E-05 to 1.0E-03 ^j	Medium
Cs-135	5.3E-02	4.66E-08	High	1.3E-03 to 1.9E-02 ^j	Medium	

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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 7)

Performance measure	Performance parameter	Performance goal (Concentration of radionuclide in effluent water)		Needed confidence	Current estimated range (mg/L)	Current confidence
		(mg/L) (see note h)	(Ci/L) (see note b)			
GLASS WASTE FORM (continued)						
	Sm-151	1.5E-06	3.83E-08	High	3.5E-08 to 5.3E-07 ^J	Medium
	Pb-210	2.3E-07	1.76E-08	Medium	1.9E-10 to 2.8E-09 ^K	Medium
	Ra-226	1.8E-05	1.76E-08	Medium	1.9E-08 to 2.9E-07 ^K	Medium
	Ac-227	2.4E-07	1.76E-08	Low	4.7E-12 to 7.1E-11 ^K	Low
	Th-230	8.6E-04	1.76E-08	Medium	8.5E-10 to 8.5E-09 ^I	High
	Pa-231	3.7E-04	1.76E-08	Low	9.5E-09 to 1.4E-07 ^K	Low
	U-232		1.76E-08			
	U-233		1.76E-08			
	U-234	8.5E+00	4.54E-07	High	2.6E-02 to 2.6E-01 ^I	Medium
	U-235		1.76E-08			
	U-236		1.85E-08			
	U-238		1.76E-08			

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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 7)

Performance measure	Performance parameter	Performance goal (Concentration of radionuclide in effluent water)		Needed confidence	Current estimated range (mg/L)	Current confidence
		(mg/L) (see note h)	(Ci/L) (see note b)			
GLASS WASTE FORM (continued)						
	Np-237	2.5E-02	1.76E-08	Medium	3.2E-04 to 4.8E-03 ^k	Medium
	Pu-238		1.20E-07			
	Pu-239		5.14E-06			
	Pu-240	1.0E-01	3.00E-06	High	1.2E-06 to 1.2E-05 ⁱ	Low ^m
	Pu-241		1.76E-08			
	Pu-242		1.76E-08			
	Am-241		5.01E-06			
	Am-242m	1.5E-03	1.76E-08	High	3.7E-05 to 5.6E-04 ^j	Low ^m
	Am-243		1.76E-08			
	Cm-245	1.0E-04	1.76E-08	Low	4.7E-10 to 7.1E-09 ^k	Low

^aLimiting 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.

^bThe concentrations are derived from the 1×10^{-5} per year or 0.1% calculated release rate limit (CRRL) (1.8×10^{-6}) requirement for each individual radioisotope based on 20 liters per package per year flux together with the package leading assumptions in notes c and h.

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 7)

Footnotes (continued)

^cAll calculations based on 33,000 MWd/MgU fuel at 1,000 yr out-of-reactor. Inventory includes cladding and hardware. Calculations assume 62,000 mg of unoxidized spent fuel in 30,000 containers that 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).

^dTable 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.

^eCurrent 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.

^fThe 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 + gaseous release must total $<3.6\text{E-}05$ Ci/yr per package.

^g $1.80\text{E-}06$ is notation for 1.8×10^{-6} .

^hAllowed maximum concentration in mg/L for all the radioisotopes of each element. Note that nonradioactive isotopes are not included.

ⁱInventory 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 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.

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 7)

Footnotes (continued)

^jEstimated 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 415 mg/L (approximately 50% of the 1,660 kg glass in each DWPF container is silica; one part in 100,000, partitioned into 20 liters, is 415 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.

^kFor these radionuclides, the allowed release is 0.1% of the CRRL. However, the estimated release reflects the actual inventory (see Table 7-21, 1,000-yr inventory), which may be much smaller.

^lFor 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 25°C, pH 7.6, with 1 order of magnitude uncertainty.

^mAlthough 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 which raise the solubility, and the possibility that colloid transport may contribute significantly to release.

The unprotected conditions that will be assumed in the performance analysis will be different for the two basic waste forms because of the intrinsic differences. The glass waste form will be assumed to be in its pour canister, with the canister closure degraded to the point that water can flow freely into and out of the canister. The spent fuel waste form will be assumed to consist of bare fuel pellets that have been exposed due to rupture of the cladding. (Issue 1.4 places a goal on cladding failures to limit the quantity of oxidized fuel to less than 1 percent of the repository total). For both waste forms, the container will be considered to remain substantially intact, thereby providing a means to accumulate water in contact with the waste form. The container will be assumed to have failed at the most likely failure location (presently thought to be near the final closure) and the size of the failure is assumed large enough to allow free flow of water into and out of the container.

The environmental conditions to be assumed in the analysis are extreme values of the range of parameters that describe anticipated processes and events. These are discussed in detail under Issue 1.10 (Section 8.3.4.2). The extreme values are not necessarily the extreme values of the parameters but are selected to represent the values for which the largest release rate occurs. Interactive effects among parameters were considered in this selection process. In addition, in some cases there are parameters for which a physically unrealistic bounding value is assumed. For emplacement in the unsaturated zone, it is difficult to construct a scenario in which liquid water can be transported from the edge of the borehole across the air gap in a way that would allow all the water that flows past the package to flow into the package. Scenarios that involve a package tilted over to contact the borehole wall or displacement of rock into contact with a package might allow some limited amount of wicking into the package, but substantial amounts of flow do not appear to be credible. However, for the bounding case, the calculation will be done assuming that the flux of water that would flow through a volume of rock equivalent in size to the borehole volume would also flow through the container. Preliminary calculations indicate that release rates using this assumption will be sufficiently below the performance objective that licensing arguments could be made using this bounding case.

The data in hand are insufficient to choose with high confidence of success a final licensing approach for rapid gaseous release of carbon-14. Several alternatives are under study (Figure 8.3.5.10-3). The development of a better understanding of the distribution and release characteristics of carbon-14 in Zircaloy cladding and assembly hardware is needed, since the relatively large release observed in the fuel temperature test may be due to the high temperature or the high radiation field or both. Another area of investigation is the breach rate of containers, since a time-distributed failure rate for containers would minimize the pulsed carbon-14 release. The interaction of carbon-14 releases from waste packages with natural carbon in the repository air and rock-water system will also be studied (Information Need 1.5.5, Section 8.3.5.10.5). Although these items are not part of the reference case, they are discussed along with the reference case items with which they are associated.

To satisfy the needs for information to be used in resolution of Issues 1.1 (Section 8.3.5.13) and 1.9 (Section 8.3.5.18), a more realistic estimate of release rates and total releases is needed. Some of the system

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components that could provide additional control on the release rate have not been included in the reference case calculations. Inclusion of an analysis of the condition of the containers would allow credit to be taken for intact containers. Zircaloy or stainless steel cladding, either intact or with minor defects, will provide an additional control on the rate of dissolution of the pellets contained within the cladding. All these factors would result in lower estimates of the amount of waste elements leaving the container and the engineered barrier system. A further lowering of the amount of radionuclides available for transport is expected to occur during transport from the edge of the engineered barrier system through the near-field environment. The NNWSI Project adopted the current DOE interpretation of the EBS system boundary to coincide with the surfaces of the excavations within the underground facility. The DOE, however, requires the Project to reevaluate the interpretation before the completion of repository and waste package advanced conceptual design. If, in the future, portions of the host rock are to be included in the EBS, the near-field radionuclide transport studies will be needed to resolve this issue (1.5) and to provide the realistic source term to Issues 1.1 and 1.9.

Radionuclide source term calculations will examine the transport processes active in the first few meters of host rock surrounding an emplaced waste package. These calculations are required to provide detailed information on the anticipated response of the hydrogeologic and geochemical systems to the maximum design thermal loading, and to provide a basis for the assessment of the effectiveness of natural and engineered barriers against the release of radioactive materials to the environment (10 CFR 60.21). The release to the accessible environment will be calculated in activities described under Issue 1.1 (Section 8.3.5.13). A realistic source term will serve as a basis for establishing bounding conditions, and for demonstrating that predicted performance under those conditions is bounding. For radionuclide transport, many species exhibit a strong affinity for sorption onto the host rock. Under anticipated conditions, it is expected that these species will interact with rock that is within meters of the waste package, as opposed to hundreds or thousands of meters from the repository. Therefore, a radionuclide source term calculated across a boundary relatively near the waste package will serve as a realistic, although not necessarily bounding, source term for transport calculations to the accessible environment.

Table 8.3.5.10-4 presents the performance measure for this activity. The measure is the relative concentrations of radionuclide species as a function of time and distance from an emplacement hole that are adsorbed to host rock, dissolved in pore and fracture water, and in the pore and fracture gases. This activity will provide characterization of the effectiveness of the host rock against radionuclide transport. The parameters required for these assessments are host rock hydrologic properties, thermal properties, transport properties, and radionuclide sorption and exchange properties. Further, release of radionuclides from the engineered barrier system and a set of conditions representing anticipated and unanticipated processes and events are required. Table 8.3.5.10-5 provides the linkages to those parameters developed in other sections of this document. The parameters of Table 8.3.5.10-5 are developed in greater detail in Sections 8.3.4 and 8.3.5.13.

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

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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 hydro-logic 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

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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

To ensure that the testing program and analyses would provide the information needed to resolve this issue and to support the resolution of Issues 1.1 (Section 8.3.5.13) and 1.9 (Section 8.3.5.18), characterization goals were set for the description of the waste form in its as-received condition, the handling and storage of the waste form before sealing it in a container, and the characterization of the physical and chemical processes that could affect radionuclide release rates. These topics are discussed briefly in the following paragraphs.

A. Waste form definition

The characteristics of the waste forms when they are received at the repository must be known to ensure proper handling, interim storage, packaging, and disposal conditions. A number of the characteristics are inter-related, such as radionuclide inventory, burnup, and waste age for spent fuel. In this instance, a characterization goal was set for one of these parameters: the radionuclide inventory. This parameter was selected because it is likely to be the least well known, and its value is used in the greatest number of cases in the performance analyses.

Data will need to be collected to allow description of a number of the characteristics of spent fuel. At present, there is insufficient information about the variability of the waste form, and the sensitivity of waste form performance to that variability, to allow a sensible goal for characterization to be set. Where this is the case, the most complete characterization consistent with the resources for information will be provided. As information on the relative importance of the various parameters becomes available, more precise characterization goals will be set.

There are two parameters known to be important with respect to spent fuel performance under disposal conditions: elements that migrate as gases during use in the reactor and the population of cladding that contains defects. The former is needed to allow prediction of the rapid release fraction of a small number of radionuclides (isotopes of cesium, iodine, and technetium); the latter is needed to allow estimation of the number of fuel rods for which water can immediately gain access to the spent fuel. For each of these parameters, a characterization goal is assigned. This information is required for resolution of both Issue 1.4 and this issue.

For glass waste forms, the characterization goals are the same as those set in waste acceptance specifications and will not be repeated here.

The goals for spent fuel description are as follows:

1. The inventory of radionuclides at emplacement will be established to within ± 20 percent for each radionuclide that will constitute more than 5 percent of the activity at any time during the first 10,000 yr after disposal.
2. The condition of the cladding will be described so that the number of rods containing defects in the cladding at the time the waste package is assembled can be estimated to within a factor of 2, or be shown to be less than 1 percent of the population.

3. The fission gas release to the pellet-cladding gap will be determined so that the gap inventory of cesium can be estimated to within a factor of 5.

B. Postacceptance, preemplacement storage, and handling of waste forms

Certain storage and handling conditions can cause changes in the waste forms that would be detrimental to long-term performance under disposal conditions. To prevent the occurrence of those conditions, goals have been set on the handling and storage of the waste forms after receipt at the repository. These goals have been assigned on the basis of the current knowledge of waste properties and taking into consideration the present understanding of the relative importance of factors affecting performance. The goals on the number of preemplacement cladding failures are motivated by requirements on the amount of fuel that can be allowed to oxidize. Goals for cladding failures are also set under Issue 1.4.

The goals for handling and storage conditions are as follows:

1. The temperature of the spent fuel waste form and the access of air to the waste form will be controlled during transport, handling, and storage before emplacement such that oxidation of spent fuel through existing cladding defects is less than the amount that would result in 5 percent cladding strain.
2. The processes used to transport and handle spent fuel at the surface handling facility will be designed so that cladding failure from mechanical abrasion or deformation considering thermally induced effects will result in less than 5 percent cladding strain.
3. For glass waste forms, the storage conditions will be such that the transition temperature of the glass is not exceeded.

Analyses to define the temperature and air access limits required under goals 1, 2, and 3 are conducted under Information Need 1.5.2. Analyses conducted to resolve Issue 4.4 (Section 8.3.2.5) will show that the surface handling facility will comply with the temperature and air access goals determined for the spent fuel and glass waste forms.

C. Chemistry of water that enters the failed containers

Waste form dissolution rates and the solubility of mobilized radionuclides can be sensitive functions of the chemistry of the water that contacts the waste forms. The chemistry of water that contacts the containers and alterations to the water chemistry due to container corrosion will be determined in the resolution of Issue 1.10 under Information Need 1.10.4. (Section 8.3.4.2.4). The chemistry of water that could enter failed containers at a rate greater than 0.5 L/yr will be characterized to within the following limits.

pH	±1 pH unit
Anions:	±1 mg/L for fluoride, chloride, and phosphate
	±10 mg/L for nitrate and sulfate
	±30 mg/L for carbonate and bicarbonate

- Cations: ± 1 mg/L for species originally present at less than 6 mg/L.
 (Nickel and chromium are excluded from this requirement.)
 ± 5 mg/L for species originally present at between 6 and 40 mg/L
 ± 20 mg/L for species originally present at greater than 40 mg/L.

D. Dissolution rate of the components of the waste forms and solubility of mobilized radionuclides

The flow rates for water in the unsaturated zone are extremely low. The residence time for water in contact with the waste forms will be very long in those cases where water can gain access to the waste form. Dissolution rates are expected to be controlled by long-term saturation limited kinetics. A model for glass dissolution by this mechanism has been developed and appears to give a good fit to the laboratory data (Grambow, 1984; Grambow et al., 1985; 1987). Data for spent fuel dissolution, while more limited in number, appear to support a similar model for spent fuel matrix dissolution.

The spent fuel waste form is more complicated than the glass waste form because it has a number of components, each with different release or dissolution rates, for which account must be given. Note that complexity of description implies neither inferiority nor superiority of the waste form in terms of the ultimate performance that will be demonstrated.

The performance goal for the spent fuel waste form is to show that the sum of the radioactivity for the solutions and gases exiting the waste packages will contain no more than one part in 100,000 per year of the inventory of each radionuclide present in the total repository 1,000 yr after closure.

For glass waste forms, the performance goal is to show that the dissolution rate of the matrix and the mobilization of elements from the matrix will be low enough to ensure that water exiting a failed container will carry with it no more than 1 part in 100,000 per year of the container inventory of total radionuclides.

For both waste forms, for any radionuclide shown to have a dissolution or mobilization rate greater than 1 part in 100,000 per year under the conditions given in the bounding case in Figure 8.3.5.10-2, the solubility and speciation of the radionuclide under anticipated conditions will be determined.

Tests and analyses to show that these goals are achieved will be conducted under Information Needs 1.5.1, 1.5.2, and 1.5.3 (Sections 8.3.5.10.1 through 8.3.5.10.3)

E. Additional barriers available to be used to resolve this issue

The following additional barriers are available to resolve the issue, if needed, under alternative approaches for liquid releases.

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1. The container failure rate under anticipated conditions and under unanticipated conditions will be described. Tests and analyses to provide estimates of the container failure rate will be done under Information Needs 1.4.2 through 1.4.4 (Sections 8.3.5.9.2 through 8.3.5.9.4).
2. Cladding failure rate will be determined from the results of tests and analyses done under Information Needs 1.5.2 and 1.5.3 (Sections 8.3.5.10.2 and 8.3.5.10.3).
3. For water that encounters a breach in the container, the fraction of water that enters the container and fraction that passes by the breach site without entering the container will be characterized. Tests to provide data for this analysis will be done under Information Need 1.5.3 (Section 8.3.5.10.3).
4. Water that accumulates within a failed container will provide variable dilution factors for different radionuclides. The concentration of readily soluble radionuclides will be diluted in proportion to the quantity of water that accumulates. This will have the effect of reducing the release rate from the container for these nuclides. Tests and analysis to support estimation of the dilution factors will be done under Information Need 1.5.3 (Section 8.3.5.10.3).

F. Potential barriers that will not be characterized

The following potential barriers will not be characterized:

1. The flow of air into a container for which a breach sufficiently large to sustain a flow of air at 1×10^{-4} atm-cm³/s will be assumed to proceed without impediment.
2. The pour canister on the glass waste form will be assumed to provide no barrier to fluid flow.

G. Transport of radionuclide-bearing solutions through the near-field environment

The system model for performance assessment will require a source term to represent the radionuclides released across some boundary in the repository and to help provide an assessment of the effectiveness of natural and engineered barriers against release of radionuclides to the environment. To accommodate the needs of the system model for a source term, tests and analyses will be conducted to show the effects of transport of solutions that leave the waste package and migrate through the near-field environment. These tests and analyses will be done under Information Need 1.5.5 (Section 8.3.5.10.5).

No specific goals will be set for the results of these analyses; however, emphasis will be placed on actinides for which the EPA release limits to the accessible environment are a small fraction of the amount that could

be released from the engineered barrier system under the performance objective for radionuclide release rate of 10 CFR 60.113. Data will be gathered predominantly for plutonium and americium (Oversby, 1986).

Interrelationships of information needs

Information Needs 1.5.1 and 1.5.2, and parts of 1.5.3 and 1.5.4 will be used for resolving Issue 1.4 and this issue (1.5). The data from Information Needs 1.5.3 and 1.5.4 not used for this issue (1.5) and all of Information Need 1.5.5 will be used in the resolution of Issues 1.1, 1.4, and 1.9, which are addressed in Sections 8.3.5.13, 8.3.5.9 and 8.3.5.18, respectively.

The schedule information provided for information needs in this section includes the sequencing, interrelationships, and relative durations of the activities in the information need. Specific durations and start/finish dates for the activities are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

8.3.5.10.1 Information Need 1.5.1: Waste package design features that affect the rate of radionuclide release

Technical basis for addressing the information need

This information need addresses the condition of the waste (spent fuel or glass) as it arrives at the repository, and the NNWSI Project waste package design features important to determining radionuclide release. To model the performance of the waste forms under repository conditions, reliable data are required on the population statistics for the parameters listed in the following parameters section.

Link to the technical data chapters and applicable support documents

The characteristics of the waste form are discussed in Chapter 7, Section 7.4.3. Glass waste forms will be further described in the waste qualification report from the waste producer. The waste container design is described in Section 7.3, and the behavior of the metal barrier components of the waste package are discussed in Section 7.4.2.

Parameters

For the spent fuel waste form, parameters are required for the fuel itself, the fuel cladding, and other assembly parts.

The fuel parameters are as follows:

1. As-fabricated fuel characteristics (composition, density, etc.).
2. Peak and average burnup.
3. Radionuclide inventory.

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4. Peak linear heat generation rate (LHGR).
5. Reactor type: pressurized water reactor (PWR), boiling water reactor (BWR), or other.
6. Fission gas release.
7. Microstructural changes in the fuel due to irradiation.
8. Discharge date.
9. Storage medium and access of air or water to the fuel.
10. Mean and peak storage temperature.
11. Preemplacement releases of radionuclides, if any.

The cladding parameters are as follows:

1. Chemical composition.
2. Rod pressurization.
3. Percentage of rods with defected cladding, types of defects, and circumstances under which failure occurred.
4. Degree of oxidation.
5. Amount and type of crud deposits.
6. Radionuclide inventory of cladding.
7. Degree of hydrogen embrittlement or hydride formation, if known.
8. Peak and average storage temperature.
9. Discharge date.
10. Degree of mechanical damage to cladding that does not result in immediate cladding failure.
11. Preemplacement releases of radionuclides from cladding or cladding deposits, if any.

The parameters required for other assembly parts are

1. Chemical composition.
2. Location in assembly.
3. Discharge date.

4. Chemical or physical changes in assembly components due to irradiation or storage.
5. Preemplacement releases of radionuclides from assembly components, if any.

The parameters for glass waste forms are

1. Chemical composition.
2. Radionuclide inventory.
3. Chemical and phase stability.
4. Pour canister design.
5. Pour canister material.
6. Pour canister material properties.
7. Pour canister closure data.
8. Content of free liquids.
9. Gas content in canister voids.
10. Explosive, pyrophoric, or combustible material content.
11. Organic material content.
12. Free volume.
13. Decay heat generation rate.
14. Radiation dose rates.
15. Chemical compatibility of waste form with pour canister.
16. Weight of glass.
17. Cracking and fine particle production.
18. Chemical compatibility of pour canister and container.
19. Shipment, storage, and repository handling thermal history.

The parameters for both waste forms are

1. Timing of delivery of the various waste types to the repository.
2. Container design.
3. Container materials.
4. Chemical compatibility of waste forms with container.
5. Container orientation.
6. Borehole liner design.
7. Borehole liner materials.
8. Compatibility of waste form with borehole liners.
9. Borehole liner corrosion rate.
10. Borehole liner corrosion products.
11. Borehole shield plug design.
12. Borehole shield plug materials.
13. Compatibility of waste forms with borehole shield plugs.
14. Alteration or corrosion products of borehole shield plugs.
15. Repository thermal loading.
16. Package thermal cycle in repository.

Logic

The parameters just listed will provide a complete description of the waste as emplaced in the repository and provide the data to determine how the waste characteristics will change during the lifetime of the repository.

8.3.5.10.1.1 Activity 1.5.1.1: Integrate waste form data and waste package design data

This activity accumulates the information in the parameters listed previously from waste producers, fuel manufacturers, and other repository studies. No tests or analyses are performed in this activity.

8.3.5.10.1.1.1 Subactivity 1.5.1.1.1: Integrate spent fuel information

This subactivity will involve participation in the Spent Fuel Working Group, liaison activities with the DOE Office of Storage and Transportation Systems and other groups that may provide data on spent fuel, and review and accumulation of spent fuel data and results to determine whether information specified in the parameters listed previously is adequately provided by producers and other repository studies.

8.3.5.10.1.1.2 Subactivity 1.5.1.1.2: Integrate glass waste form information

This subactivity will involve participation in the waste acceptance process; liaison activities with West Valley Demonstration Project (WVDP), Savannah River Laboratory (SRL), and the Defense Waste Processing Facility (DWPF); and review and accumulation of glass waste form data and results to determine whether information specified in the parameters listed previously is adequately provided by producers and other repository studies. Most of the information specified in the glass waste form parameters is expected to be provided in the Waste Qualification Report as part of the waste acceptance process. The major goal of this activity is to ensure that the needed data are provided.

8.3.5.10.1.1.3 Subactivity 1.5.1.1.3: Integrate waste package and repository design information

This subactivity will involve review and accumulation of data other than that provided by waste producers and the NNWSI Project waste form studies, including the parameters common to spent fuel and glass waste forms in the list given earlier.

8.3.5.10.1.2 Application of results

The results of this information need will determine the characteristics of the waste forms as received and emplaced at the repository, and provide the data to determine how those characteristics will change with time. Because they will establish important parameters such as waste form weight, radiation dose rates, and thermal properties, these activities are important

to all design and safety issues. The data will be used as the basis for the testing and modeling of waste form performance, and thus will be used in resolving Issues 1.1 (Section 8.3.5.13), 1.4 (Section 8.3.5.9), 1.5, and 1.9 (Section 8.3.5.18), as well as issues requiring knowledge of the radionuclide release source term.

8.3.5.10.1.3 Schedule and milestones

This information need addressing waste package design features, contains one activity: 1.5.1.5 (integrate waste form data and waste package design data). No milestones are defined; hence, timelines depicting schedule information are not presented in this section. Summary schedule and milestone information for this information need can be found in Section 8.5.2.2.

The one activity in this information need is ongoing and involves the participation of outside committees to collect and review pertinent data used in other activities.

Work performed under this information need is not seriously constrained by other program elements.

8.3.5.10.2 Information Need 1.5.2: Material properties of the waste form

Technical basis for addressing the information need

This information need covers the experimental work carried out to determine the material properties of the spent fuel and glass waste forms and to assess how these properties would affect the behavior of the waste forms under the NNWSI Project repository conditions. The data generated by these activities will be used under Information Need 1.5.3 (Section 8.3.5.10.3) to develop models for the long-term performance of the waste forms.

Link to the technical data chapters and applicable support documents

The available data on spent fuel dissolution are discussed in Section 7.4.3.1.1, and data on the degradation and leaching of the glass waste form in Section 7.4.3.2. The available data on the oxidation of irradiated uranium dioxide (UO_2) fuel are discussed in Section 7.4.3.1.2. The available data on the corrosion of Zircaloy are discussed in Section 7.4.3.1.3.

Parameters

The information needed from other information needs includes the following:

1. Waste form characteristics and waste package design features (Information Need 1.5.1, Section 8.3.5.10.1).

2. Chemistry of the water contacting the waste form (Information Need 1.10.4, Section 8.3.4.2.4).
3. Temperature as a function of time (Information Need 1.10.4, Section 8.3.4.2.4).
4. Release scenarios (Information Need 1.5.3, Section 8.3.5.10.3).

The information that will be obtained in this information need includes the following:

1. Release rate of radionuclides from the spent fuel waste form (includes both fuel and nonfuel components).
2. Mechanisms of release from spent fuel.
3. Oxidation rate of spent fuel as a function of temperature.
4. Primary mechanisms and rates of Zircaloy cladding failure.
5. Release rate of radionuclides from the glass waste forms.
6. Mechanisms of release from the glass waste forms.

Logic

The parameters given in the preceding list define the material properties of the waste forms that will determine their performance in the repository.

The primary mechanism for the transport of radioactivity from a failed waste package is dissolution of the waste form into ground water followed by migration due to the natural flow of ground water. It is thus important to determine both the release rate of the radionuclides of interest from the waste form as a function of time as well as the equilibrium solubilities of these elements in ground water of appropriate composition.

Because the spent fuel waste form in a failed container may be exposed to the oxygen in air for a period of time before its initial contact with ground water, it is necessary to determine the oxidation rate of uranium dioxide and the effect of oxidation on dissolution. In addition, the volume change attendant upon the conversion of UO_2 to U_3O_8 may cause gross failure of the Zircaloy cladding on a fuel rod with preexisting minor cladding defects. This would expose a much greater area of fuel to both oxygen and ground water than would be the case for an essentially intact fuel rod and would affect both the oxidation rate and the dissolution rate. This affects the resolution of both this issue and Issue 1.4 (Section 8.3.5.9).

The Zircaloy cladding in the spent fuel waste form may provide a barrier for the release of radionuclides, especially those elements present in the rapidly released, gap and grain boundary inventory such as cesium and iodine. The corrosion rate of Zircaloy will be studied to determine the effectiveness of the cladding in retarding the release of radionuclides. The nonfuel components of the spent fuel waste form (including cladding) that contain

activation products will also contribute to the radionuclide inventory of the repository. Corrosion of these assembly parts is likely to be a major source of several radionuclides (nickel-59, niobium-94, carbon-14).

Radionuclide release from glass waste forms can only occur after breach of both the container and the pour canister, and subsequent entry of water.

8.3.5.10.2.1 Activity 1.5.2.1: Characterization of the spent fuel waste form

The purpose of this activity is to conduct tests that will provide data on the release rate of radionuclides from the spent fuel waste form. In all, this activity consists of six subactivities; however, the bulk of the experimental effort is covered by the first three subactivities discussed.

8.3.5.10.2.1.1 Subactivity 1.5.2.1.1: Dissolution and leaching of spent fuel

Objectives

The objective of this subactivity is to determine the release rate of radionuclides from spent UO_2 fuel. Tests will be conducted to determine the effect on the release rate of the parameters in the following list. The results of these tests will be used to develop models of spent fuel dissolution and radionuclide release under Information Need 1.5.3 (Section 8.3.5.10.3).

Parameters

Tests are required for the following parameters:

1. Fuel burnup.
2. Fission gas release of the fuel during reactor operation.
3. Temperature.
4. Oxidation state of the uranium in the spent fuel.
5. Water chemistry.
6. Reactor type: pressurized water reactor (PWR), boiling water reactor (BWR), or other.
7. Grain size of the fuel.
8. Radiation field.

Description

The basic methodology of the tests will be to subject specimens of spent fuel rods to contact with the NNWSI Project reference ground water (well J-13 water). Tests will be conducted using a variety of spent fuel types that represent the population of fuel expected to be emplaced in the repository. Periodic samples of the solution will be analyzed for water chemistry and radionuclide content. At the end of the tests, samples of the leached fuel will be examined with the scanning electron microscope and optical microscope to determine, if possible, the location of any preferential dissolution. An effort will be made to identify any phases that precipitate during the test. The results of two series of tests using these methods are summarized in Section 7.4.3.1.1.

8.3.5.10.2.1.2 Subactivity 1.5.2.1.2: Oxidation of spent fuel

Objectives

The objective of this subactivity is to determine the oxidation rate of irradiated UO_2 fuel as a function of the parameters in the following list. The results of these tests will be used to support the development of release models under Information Need 1.5.3 (Section 8.3.5.10.3). Some of the oxidized fuel produced by this activity will be used in spent fuel dissolution tests.

Parameters

Tests are required for the following parameters:

1. Temperature.
2. Grain size of the fuel.
3. Particle size of the fuel (fracture density).
4. Atmospheric humidity.
5. Radiation field.
6. Burnup of the fuel.
7. Fission gas release of the fuel.

Description

Two types of tests are planned: (1) thermogravimetric analyses (TGA) and (2) long-term dry-bath oxidation tests. Both techniques maintain the spent fuel specimen at a constant temperature and humidity in a 20% O_2 + 80% N_2 atmosphere. The primary means of determining the degree of oxidation is by monitoring the weight gain of the sample over the course of the test. The two methods are complementary. The TGA tests provide continuous monitoring of weight changes of small samples for periods up to approximately three months. The dry-bath oxidation tests use larger samples and can be run for longer periods of time (two or more years) and can, therefore, provide information on oxidation rates at lower temperatures than the TGA system; however, the record of weight gain by the sample is not continuous. After oxidation, fuel specimens from both types of tests will be examined using x-ray diffraction, ceramography, and the ion-microprobe. Einziger (1985)

presents a more complete technical description of the tests to be conducted under this subactivity.

8.3.5.10.2.1.3 Subactivity 1.5.2.1.3: Corrosion of Zircaloy

Objectives

The objectives of this subactivity are to determine the principal modes of Zircaloy cladding degradation and to determine the failure rate of cladding due to these modes. The results of these tests will be used to support the development of release models under Information Need 1.5.3 (Section 8.3.5.10.3). Those release models are needed to resolve both this issue and Issue 1.4 (Section 8.3.5.9).

Parameters

Tests are required for the following parameters:

1. Presence or absence of liquid water.
2. Water chemistry, especially iodine and fluorine content.
3. Stress levels in the cladding (includes pressurization and pressure due to fission gas release).
4. Temperature.
5. Compatibility of Zircaloy with other metals in the waste package.
6. Hydrogen (hydride) content of the cladding.
7. Thickness of the external oxide layer on the cladding.
8. Radiation field.
9. Irradiation history of the cladding.

Description

Smith (1985) has summarized the conditions in a tuff repository as they pertain to Zircaloy corrosion and has identified the corrosion processes expected to operate under these conditions. As discussed in Section 7.4.3.1.3, the likely modes of cladding failure are (1) stress corrosion cracking, (2) electrochemical corrosion, and (3) hydride reorientation. Uniform corrosion is thought to be too slow to be an important mode of cladding degradation. Stress rupture of the cladding may occur if a small cladding defect exists and the fuel oxidizes or if undefected rods are subjected to high temperatures. Tests are planned to study each of the preceding failure modes and to quantify the rate at which they occur. To obtain results on a laboratory time scale, it is likely that testing will need to be carried out under conditions more extreme than those anticipated

for the tuff repository. Extrapolation of the results to repository conditions will require mechanistic models for the various failure modes and will be carried out under the activities for Information Need 1.5.3 (Section 8.3.5.10.3).

The report by Smith (1985) discusses the planned test matrix. Three types of tests are currently planned:

1. Electrochemical corrosion tests will involve the exposure of Zircaloy cladding to ground water in the presence of air, tuff, and stainless steel at a variety of temperatures and pressures. The effect of particular ions thought to be important will be evaluated by modifying the chemistry of the NNWSI Project J-13 well water used in these tests.
2. Stress corrosion cracking testing will be carried out using C-rings of Zircaloy, which will be stressed to near their yield point in the presence of ground water, and by the use of an apparatus allowing cladding segments to be overpressurized in the presence of liquid water.
3. The role of stress rupture will be evaluated by overpressurizing Zircaloy-clad fuel rod segments.

In all these tests, the Zircaloy will be examined after testing by a variety of techniques, including, but not limited to, metallography, scanning electron microscopy, transmission electron microscopy, and a scanning Auger technique. In addition to these tests, the importance of hydride reorientation for Zircaloy failure will be evaluated. Additional tests may be undertaken as a better understanding of the behavior of Zircaloy under tuff repository conditions develops.

8.3.5.10.2.1.4 Subactivity 1.5.2.1.4: Corrosion of and radionuclide release from other materials in the spent fuel waste form

Objectives

The objectives of this subactivity are to quantify the corrosion rate and consequent release of radionuclides from components of the spent fuel waste form not included in the studies on the uranium dioxide fuel itself and its Zircaloy cladding. The primary components to be studied are stainless steel, Inconel, and naval brass parts used as spacers, fittings, and other structural elements of reactor fuel assemblies. The results of these tests will be used to support the development of radionuclide release models under Information Need 1.5.3 (Section 8.3.5.10.3).

Parameters

Tests are required for the following parameters:

1. Composition of material.
2. Water chemistry.

3. Temperature.
4. Radiation field.
5. Irradiation history of the material.
6. Atmospheric humidity.

Description

At present, the tests to evaluate the release of radionuclides from assembly materials are in the planning stage. Some form of semistatic leach testing under conditions similar to those anticipated in the tuff repository will probably be performed. The tests will need to identify both the corrosion rate of the various assembly materials and the rate of radionuclide release from the materials and their corrosion products.

8.3.5.10.2.1.5 Subactivity 1.5.2.1.5: Evaluation of the inventory and release of carbon-14 from Zircaloy cladding

Objectives

The objectives of this subactivity are to determine the source, inventory, and location of carbon-14 in Zircaloy cladding. In addition, the potential for release of carbon-14 in the form of carbon dioxide from cladding will be studied. The parameters in the following list are presently thought to be of importance in determining both the inventory and release characteristics of carbon-14 in Zircaloy cladding. The results of these tests will be used to support the development of radionuclide release models under Information Need 1.5.3 (Section 8.3.5.10.3).

Parameters

Tests are required for the following parameters:

1. Reactor type: pressurized water reactor (PWR), boiling water reactor (BWR), or other.
2. Irradiation history.
3. Extent and nature of crud deposits on the cladding.
4. Thickness of oxide film on the cladding.
5. Temperature.
6. Radiation field.
7. Nature of atmosphere surrounding the cladding (oxidizing or inert).

Description

Experiments are planned to determine the release characteristics of carbon-14 from Zircaloy cladding. These involve heating whole assemblies, individual rods, or rod segments in an oxidizing atmosphere and measuring the

release of carbon-14 as a function of time and temperature. Other studies are aimed at establishing how much of the carbon-14 is located within the Zircaloy and how much is carried by the external coatings of crud and zirconium oxide. These studies involve controlled etching of cladding segments before heating to release the carbon as carbon dioxide. In both types of test, the cladding will be examined to document the nature and extent of any surface deposits as well as any microstructure within the body of the cladding. Additional tests may be conducted as more information on carbon-14 in Zircaloy is gathered.

The source of the carbon-14 has a large role in determining whether the radioactive carbon is within the Zircaloy or is in surface deposits. If the carbon-14 is produced primarily by (n,p) reactions on nitrogen-14 impurities within the cladding, then most of the carbon-14 would be expected to be located there. If, on the other hand, (n,alpha) reactions on oxygen-17 in the reactor cooling water are the dominant source, then the carbon-14 will probably be mainly located in surface deposits. The relative importance of these sources may depend on the type of reactor involved. The release characteristics of the carbon-14 will depend strongly on the relative importance of these two sources; the carbon-14 should be released from surface deposits much more quickly than if the carbon must diffuse through a significant thickness of cladding. Isotopic analyses of the stable carbon-12 and carbon-13 associated with the released carbon-14 may aid in identifying the source of the latter.

8.3.5.10.2.1.6 Subactivity 1.5.2.1.6: Other experiments on the spent fuel waste form

Objectives

As testing continues on the properties and behavior of the spent fuel waste form, it is possible that additional tests not covered by the other five subactivities in this activity will be required. Those tests will be conducted under this subactivity. Currently, only one area of investigation falls into this category: the behavior of stainless steel-clad fuel under tuff repository conditions.

Description

Test descriptions will be issued as the need arises.

8.3.5.10.2.2 Activity 1.5.2.2: Characterization of the glass waste form

The purpose of the subactivities in this analysis is to provide the data required to calculate release rates from glass waste forms.

8.3.5.10.2.2.1 Subactivity 1.5.2.2.1: Leach testing of glass

Objectives

The objectives of this subactivity are to (1) use static leach testing to provide high-quality, high-precision data on the rates and amounts of radionuclide release from waste glass in contact with standing water and (2) use unsaturated leach testing to provide data on the rates and amounts of radionuclide release from waste glass that is contacted by water, which then flows off the glass without remaining for long periods of time.

Parameters

The information needed from other information needs includes

1. Waste glass composition.
2. Leaching water composition.
3. Temperature.
4. Ratio of water-to-glass surface area.
5. Container material.
6. Pour canister material.
7. Other waste form characteristics from Information Need 1.5.1 (Section 8.3.5.10.1).

The output parameters for this activity are the rates of release of radionuclides from waste glasses in contact with water and in the presence of important materials such as the container material.

Description

Leaching of glass in contact with standing water may occur when water fills a breached glass container and pour canister. Leach testing under static conditions will provide constraints on the release rate under these conditions. In addition, leach testing under static conditions is the simplest form of leach testing, and the results may be generally applied to provide constraints upon other leaching scenarios. The simplicity of these experiments makes them the most reproducible form of leach testing. The testing done in this activity is intended to test the most important scenarios for release (e.g., temperature, water chemistry, and interaction with repository materials). Accordingly, long-term test matrices will be set up drawing upon the information obtained from the materials interactions tests (Subactivity 1.5.2.2.2, Section 8.3.5.10.2.2.2) that will examine a broad range of possible leaching conditions.

A possible scenario for release from glass may be that in which water enters a breached pour canister and reacts with the glass (but is not held in contact with the glass) and then flows away. Water dripping onto and off glass is one example. Because of the extremely high glass-to-water ratios

that may occur under these conditions, a special test called the NNWSI Project Unsaturated Test Method has been developed to examine the effects of release under these conditions (Section 7.4.3.2). As part of this activity, unsaturated testing will be performed to provide the complementary data to that described for static leach testing.

Glasses to be tested in this subactivity will include both radioactive and simulated-waste glasses. A range in compositions representing the range to be produced (as described by the producer in the Waste Compliance Plan and Waste Qualification Report) will be used. All related confirmation testing will be conducted under this activity (refer to milestones in Section 8.3.5.10.2.4).

8.3.5.10.2.2.2 Subactivity 1.5.2.2.2: Materials interactions affecting glass leaching

Objectives

The objective of this subactivity is to examine a broad range of factors that may influence glass leaching and degradation. Those determined to be most important will be tested further in Subactivity 1.5.2.2.1 (Section 8.3.5.10.2.2.1). This activity will provide information on mechanisms for input to development of the glass leaching model, Activity 1.5.3.4 (Section 8.3.5.10.3.4). Both calculational and experimental techniques will be used to examine the effects of possible interactions so that no important mechanisms for glass release will fail to be considered by the testing and modeling programs.

Parameters

The information needed from other information needs includes

1. Waste glass composition.
2. Leaching water composition.
3. Temperature.
4. Ratio of water-to-glass surface area.
5. Container material.
6. Pour canister material and heat-treated canister material.
7. Radiation effects on leachant composition.
8. Cracking and disaggregation of glass.
9. Changes in fluid composition caused by other repository components such as grout and concrete.

10. Other waste form characteristics from Information Need 1.5.1
(Section 8.3.5.10.1).

The output parameters for this activity are the effects on glass alteration rate, and on glass leaching rate and mechanism caused by the interactions of the studied materials.

Description

A large number of interactions may affect the rate of glass degradation in the repository. Among the most important are interactions involving the parameters in the preceding list. Other interactions will be identified and examined as part of this activity.

Two types of experimental work will be conducted. In the first type, leaching experiments will be performed in which the interacting material, or radiation, is present with the glass. Several leaching tests will be used including static testing, unsaturated testing, and pulsed flow testing. In the second type of testing, fluid chemistries will be altered to simulate repository influences. In both tests, EQ3/6 modeling will be used to aid in designing the experiments, and the results will then be used to aid in the development of the glass modeling EQ3/6 package of codes. Container materials will be added to the experiments based on the metal selection process (Issue 1.4, Section 8.3.5.9). Until the metal is selected, type 304L stainless steel (the pour canister material) will be used.

8.3.5.10.2.2.3 Subactivity 1.5.2.2.3: Cooperative testing with waste producers

Objectives

The objective of this subactivity is to conduct a cooperative testing program with the waste producers to allow for the testing of full-scale waste forms and to ensure that the laboratory-scale test results obtained by the producers are consistent with those obtained by the NNWSI Project.

Parameters

The most important parameters for this subactivity are the following:

1. The effect of scale (full-scale versus laboratory-scale) tests on leaching rates.
2. Water flow and contact with glass in a pour canister.
3. Reproducibility and accuracy of testing.
4. Glass compositional effects on leach rates.

Other parameters are the same as those listed for Subactivity 1.5.2.2.2 (Section 8.3.5.10.2.2.2).

Description

This subactivity involves cooperation with the waste form producers in designing and interpreting leach tests on laboratory-scale and full-scale waste forms. No testing under this subactivity will be performed by the NNWSI Project. Full-scale testing will be performed by the waste producers on whole canisters and pieces cut from canisters to ensure that the laboratory-scale measurements can be adequately applied to actual leaching in the repository. The NNWSI Project will provide the following: (1) assistance in designing the experiments, (2) assistance in interpreting the results including geochemical analysis using EQ3/6 and the glass modeling codes, and (3) repository relevant materials to be used in testing possible repository interactions.

The waste producers are also conducting laboratory-scale tests similar to those done by the NNWSI Project. In this subactivity, those results will be compared to ensure that the waste producers and the NNWSI Project both observe similar behavior in glass leaching experiments. Additional tests may be added to the other two NNWSI Project glass testing activities to confirm these results or to resolve inconsistencies.

Because a large body of consistent data on glass leaching behavior is required, the cooperation with waste form producers is important to confirm that the data provided by waste-producer tests will be usable in licensing the repository.

8.3.5.10.2.3 Application of results

The information generated under this information need will be used to develop models and scenarios for the release of radionuclides in Information Need 1.5.3, Section 8.3.5.10.3. This information is also the primary input to those models. Other performance issues that are directly affected by the material properties of the waste form are Issues 1.1 (Section 8.3.5.13), 1.2 Section 8.3.5.14), and 1.4 (Section 8.3.5.9).

8.3.5.10.2.4 Schedule and milestones

This information need, addressing material properties of the waste form, contains two activities: 1.5.2.1 (characterization of the spent fuel waste form), and 1.5.2.2 (characterization of the glass waste form). In the figure that follows, the schedule information for these activities is presented in the form of timelines. The timelines extend from implementation of the activities to the issuance of the final products associated with the activities. Summary schedule and milestone information for this information need can be found in Section 8.5.2.2.

Both of the activities in this information need are ongoing. The activities involve experimental work and modeling, which is progressing in parallel with other Issue 1.5 activities. There will be frequent transfers of information among the parallel activities until resolution of the issue.

Activities in this information need are currently not constrained by other program elements. However, as the activities progress, interfaces with other activities become more important.

The activity numbers and titles corresponding to the timelines are shown on the left of the following figure. The points shown on the timelines represent major events or important milestones associated with the activities. Solid lines represent activity durations and dashed lines show interfaces.

The points on the timeline and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone M005. Issue interim report on oxidation rates and mechanisms of spent fuel.
2	Milestone P111. Initiate long-term confirmation testing of spent fuel.
3	Milestone M269. Complete spent fuel waste form testing for design.
4	Milestone M006. Issue report on test results of dissolution rates of partially oxidized fuel.
5	Milestone M011. Issue final report on Zircaloy corrosion.
6	Milestone P201. Issue final report on oxidation rates and mechanisms of spent fuel.

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<u>Point number</u>	<u>Description</u>
7	Milestone P256. Complete confirmatory testing of spent fuel waste forms for license application.
8	Milestone Z067. Issue final report on the dissolution of spent fuel.
9	Milestone Z069. Complete confirmatory testing of spent fuel waste forms.
10	Milestone Z064. Issue report on results of unsaturated testing of glass waste forms.
11	Milestone Z065. Complete determination of the radionuclide release rate from glass waste forms at 60°C relative to 90°C.
12	Milestone W208. Complete parametric testing of glass.
13	Milestone M009. Initiate long-term confirmation testing of HLW glass.
14	Milestone P112. Complete West Valley glass waste form testing for design.
15	Milestone Z066. Complete studies of alteration of glass.
16	Milestone Z068. Issue final report on leaching of waste glass.
17	Milestone Z070. Complete confirmatory testing of glass waste forms.
18	Complete documentation of waste form results for license application.

8.3.5.10.3 Information Need 1.5.3: Scenarios and models needed to predict the rate of radionuclide release from the waste package and engineered barrier system

Technical basis for addressing the information need

This information need will draw together the scenarios and conditions for radionuclide release provided by information needs or investigations under the the following issues or characterization programs:

<u>Issue or program</u>	<u>Short title</u>
1.1	Total system performance (Section 8.3.5.13)
1.4	Containment by waste package (Section 8.3.5.9)
1.10	Waste package characteristics (postclosure) (Section 8.3.4.2)
8.3.1.2	Geohydrology
8.3.1.3	Geochemistry
8.3.1.4	Rock characteristics
8.3.1.5	Climate
8.3.1.6	Erosion
8.3.1.8	Postclosure tectonics

This information will be combined with the models that will be used to predict radionuclide release under anticipated and unanticipated conditions for 10,000 yr (10 CFR 60.112 and 40 CFR 191.13) and under expected conditions for 100,000 yr (10 CFR 960.3-1-5).

Link to the technical data chapters and applicable support documents

The scenarios and conditions for radionuclide release are derived from the information on site geology (Chapter 1), hydrology (Chapter 3), geochemistry (Chapter 4), climatology (Chapter 5), repository design (Chapter 6), emplacement environment (Section 7.1), waste package design (Section 7.3), waste package environment (Section 7.4.1), and metal barriers studies (Section 7.4.2). Some scenarios requiring analysis will arise from information need of total system performance assessment, which is discussed in Section 8.3.5.13.

Performance assessment models that will be used to predict radionuclide release from the engineered barrier system have been discussed in Section 7.4.5 and the interrelationships are shown in Figure 8.3.5.10-1. The design-related inputs to these analyses appear in Section 7.3. Details of activities that will develop waste package process models that will be implemented in performance assessment modeling appear in waste package environment (Section 7.4.1), metal barrier studies (Section 7.4.2), waste form degradation (Section 7.4.3), and geochemical modeling (Section 7.4.4). Model inputs are shown in Table 8.3.5.10-1.

Parameters

Input parameters for scenario development are the following:

1. Output parameters from Issue 1.1 (conditions that reflect climatic, geohydrologic, or geologic phenomena in the far field but which result in changes at the repository level computed by total system performance models) (Section 8.3.5.13).
2. Output parameters from Information Need 1.4.4 (waste package container failure modes and times) (Section 8.3.5.9.4).
3. Output parameters from Issue 1.10 (configurations and characteristics of waste package designs) (Section 8.3.4.2).
4. Output parameters from Issue 1.11 (characteristics of the repository and engineered barriers) (Section 8.3.2.2).
5. Output parameters from Issue 1.12 (characteristics of the shaft and borehole seals that may affect waste package performance) (Section 8.3.3.2).
6. Output parameters from Characterization Programs 8.3.1.2 and 8.3.1.3 (changes in geohydrologic and geochemical conditions).
7. Output parameters from Characterization Programs 8.3.1.4 through 8.3.1.8 (changes in geologic, hydrologic, and geomechanical conditions that may directly affect waste package performance).

Output parameters for scenario development are the scenarios themselves.

Data needed for the geochemical modeling of the reaction of waste forms with water are the following:

1. The equilibrium aqueous speciation of solutes.
2. The equilibrium solid and aqueous compositions of systems consisting of mixtures of gas, liquid, and solids.
3. The thermodynamic and kinetic data for solid and liquid species required to calculate equilibria and reaction rates in gas-liquid-solid systems.

The output parameters from geochemical modeling are the following: fluid compositions, amount and composition of solids, and overall rates of reaction and approach to equilibrium for complicated systems.

The input parameters for waste form release models are the following:

1. The waste form characterization parameters specified in Information Need 1.5.1.

2. The waste form material properties specified in Information Need 1.5.2.
3. The parameters specified previously in this information need (1.5.3).

The output parameters from waste package release models are the rates of release of radionuclides from waste packages.

The performance assessment models will require two kinds of input parameters, both of which have been described earlier in this section. First, the parameters describing anticipated and unanticipated events (i.e., the scenarios) serve to establish the range of cases for which performance must be calculated. These parameters also specify the range of conditions under which the waste package must perform. Second, the remaining parameters for release and geochemical interactions provide the mechanisms of waste release that will be integrated by the performance assessment calculation of release from the engineered barrier system. The parameters required by performance assessment will contain the probabilistic information necessary to meet the reasonable assurance standard required by the NRC.

The output parameters obtained from the waste package performance assessment model are cumulative distribution functions for the time to failure of the container, the release rates of radionuclides from failed waste packages, and release rates of radionuclides from the engineered barrier system.

Logic

Calculation of the release rates of radionuclides from the engineered barrier system requires an integrated analysis of all the significant factors affecting loss of waste package containment. These include the release of radionuclides from the waste form and the movement of radionuclides away from a breached package. Release begins with container failure. Gaseous radionuclides may be assumed to leave the package upon loss of containment. Solid phase radionuclides that are contained within the waste form will require contact with ground water for release to occur. Therefore, the amount and chemistry of ground water as influenced by the waste package environment, the condition of the container, the nature of the interaction between waste form and ground water, and the inventory of waste present will affect the availability of radionuclides for transport. Once the radionuclides are in solution, pathways by which the waste may leave the waste package will complete the determination of releases from the engineered barrier system.

The information provided under this information need constitutes the basic models needed to assess waste package performance. They incorporate all applicable information from characterization, design, and performance studies.

There are five activities in this information need. Each of the first four activities addresses a specific modeling need, and they are all combined in the fifth activity (1.5.3.5) (Section 8.3.5.10.3.5).

8.3.5.10.3.1 Activity 1.5.3.1: Integrate scenarios for release from waste package

The following subactivity supports this evaluation.

8.3.5.10.3.1.1 Subactivity 1.5.3.1.1: Integrate waste package scenarios

Objectives

The objective of this subactivity is to identify and assemble the specific parameters needed for waste package release calculations and collect the required data from the investigations conducted to satisfy those needs. This information will be used to construct scenarios for release, consisting of sets of parameter values to be used for waste package performance assessment. These scenarios will encompass the values needed to represent anticipated and unanticipated events.

Parameters

The input parameters for this subactivity are listed in the combined list in the technical basis section for this information need. The most important parameters are expected to be as follows:

1. Package environment.
2. Package configuration.
3. Containment performance.
4. Anticipated and unanticipated processes and events not developed under this subactivity.

The output parameters are the set of scenarios representing anticipated and unanticipated events under which release is expected to occur.

Description

The possible sources of information were discussed in the preceding parameters section. Once collected, the parameters will be reformatted into input data for modeling of the waste package performance assessment modeling. The input data will contain the required parameters in a probabilistic form to allow calculations that will address the reasonable assurance standard for radionuclide release.

The parameters will consist of the data needed to describe the environment surrounding the waste package, the configuration of the waste package, and all input variables required by the release models of the performance assessment model. Most of these parameters will be developed in this information need and will be described in the following information needs. Since release cannot begin until the container has failed, the time of failure supplied by the loss of containment calculations will form a part of the parameter set (Information Need 1.4.5, Section 8.3.5.9.5). Some scenarios

will be supplied from total system performance assessment under Information Need 1.1.3 (Section 8.3.5.13.3).

8.3.5.10.3.2 Activity 1.5.3.2: Develop geochemical speciation and reaction model

Objectives

The objective of this activity is to further develop the geochemical modeling code EQ3/6 for use in modeling of waste form radionuclide release and the behavior of released radionuclides. The need to make long-term predictions of release rates and the fate of released radionuclides requires the use of a geochemically sound model that accounts for the perturbations that may exist within the repository and is consistent with existing thermodynamic and waste form experimental data. For use in understanding long-term behavior, geochemical modeling codes must be capable of modeling processes already identified as major factors affecting radionuclide behavior, such as dissolution and precipitation. For use in modeling waste form release, the codes must be capable of modeling the dissolution behavior of the waste in ways that are consistent with experimental data and that provide information about the important factors affecting radionuclide release.

The EQ3/6 code package, the associated data base, and the use of the code in geochemical applications have been described in Section 7.4.4. The codes have already been used to interpret the results of rock-water interactions tests, to evaluate ground-water analyses and determine whether equilibrium conditions exist, to determine solubility limits for radionuclides under various realistic conditions, and to aid in the design of laboratory experiments by identifying parameters that need to be measured to understand the chemical processes that drive the experimental system. The EQ3/6 package may be used to calculate the fluid compositions and solid phases with their amounts and their radionuclides content that would result from the equilibration of hypothetical solutions resulting from the dissolution of waste forms in water. Similarly, it may be used to calculate the changes in composition of a water as it flows through and reacts with repository rock, engineered barrier materials, or a waste form. The codes are also useful for testing the thermodynamic feasibility of proposed mechanisms and for identifying the equilibrium reactions that control a given process. Two subactivities support this evaluation.

8.3.5.10.3.2.1 Subactivity 1.5.3.2.1: Develop data base for geochemical modeling

Objectives

The objective of this subactivity is to develop a supporting data base containing thermodynamic and kinetic information on aqueous species and solids that may occur in the repository.

The application of EQ3/6 to modeling of fluids important to radionuclide release behavior requires this data base, which is accumulated through review and verification of published values and through determination and validation of new data determined to be of the highest importance in continuing the modeling goals outlined in the other investigations in this information need and in Information Need 1.5.5, (Section 8.3.5.10.5). An important aspect of this activity is a sensitivity analysis to determine which data are the most critical to achieving modeling needs described under Subactivity 1.5.3.2.2 (Section 8.3.5.10.3.2.2).

Description

EQ3/6 data files contain the standard thermodynamic data that are reported in the literature for solids, aqueous species, and gases. These values have been gathered from the available literature as an ongoing effort. Despite a doubling in the total species in the data base and many improvements in consistency, organization, and documentation, data base work has lagged behind code development. Therefore, a significant increase in effort will be directed toward improving and upgrading the data base.

Requisite thermodynamic values for aqueous species and solid phases specific to nuclear waste that are reported in the literature will be critically evaluated for instances where data are missing or inadequate for modeling needs. In these instances, laboratory work will be conducted to obtain that data. Full compatibility with the key values recommended by the Committee on Data for Science and Technology (CODATA) task group and the thermodynamic data base sponsored by the Nuclear Energy Agency (NEA) will be developed. The validation of the data base will be carried out by comparing the results of theoretical calculations using the EQ3/6 package with experimental results and field data.

The implementation of the aspects of the EQ3/6 package required to adequately model radionuclide behavior will require other types of information in addition to that currently contained in the thermodynamic data base. This information includes kinetic rate constants, nucleation rates, and sorption coefficients. When required by the modeling efforts supported by EQ3/6, these data will also be evaluated and experimentally determined.

8.3.5.10.3.2.2 Subactivity 1.5.3.2.2: Develop geochemical modeling code

Objectives

The objective of this subactivity is to upgrade the EQ3/6 package to model important chemical processes in a nuclear waste repository. These codes will then be used in the other waste package modeling efforts (this information need) to aid in design and interpretation of experimental work on waste form degradation (Information Need 1.5.2, Section 8.3.5.10.2), to model the behavior of radionuclides after release from the waste package (Information Need 1.1.4, Section 8.3.5.13.4 and Information Need 1.5.5, Section 8.3.5.10.5), and to aid in the description of the waste package environment (Information Need 1.4.2, Section 8.3.5.9.2 and Information Need 1.10.4,

Section 8.3.4.2.4). Code documentation and verification will be done concurrently with development.

Description

The following capabilities will be added to the EQ3/6 code package to achieve the objectives:

1. Extend the geochemical flow model. The current flow model may be used to examine the evolution of a packet of ground water as it moves along a flow path. A different flow model is required to model the interaction of a stationary object, such as the waste form, with successive packets of water. This models the evolution of the waste form (formation of precipitates and loss of soluble elements), and provides solution compositions leaving the waste package.
2. Extend the kinetics capabilities. The current capabilities will be tested and modified to include the effects of nucleation and substances inhibiting precipitation. Kinetic data will be accumulated from published work, and the possibility of extracting kinetic information from dissolution data will be examined and implemented if appropriate. New kinetics data on important systems will be collected as part of Subactivity 1.5.3.2.1.
3. Complete model for systems open to gases. The present fixed-fugacity option will be upgraded to better model the expected scenarios in Yucca Mountain. Currently, equilibrium with an unlimited gas reservoir may be modeled. The option will be expanded to permit modeling of closed systems containing varying amounts of gas.
4. Upgrade the data base management programs. The data base handling programs MCRT and EQTL will be upgraded to incorporate random (direct) access storage of the data files, so that rapid checks of data may be made. A capability to handle new temperature extrapolation algorithms will be added. The required handling algorithms for new data developed in the data base program will be developed (e.g., kinetics, sorption, and nucleation data).
5. Extend solid solutions to include site mixing concept. This addition would make the modeling of intermediate-composition phases more accurate and provide a better way to handle the substitution of radionuclides into specific sites in minerals. The current method calculates properties of intermediates using both ideal and nonideal (as appropriate) mixing of end members. The new capability would deal explicitly with intrasite mixing (where an ion can occur on more than one site in a mineral) and will be selectively applied to cases where substitutions result in structural changes in a mineral that are not present in any end-member phases.

6. Add equilibrium sorption model: A model for sorption onto waste package and repository materials is required to adequately model radionuclide concentrations in water and the migration of radionuclides. A suitable model will be identified and incorporated into the EQ3/6 code package. Sorption data available in the literature will be adopted as appropriate. New sorption data on important systems will be collected as part of Information Need 1.5.5 and Characterization Program 8.3.1.3.
7. Extend the code for compatibility with other models. Because EQ3/6 is used in support of other modeling efforts, revisions or additions for compatibility and flexibility may be required.

8.3.5.10.3.3 Activity 1.5.3.3: Generate models for release from spent fuel

8.3.5.10.3.3.1 Subactivity 1.5.3.3.1: Generate release for spent fuel models

Objectives

The primary mechanism for the release of radionuclides from spent fuel is via water that has come in contact with the waste form through a breach in a container. A few radionuclides such as carbon-14 (or krypton 85 in the containment period) can be released in the gas phase in the absence of liquid water. The objective of this activity is to develop models for the release of radionuclides from the spent fuel waste form as a function of time using the scenarios identified in Activity 1.5.3.1 of this issue. This development will require the development of submodels for oxidation and radionuclide release from spent UO_2 fuel, the corrosion and failure rates of Zircaloy cladding, and the release rate of radionuclides from nonfuel assembly parts. These submodels will be based on the experimental data generated under Information Need 1.5.2. The models developed in this activity will be used in resolving both Issues 1.4 and 1.5.

Parameters

The parameters required for this activity are given in the combined list for this information need. The most important input parameters are expected to be the water contact rate and mechanism, water chemistry, temperature, and time. The output parameter provided by this activity will be a model for radionuclide release from the spent fuel waste form within breached containers.

Description

Tests to determine the behavior of the spent fuel waste form under the anticipated conditions at Yucca Mountain are described in Sections 7.4.3.1 and 8.3.5.10.2 (Information Need 1.5.2). These tests form the basis for the modeling to be carried out under this activity. To extrapolate the observations made in the laboratory to the time scale for which the performance of the repository must be specified to satisfy the 10 CFR Part 60 requirements, it will be necessary to develop predictive models based on an understanding

of the mechanisms involved in the degradation of the waste form. Several submodels will be generated describing the behavior of each component of the waste form that affects the release of radionuclides.

The largest reservoir of radionuclides in the waste form is the spent UO_2 fuel, and the primary barrier to the release of radionuclides is the fuel material itself. Thus, the most important submodel to be generated under this activity is the one for the dissolution of and radionuclide release from the spent fuel. This model will yield predictions of the concentration of radionuclides as a function of time in the ground water that has come in contact with spent fuel. Analyses of the available data (Section 7.4.3.1.1) indicate that the radionuclides of interest occur in two regions within the spent fuel, and are released at different rates, depending on the region. One group of radionuclides is present within the UO_2 fuel matrix, and therefore has a release rate that is limited by the dissolution of that matrix. The other group of radionuclides is located both in the matrix and along fuel grain boundaries or in the gap between the fuel pellets and the cladding. The grain boundary and gap inventory of these nuclides is typically 1-2 percent of their total inventory. This fraction is released rapidly upon contact of the fuel by water. The latter group also includes those that are present in a gaseous phase and can, therefore, be released from a breached container even without the presence of water as a solvent and transport medium. The submodels will account for all of these release mechanisms.

Development of the submodel will be assisted by the use of EQ3/6 code analyses. These analyses will provide insight into the role of solid phases in determining the equilibrium solution concentrations of elements present in sufficient quantity to saturate the ground water. The final submodel will incorporate EQ3/6 calculations of the dissolution rate and solution concentrations of radionuclides of interest in performance assessment. The usefulness of the EQ3/6 code to this effort is critically dependent upon the availability of good thermodynamic data for the chemical elements and saturating phases of interest.

Since the transport of most radionuclides from spent fuel requires that water come in contact with the fuel, the presence of undefected cladding would provide a second barrier (after the container) between the fuel and the environment. The failure rate of the cladding will have a large effect on the release rate of the gap and grain boundary inventory of the fuel as discussed previously. A second submodel will be developed that will estimate the failure rate of Zircaloy cladding as a function of time. This submodel will incorporate the results of experimental tests aimed at identifying the important modes of corrosion resulting in failure of the cladding and the rates of those modes. Mechanistic models of Zircaloy failure will be developed to extend the laboratory measurements to the time scale of the repository isolation period.

The third submodel will quantify the oxidation rate of spent UO_2 fuel exposed to an atmosphere containing oxygen. Because the ground-water infiltration rate at Yucca Mountain is low, if both the container and cladding fail, fuel may be exposed to the air for some time before it is contacted by water. The higher oxides of uranium may have different leaching behavior than UO_2 . In addition, oxidation of fuel in slightly defected

cladding could lead to gross failure of the cladding due to expansion of the fuel during oxidation. The oxidation submodel will be based on the results of oxidation experiments on spent fuel discussed in Information Need 1.5.2. The oxidation rate of UO_2 strongly depends on temperature; the model, therefore, will be time dependent. At some time after emplacement, the temperature of the fuel is expected to be sufficiently low that no significant oxidation of the fuel will occur in the time available. After that time, this submodel will not play an active role in determining the release of radionuclides from the waste form.

The fourth and final submodel will describe the release of radionuclides from cladding and other fuel assembly hardware (mostly Zircaloy, Inconel and stainless steel).

The submodels will be combined to make a single model for the release of radionuclides from the spent fuel waste form. Obviously, there will be significant interactions between the submodels. For example, the release of most radionuclides cannot occur until the fuel is exposed by cladding failure and water contacts the fuel. Thus, the predictions of the Zircaloy submodel must be used as input for the submodel describing the release of radionuclides from the fuel.

8.3.5.10.3.4 Activity 1.5.3.4: Generate models for release from glass waste forms

8.3.5.10.3.4.1 Subactivity 1.5.3.4.1: Generate release models for glass waste forms

Objectives

The release of radionuclides from glass waste forms may occur if water contacts a container that has breached. The objective of this activity is to design models for glass release based on the scenarios identified in Activity 1.5.3.1 (Section 8.3.5.10.3.1). The geochemical modeling codes described in Activity 1.5.3.2 (Section 8.3.5.10.3.2) will be an important part of these models. The models generated by this activity will provide estimates of radionuclide release as a function of repository conditions and will be used in resolving Issue 1.4 and this issue (1.5).

Parameters

The parameters required for this activity are given in the combined list for this information need. The most important input parameters are expected to be water contact rate and mechanism, water chemistry, temperature, time, and interactions with repository materials. The parameter provided by this activity will be a model for radionuclide release from glass waste within breached containers.

Description

The behavior of glass waste forms under the expected conditions at Yucca Mountain is described in Section 7.4.3.2. The extension to long times of the

semiempirical relationships discovered by laboratory testing cannot be made without understanding the mechanisms involved and assessing the effects of factors such as the slow buildup of crystalline layers. The model to be developed will account for glass degradation and radionuclide release using geochemically sound methods that incorporate expected perturbations in the repository environment, and will be consistent with the existing laboratory and natural analog studies.

Glass performance modeling will depend upon two basic concepts. First, the rate of release from the thermodynamically unstable waste glass is a kinetically controlled process. No formal equilibrium can exist. Second, once components are released from glass, the formation of solids and composition of fluids may be modeled by equilibrium processes. The final outcome of these equilibrium processes will be modeled, providing important limits on the behavior of radionuclides. In addition, the kinetics of these processes may be modeled to provide more accurate estimates of radionuclide concentrations in waste package fluids as a function of time throughout the life of the repository.

The model for glass degradation will incorporate the following items, presented here in the order in which they will be developed:

1. Calculation of the composition of the solutions that are in true equilibrium with the solid phases that precipitate on the surface of nuclear waste glasses.
2. Calculation of the rate of degradation of glass using kinetic rate laws based on transition state theory, deriving rate constants from experimental and natural-analog studies.
3. Calculation of the rate of formation of solid precipitates and the concomitant rate at which radionuclides are permanently sequestered in those stable phases.
4. Calculation of the effects of repository materials on the previously stated items, including heat-affected stainless steel from the pour canister.
5. Calculation of the composition of fluids leaving a glass waste package by combining the preceding items.

In each item, the appropriate analytical expressions will be identified from experimental work, from review of the glass degradation literature, and from geochemical modeling concepts incorporated in the EQ3/6 code. Calculations will be performed using EQ3/6.

Validation of the glass model will be done in two stages. First, the model will be developed in concert with experimental work and will be tested for its ability to describe accurately the experimental work. An important aspect of this is the use of modeling to aid in understanding the physical processes important in glass degradation. Second, the results of long-term modeling will be compared with extrapolations of laboratory data, and with natural analogs. This second effort will both test the validity of the model and, more importantly, examine whether the experimental work has examined all

the important geochemical interactions that are predicted to occur over long periods of time.

8.3.5.10.3.5 Activity 1.5.3.5: Waste package performance assessment model development

Three subactivities support this performance evaluation.

8.3.5.10.3.5.1 Subactivity 1.5.3.5.1: Development of system model

Objectives

The development of the system model for waste package performance assessment is the subactivity that integrates into a single deterministic model the submodels of processes that affect waste package releases. Models for waste form degradation and radionuclide release will be combined with mechanistic representations of waste package environment, waste package design features and mechanical models, and container degradation models. The resulting waste package system model will calculate (1) the performance-related parameters used in evaluating compliance with Issue 1.4, substantially complete containment (Section 8.3.5.9), and (2) the release rates of radionuclides from failed waste packages as a function of scenario inputs, for use in evaluating compliance with this issue and Issue 1.1.

The design objectives for satisfying Issue 1.4 recognize that among the tens of thousands of waste packages there will be differences in individual performance. The design objectives are set in terms of percent of waste packages, or releases or release rates summed over the set of waste packages. To reflect these differences in individual waste package characteristics in the modeling, the deterministic system model can be executed a number of times with different inputs. Alternatively, the probabilistic system model may be used with inputs appropriate to the problem and to the use in issue resolution, as discussed in the following paragraphs.

The design objectives for satisfying Issue 1.4 admit either a partially probabilistic interpretation (with probability distributions of key input waste package parameters supported by measurements to be done) or a deterministic interpretation (with established distributions of key input parameters; for example, the heat loading per package could be established based on the projected waste form characteristics). In either interpretation, the approach to resolution of the issue will use only those distributions that are established or well supported by documentation or measurements. Other input parameters that may have distributions will be represented by bounding distributions or bounding values; the purpose of this is so that the calculated result will be a bound on the true result. The calculated bound will then be compared to the limiting value set in the design objectives for the issue.

The system model will be constructed from simplified submodels of the processes affecting waste package life and performance. These submodels will

be derived from studies performed under this investigation as well as those satisfying needs under Issues 1.4 (Section 8.3.5.9) and 1.10 (Section 8.3.4.2). They will be derived through sensitivity analysis of the processes modeled, and therefore will be composed of relationships incorporating the most sensitive parameters. Each submodel will be subjected to verification and validation exercises.

Parameters

The system model will combine the submodels to calculate waste package integrity as a function of time, before and up to containment failure. After failure, release rates will be determined for each radionuclide. This model will produce deterministic predictions of radionuclide release for a set of parameters describing a given scenario. The submodels that make up the system model will include the following models (refer to the listed information needs and sections for parameters of the models):

1. Waste package geometry and thermal/mechanical properties.
 - a. Waste package geometry
 - i. Waste package and borehole configuration and dimensions (Information Needs 1.10.2 and 1.10.3 in Sections 8.3.4.2.2 and 8.3.4.3.3, respectively)
 - ii. Waste package contents (materials, mass, elemental and isotopic composition) (Information Needs 1.10.2 and 1.5.1 in Sections 8.3.4.2.2 and 8.3.5.10.1, respectively)
 - iii. Changes to waste package geometry over time.
 - b. Radiation (Information Needs 1.5.1 and 1.10.2 in Section 8.3.4.2.2 and calculations as part of this activity, respectively).
 - i. Gamma ray source.
 - ii. Gamma ray attenuation.
 - iii. Heat source from radioactive decay.
 - c. Heat transfer (thermal) (Information Needs 1.5.1, 1.10.2, and 1.10.4 in Section 8.3.4.2.2, Section 8.3.4.2.4, and calculations as part of this subactivity, respectively).
 - i. Heat transfer from waste forms to host rock, temperature field effects.
 - d. Mechanical (Information Needs 1.5.1, 1.10.2, and 1.10.4 in Section 8.3.4.2.2, Section 8.3.4.3.4, and calculations as part of this subactivity, respectively).
 - i. Loads (external, internal, thermal).
 - ii. Yielding (ductile and brittle failure).

2. Container degradation (corrosion) (Information Needs 1.4.2 and 1.4.3 in Sections 8.3.5.9.2 and 8.3.5.9.3, respectively).
 - a. Corrosion modes in aqueous conditions.
 - b. Corrosion modes in unsaturated conditions.
3. Water package environment (ground water movement and chemistry) (Information Need 1.10.4 in Section 8.3.4.3.4).
 - a. Flow surrounding the engineered barrier system.
 - b. Flow mechanisms for water contacting the waste package.
 - c. Flow mechanisms for water within the waste package after loss of containment.
 - d. Water volume available for contact with waste package and waste form.
 - e. Transport in near-field host rock.
 - f. Temperature in host rock at borehole wall.
4. Radionuclide release from waste forms (this activity).
 - a. Spent fuel waste form.
 - b. Glass waste form.

Description

The system model will be constructed in a computationally efficient manner so that a set of scenarios and conditions sufficiently large to span the range of anticipated and unanticipated events can be considered. After formulation and initial testing of the system model is complete, verification and validation exercises will be performed on the system model as a whole. Verification exercises will concentrate on the numerical accuracy of the logic linking together the system model components. Validation of the system model, in the sense of comparing system model output to experiments that represent an integration of the processes expected to be active in the repository, will not be possible because of the long time scales required. Therefore, validation of the system model will be performed ultimately by peer review.

8.3.5.10.3.5.2 Subactivity 1.5.3.5.2: Development of uncertainty methodology

Objectives

Because of heterogeneities in the environment and in components of the waste package, deterministic calculations of performance alone may not suffice to provide resolution of Issue 1.4 and this issue and to provide the

reasonable assurance standard required by the NRC. Therefore, a method for analyzing waste package performance that addresses these uncertainties must be developed. The objective of this study is to develop such a method so that the performance assessment calculations for the waste package will provide probability distributions for individual package and ensemble performance parameters, incorporating these uncertainties in conditions and package parameters.

With appropriate structuring of the questions and input distribution values, the uncertainty methodology can be used to answer these types of questions: (1) how does the performance of the different individual waste packages roll up to form the performance of the set of waste packages, to be compared to regulatory requirements and (2) what are the probability distributions of the performance measures of the set of waste packages. The answer to the latter question can provide a part of the support for a reasonable assurance that the performance requirements will be satisfied. A third type of question is what are the probability distributions for the release rates over time of radionuclides from the waste package. This last answer will be provided to Issue 1.1 to help resolve that issue of the EPA limit on cumulative releases to the accessible environment. That EPA requirement is stated in explicitly probabilistic terms.

Parameters

The input parameters are the same as those developed under Sub-activity 1.5.3.1.1 (Section 8.3.5.10.3.1.1). The output parameters are cumulative distribution functions for performance measures and for radionuclide release from the engineered barrier system as a function of time.

Description

The uncertainty methodology will use the deterministic system model as a means to predict performance from a given parameter set. Through appropriate sampling procedures, parameter sets will be assembled that represent the anticipated and unanticipated events, as well as variations in waste package components. Examples of this overall approach include the Latin Hypercube and Monte Carlo methods. By repeatedly computing performance with the system model for the sample of inputs, representative probability distributions for release performance may be computed. Because the number of sensitive parameters affecting waste package performance is not expected to be small, the number of performance calculations using the system model is expected to be very large, perhaps several thousand simulations. Therefore, the derivation of a practical but representative sampling method is central to prediction of release distributions.

The uncertainty methodology will be part of the waste package performance assessment model. Therefore, verification and validation of the methodology will be required. After development, verification exercises will be conducted to ensure the mathematical accuracy of the methods. Validation of the model will be accomplished by validation of the system model and through other means as available. As for the system model, the final validation of the uncertainty model will be performed through peer review.

8.3.5.10.3.5.3 Subactivity 1.5.3.5.3: Water flow into and out of a breached container

Objectives

Although the capillary barrier of the unsaturated zone will normally prevent liquid water from contacting the waste container, under some conditions water flow in the unsaturated zone can result in several mechanisms for water contact with the container. The most likely mechanism for expected flow rates is by wicking from the partially saturated rock where the container is in direct contact with the rock. A second possible mechanism, which would operate at higher flow rates, would be by dripping of water from a fracture onto the container. The objective of this activity is to determine what fraction of the water that drips onto a container would enter the container through a breach in the container wall.

Parameters

Input parameters for this subactivity include the following:

1. Water drip rate.
2. Water temperature.
3. Container orientation.
4. Container breach location.
5. Container breach geometry.

The output parameter will be water flow rates into and out of a failed container and quantity of water that can accumulate in a failed container.

Description

Experiments will be conducted under this subactivity to determine the effect of each of the parameters on the fraction of water that drips onto a container but does not enter a breach in the container. The initial experiments will be conducted using small metal cylinders that contain a well-characterized defect that has been intentionally induced into the cylinder. The fraction of water that enters through the breach will be determined as a function of breach size, breach location, drip rate, and orientation of the container (and breach) relative to the water source. Results of these experiments will be modeled to predict how the results should scale with size. On the basis of the results of the model calculations, some larger scale tests will be designed and executed. The effect of water temperature will be studied in a separate series of experiments using one or two configurations selected to be most probable for the repository situation.

The information developed in the study will be used in the determination of the concentration of radionuclides in solution in failed containers; dilution factors; and release rates of radionuclides from the engineered barrier system for anticipated and unanticipated processes and events (Information Need 1.5.4, Section 8.3.5.10.4). These results in the form of distributions of releases will form a part of the source term for calculation for total system performance assessment conducted to satisfy Information Needs 1.1.5 and 1.1.6 (Sections 8.3.5.13.5 and 8.3.5.13.6).

8.3.5.10.3.6 Application of results

The activities and information needs discussed in this section, along with their subject and SCP section number, are as follows:

<u>Activity or information need</u>	<u>Subject</u>	<u>SCP section</u>
1.1.5	Probabilistic release assessments	8.3.5.13.5
1.5.4	Release rates from waste package and engineered barrier system	8.3.5.10.4
1.5.5	Radionuclides leaving waste package near-field environment	8.3.5.10.5
1.10.4	Description of near-field environment	8.3.4.2.4
1.5.3.1	Integrate scenarios for release	8.3.5.10.3.1
1.5.3.2	Develop geochemical speciation and reaction model	8.3.5.10.3.2
1.5.3.3	Release model for spent fuel	8.3.5.10.3.3
1.5.3.4	Release model for glass waste forms	8.3.5.10.3.4
1.5.3.5	Waste package performance assessment modeling	8.3.5.10.3.5

The information developed in Activity 1.5.3.1 will be used by Activities 1.5.3.3, 1.5.3.4, and 1.5.3.5.

The information in Activity 1.5.3.2 will also be used by Activities 1.5.3.3, 1.5.3.4, and 1.5.3.5 and for Information Needs 1.1.5 and 1.10.4.

The information in Activity 1.5.3.3 will be used by Activity 1.5.3.5 and Information Need 1.5.5.

The information in Activity 1.5.3.4 will be used by Activity 1.5.3.5 and Information Need 1.5.5.

The information developed in Activity 1.5.3.5 will be used in the determination of the release rates of radionuclides from the engineered barrier system for anticipated and unanticipated processes and events (Information Need 1.5.4). These results in the form of distributions of releases will form a part of the source term for total system performance assessment calculations conducted to satisfy Information Needs 1.1.5 and 1.1.6 (Sections 8.3.5.13.5 and 8.3.5.13.6).

8.3.5.10.3.7 Schedule and milestones

This information need, addressing the development of scenarios and models to predict releases from the waste package and engineered barrier system (1.5.3) contains five activities: 1.5.3.1 (integrate scenarios for release from waste package), 1.5.3.2 (develop geochemical speciation and reaction model), 1.5.3.3 (generate models for release from spent fuel), 1.5.3.4 (generate models for release from glass waste forms), and 1.5.3.5 (waste package performance assessment model development). In the figure that follows, the schedule information for these activities is presented in the form of timelines. The timelines extend from implementation of the activity to the issuance of the final products associated with the activities. Summary schedule and milestone information for this information need can be found in Section 8.5.2.2.

This information need involves modeling. The modeling progresses in parallel with other activities under Issue 1.5. There will be frequent transfers of information among the parallel activities until resolution of the issues.

Activities in this information need are currently not constrained by other program elements. However, as the activities progress, interfaces with other activities become more important.

CONSULTATION DRAFT

The activity numbers and titles corresponding to the timelines are shown on the left of the preceding figure. The points shown on the timelines represent major events or important milestones associated with the activities. Solid lines represent activity durations and dashed lines show interfaces.

<u>Point number</u>	<u>Description</u>
1	Input received from Information Need 1.4.5 on time of container failure.
2	Scenarios supplied from total system calculations by Information 1.1.2.
3	Information required to calculate release scenarios for anticipated and unanticipated events available.
4	Milestone P332. Issue revised EQ3/6 data base.
5	Milestone P333. Issue draft EQ3/6 user's manual update.
6	Milestone M399. Issue final EQ3/6 user's manual.
7	Milestone P334. Issue final EQ3/6 data base.
8	Input received from Information Need 1.5.2 on spent fuel dissolution.
9	Milestone M012. Complete modeling of expected long-term performance of spent fuel waste forms under repository conditions to support draft environmental impact statement (DEIS).
10	Complete modeling of expected long-term performance of glass waste forms under repository conditions to support DEIS.
11	Milestone T065. Complete and document waste package performance analysis codes.
12	Milestone T076. Complete waste package performance assessment code verification and validation.
13	Output performance assessment models to Information Need 1.5.4 for calculation of release rates.

8.3.5.10.4 Information Need 1.5.4: Determination of the release rates of radionuclides from the waste package and engineered barrier system for anticipated and unanticipated events

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The bases for the models required to perform these calculations have been discussed in Section 7.4.5. The studies that develop data, parameters, and models necessary to perform the calculations are described in Sections 8.3.4, 8.3.5.9, and 8.3.5.10.

Parameters

Parameters needed for the calculation of waste package releases include

1. Waste package design (Information Need 1.10.2; Section 8.3.4.2.2).
2. Waste package design features affecting radionuclide release (Information Need 1.5.1).
3. Waste package system model and uncertainty methodology (Information Need 1.5.3).
4. Release scenarios for anticipated and unanticipated events (Information Need 1.5.3).
5. Performance of the waste forms under the scenarios in item 4 (Information Need 1.5.2).
6. Probability distributions for system model inputs (Information Need 1.5.3).

Logic

After the scenarios for release resulting from anticipated and unanticipated events have been assembled and the models for predicting release have been developed, verified, and validated, releases from the engineered barrier system may be calculated. These releases will be calculated for each radionuclide using both deterministic and uncertainty models. These releases will form the source term to be provided to the analyses for the total system performance assessment. Further, during the earlier waste package design phases, these integrated performance calculations will provide input to later waste package designs.

Two activities will be performed under this information need. The activities will respectively exercise the deterministic system model and the uncertainty methodology developed for waste package performance assessment in Section 8.3.5.10.3.

8.3.5.10.4.1 Activity 1.5.4.1: Deterministic calculation of releases from the waste package

Objectives

The objective of this activity is to use the waste package system model developed in Activity 1.5.3.5 (Section 8.3.5.10.3.5) to predict waste package performance using the scenarios developed in Activity 1.5.3.1 (Section 8.3.5.10.3.1).

Parameters

The input parameters needed for this activity are given in the combined list in the technical basis section for this information need. The output parameters obtained are the predicted waste package release performance under specified scenarios.

Description

The calculations of waste package performance will be made in three phases: (1) for the design concepts discussed in Section 7.3, (2) for the advanced conceptual design, and (3) for the license application design. The later phases will use modeling concepts developed in the previous phases, and therefore are difficult to discuss at this point. However, it is likely that analyses in all phases will incorporate many of the same elements.

The analysis of waste package designs will proceed by assembling sets of model input parameters developed in Information Need 1.5.3 and executing the system model to obtain predictions of waste package release. Releases will be calculated for scenarios that represent both anticipated and unanticipated events. Some of the calculations will represent bounding performance calculations, but the bulk of the analyses will support the uncertainty analysis required for probabilistic calculation of releases. In addition, in the earlier phases of waste package designs, information developed in the system model calculations will be available as input to later design phases.

8.3.5.10.4.2 Activity 1.5.4.2: Probabilistic calculation of releases from the waste package

Objectives

Because of heterogeneities in both the environment and components of the waste package, deterministic calculations of performance alone may not be sufficient to provide the performance measure for the set of waste packages for this issue and to support the reasonable assurance standard required by the NRC. The objective of this activity is to provide a probabilistic analysis of waste package performance addressing these uncertainties and the probability distribution of release rates for use in Issue 1.1 (Section 8.3.5.13), using the uncertainty model developed in Activity 1.5.3.5 (Section 8.3.5.10.3.5).

Parameters

The input parameters needed for this activity are given in the combined list in the technical basis section for this information need. The output parameters obtained are cumulative distribution functions for radionuclide release rates from the engineered barrier system as a function of time, and for the maxima over time of the annual release rates.

Description

The uncertainty methodologies developed in Activity 1.5.3.5 will be employed using the system model to assess the reliability of waste package release predictions. This task will be accomplished in concert with the phases of system model development and application. The exact procedure to be followed in these analyses is partially the subject of activities under Activity 1.5.3.5. However, the most likely approach will be to exercise the system model for a range of model inputs selected by a procedure for sampling from distributions of input random variables. From the system model simulations it will be possible to construct the probability distributions for engineered barrier system releases required by the reasonable assurance standard.

The uncertainty calculations will be performed for each of the design phases although they are only required for the license application design analysis. This procedure will allow testing on the early design phases and modification of the methodology during later phases. At least two types of uncertainty will be addressed. First, the uncertainty in the predicted release rates as a result of uncertainties in the fabrication and environment of the waste package will be calculated. Then the secondary uncertainty, that is the confidence in the best estimate of complementary cumulative distribution function for releases, will be assessed. Together with the deterministic simulations for bounding case releases, these results will provide a source term for total system performance assessment and will support the reasonable assurance standard set by the NRC.

8.3.5.10.4.3 Application of results

The releases calculated in these studies provide resolution of this issue (1.5). They will also be used as input to the resolution of issue 1.4, the studies under Information Need 1.5.5 and as input to total system performance assessment performed under Issue 1.1 (Section 8.3.5.13).

8.3.5.10.4.4 Schedule and milestones

This information need, addressing releases from the waste package and engineered barrier system, contains two activities: 1.5.4.1 (deterministic calculation of releases from the waste package), and 1.5.4.2 (probabilistic calculation of releases from the waste package). In the figure that follows, the schedule information for these activities is presented in the form of timelines. The timelines extend from implementation of the activities to the

issuance of the final products associated with the activities. Summary schedule and milestone information for this information need can be found in Section 8.5.2.2.

This information need involves calculations using both deterministic and uncertainty models developed in Information Need 1.5.3 to determine releases from the engineered barrier system. These activities are progressing in parallel with other activities in Issue 1.5. There will be frequent transfers of information among the parallel activities until resolution of the issue.

Activities in this information need are not currently constrained by other program elements. However, as the activities progress, interfaces with other activities under this issue will become more important.

The activity numbers and titles corresponding to the timelines are shown on the left of the following figure. The points shown on the timelines represent major events or important milestones associated with the activities. Solid lines represent activity durations and dashed lines show interfaces.

<u>Point number</u>	<u>Description</u>
1	Milestone M260. Issue report on preliminary long-term waste package performance assessment for waste package conceptual designs.
2	Milestone M263. Complete waste package performance assessments for advanced conceptual design (ACD).
3	Milestone M268. Complete waste package performance assessments for license application design.

CONSULTATION DRAFT

- 4 Output release calculations to Issue 1.4 (containment by waste package), Information Need 1.5.5 (radionuclides leaving near-field of waste package), and Issue 1.1 for total system release calculations.
- 5 Milestone M273. Issue final report on license application design waste package performance assessment, regulatory performance of aggregate of waste packages, and reliability in meeting repository requirements and waste package radionuclide source term.
- 6 Milestone IRO2. Preliminary issue resolution report addressing the performance objective for controlled radionuclide release by the engineered barrier system.

8.3.5.10.5 Information Need 1.5.5: Determination of the amount of radionuclides leaving the near-field environment of the waste package

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Section 7.4.1 discusses the fluid flow model to be developed in Information Need 1.10.4. The model validation efforts are also discussed in Section 7.4.1 and collected in studies under Information Need 1.10.4. Data acquisition for radionuclide transport properties was begun in FY 1986. No published results were available at the time of the writing of Chapter 7.

Parameters

The data needed for determination of the amount of radionuclides leaving the near-field environment of the waste package are

1. Scenarios for release events (Information Need 1.5.3).
2. Hydrologic parameters for host rock (Investigation 1.13.2 (Section 8.3.1.2.2) and Information Need 1.10.4 (Section 8.3.4.2.4)).
3. Waste package environment tests (Information Need 1.10.4, Section 8.3.4.2.4).
4. Near-field flow and transport model (Information Need 1.10.4).
5. Radionuclide release predictions (Information Need 1.5.4, Section 8.3.5.10.4).

The output parameters are transport properties of radionuclides and radionuclide concentrations in the near-field environment.

Logic

The purpose of this investigation is to provide a source term for use in the 100,000-yr comparison among sites required by 10 CFR 960.3-1-5.

Several processes may act locally to retard the movement of waste in the first few meters of host rock after the radioactive material is released from the engineered barrier system. These processes include sorption mechanisms and, under some conditions, matrix diffusion. Depending on the scenario for transport from the waste package, either or both of these processes may be effective for many waste species.

The source term derived from the release calculations performed for Information Need 1.5.4 will not account for sorption and matrix diffusion effects occurring in the first few meters of rock surrounding the waste package, without modification of the waste package environment component to account for these effects. Flow and transport calculations will be made as described in Information Need 1.10.4 (Section 8.3.4.2.4) to include the hydrologic and geochemical environment immediately surrounding the waste package. These calculations are required to understand the boundary conditions required for the reliability analysis of the waste package. These calculations will not, however, include the transport of radionuclides through the near-field rock following release from the waste package.

To perform these calculations, parameters describing transport mechanisms active in the near-field environment must be determined. These parameters include the formation and transport properties of radionuclide-containing colloids, radionuclide solubilities in repository ground water, diffusivities of waste species, and effective partition coefficients for waste species in Topopah Spring tuff. The colloid and solubility data will be developed in activities described in Information Need 1.5.3 and Investigation 1.14.5 (Section 8.3.1.3.5). Laboratory measurements of apparent diffusion coefficients and distribution coefficients for radionuclides will be done using rock wafers and rock cores. The wafers are rock samples that have been part of waste form dissolution tests discussed in the following section. The effect of transport scale on transport processes will be studied by using different size rock cores.

8.3.5.10.5.1 Activity 1.5.5.1: Determine radionuclide transport parameters

This activity will measure the distribution of actinides and fission products in rock samples. The rock samples will be subjected to contact with radionuclides under a variety of conditions so that the effects of degree of saturation and transport scale can be evaluated. Two subactivities support this analysis.

8.3.5.10.5.1.1 Subactivity 1.5.5.1.1: Radionuclide distribution in tuff wafers

Many of the waste-form dissolution tests include pieces of the Topopah Spring tuff in the test solution. These tuff pieces are included to determine the effect of the presence of rock on the dissolution rate of the waste form. The rock sample is, therefore, sitting in a solution of dissolved waste form and simulates the condition where local saturation of a portion of the repository occurs. For long-term tests, the solution concentrations are relatively constant, and the test conditions approximate those of steady-state diffusive flow. At the conclusion of the test, the rock wafer is examined with an ion microscope to determine the location of the radionuclides as a function of depth in the sample. A brief description of the method and some preliminary results are in the paper by Phinney et al. (1986). The position of the radionuclides in the wafer can be combined with the test duration to calculate the effective diffusion rate for the radionuclide. The concentration of the radionuclide at the surface of the rock can be combined with the solution concentration to give an effective distribution coefficient. The shape of the diffusion profile near the surface of the rock can be used to assess whether sorption or precipitation are controlling the retardation process.

8.3.5.10.5.1.2 Subactivity 1.5.5.1.2: Radionuclide distribution in tuff cores

The tuff-wafer experiments just discussed only examine transport on a small scale (a few micrometers) and under saturated conditions. To determine the effects of transport scale on transport properties, tuff core samples are being used. Solutions of radionuclides are forced through the core sample at a fixed water-flow rate. The water flow is monitored using tritium. Solutions of other radionuclides are compared with the flow rate for tritium to determine retardation parameters. Plans to evaluate retardation properties as a function of water flow rate and solution composition are in the development stage.

Transport properties may also be a function of degree of saturation of the rock. To investigate this possibility, the tuff core experiments will be modified to allow for unsaturated flow. In these experiments the effects of flow rate and degree of saturation will be studied. The goal is to develop a sufficient understanding of the unsaturated flow properties to allow coupling of these experiments with the unsaturated flow studies described in Information Need 1.10.4 (Section 8.3.4.2.4). This will allow monitoring of water movement with resistivity imaging techniques (the impedance camera), tracking of solute transport by the radioactivity (for gamma emitters), and finally, location of the radionuclide distribution in the rock using the ion microscope.

8.3.5.10.5.2 Activity 1.5.5.2: Radionuclide transport modeling in the near-field waste package environment

This activity will use the flow and transport model for hydrologic representation of the near-field host rock developed under Information Need 1.10.4 (Section 8.3.4.2.4). The model will be validated using data from integrated testing activities and tracer tests planned in the exploratory shaft.

8.3.5.10.5.2.1 Subactivity 1.5.5.2.1: Validation of near-field transport model using laboratory and field experimental data

The hydrothermal flow and transport model developed for detailed analysis of the near-field waste package environment will require validation before it is used to determine releases from the near field. This subactivity will provide model validation by comparison to hydrothermal tracer experiments performed on laboratory core samples, and in situ tracer experiments currently planned for the exploratory shaft (Section 8.3.4.2). In performing these comparisons, split sample techniques will be used to provide for both model calibration and validation.

8.3.5.10.5.2.2 Subactivity 1.5.5.2.2: Application of near-field transport model to waste package releases

After model validation, the near-field flow and transport model will be applied to simulate transport of radionuclides through the first few meters of rock surrounding the waste package. Predictions of package release from the waste package system model will be used as the source term. Particular attention will be given to the effects of sorption processes and diffusion of material into the matrix. The interaction of flow in the rock matrix and flow in fractures is expected to be an important factor in assessing potential transport paths for radionuclides. The degree of importance of fracture flow will be coupled to the scenarios examined in Section 8.3.5.10.4. Final results of these calculations will determine the most likely source term for total system performance calculations.

8.3.5.10.5.3 Application of results

The results of this analysis will be applied to determine the effects on the radionuclide source term caused by the host rock in the immediate vicinity of the waste package. There are two methods by which this may be accomplished. The first is to modify the waste package source term calculations (Section 8.3.5.10.3) to account for sorption and precipitation processes active in the host rock immediately surrounding the waste package. The second is to examine the possibility of using the results of the present investigations to modify the calculation of releases within the waste package system model to account for the retarding processes active in the host rock.

CONSULTATION DRAFT

The point at which the application is made does not affect the structure or schedule for the activities.

The purpose of this information need is to provide a source term for use in the 100,000-yr comparison among sites as required by 10 CFR 960.3-1-5.

8.3.5.10.5.4 Schedule and milestones

This information need, addressing the amount of radionuclides leaving the near-field waste package environment, contains two activities: 1.5.5.1 (determine radionuclide transport parameters), and 1.5.5.2 (radionuclide transport modeling in the near-field waste package environment). In the figure that follows, the schedule information for these activities is presented in the form of timelines. The timelines extend from implementation of the activities to the issuance of the final products associated with the activities. Summary schedule and milestone information for this information need can be found in Section 8.5.2.2.

This information need involves experimental work, modeling, and analyses to determine the transport mechanisms and predict the amount of radionuclides leaving the near-field environment of the waste package. The activities progress in parallel with other activities under Issue 1.5. There will be frequent transfers of information among the parallel activities until resolution of the issue.

Activities in this information need are currently not constrained by other program elements. However, as the activities progress, the interfaces with other activities become more important.

The activity numbers and titles corresponding to the timelines are shown on the left of the following figure. The points shown on the timelines represent major events or important milestones associated with the activities. Solid lines represent activity durations and dashed lines show interfaces.

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
1	Provide output to unsaturated flow studies in Issue 1.10, Information Need 1.10.4.
2	Milestone W260. Complete local flow and transport model.
3	Output preliminary information on source term to Information Need 1.5.3 and to Issue 1.1 for total system calculation.
4	Milestone P204. Issue final report on near-field radionuclide source term.

Nuclear Waste Policy Act
(Section 113)

Section 83.5.11

Consultation Draft

SEAL PERFORMANCE

Site Characterization
Plan

Yucca Mountain Site, Nevada Research
and Development Area, Nevada

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Washington, DC 20585

8.3.5.11 Plans for assessing seal system performance

The seal system is composed of the shafts and ramps, exploratory boreholes and their seals, and the sealing components associated with the underground facility. The portions of 10 CFR Part 60 that are related to the shafts, boreholes, and their seals are Sections 60.134(a) and (b). Section 60.113 relates a performance criterion on the engineered barrier system. Because the engineered barrier system comprises the waste package and the underground facility, the seals in the underground facility are indirectly affected by this performance criterion. The approach to establishing the performance goal for the NNWSI Project seal program is described in Section 8.3.3.2 of this document. The approach and plans for assessing the performance of seal designs is described in the following.

Figure 8.3.5.11-1 illustrates the overall logic currently being used to arrive at seal designs that can achieve a desired level of performance. This figure also correlates the six steps in the NNWSI Project repository seal program with these design- and performance-related efforts. These steps are defined in the following paragraphs and are presented in more detail elsewhere (Fernandez, 1985) and in Section 8.3.3.

The first four steps are performed during advanced conceptual design and are as follows:

1. Assess the need for sealing.
2. Define the performance goals and design requirements.
3. Measure material properties.
4. Define sealing designs, assess the performance of these designs, and select the suitable sealing designs.

The last two steps are performed during the license application design:

5. Perform laboratory analyses and field testing, if required.
6. Reassess the performance of sealing designs (including reallocation of performance, if needed) and select the suitable design.

The focus of this section is to briefly summarize plans for assessing the performance of sealing components. Section 8.3.3 provides more explanation of planned seal performance analyses and information on (1) type of seal, (2) function of seal, (3) location of seal, (4) physical process by which the seal functions, (5) material properties key to seal performance, (6) performance measures for the seal, (7) goals and desired confidence. The remainder of this section summarizes the broad outline of the overall strategy and the plans for assessing seal performance. A preliminary evaluation of the performance of sealing components will be made as part of step 2. In this step, design options will be rank ordered considering the relative performance of the evaluated design options and the ease in meeting the goal. The logic to be used in this step is presented in Figure 8.3.5.11-2. A detailed evaluation of the performance of sealing components will be made while developing the license application design (LAD). This evaluation will

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Figure 8.3.5.11-1. Flowchart illustrating the approach for answering the performance-related questions (modified from Fernandez, 1985).

Figure 8.3.5.11-2. Logic to select preferred performance goals for seal program.

consider initial and altered seal material properties. To establish these altered properties it will be necessary to evaluate how the initial material properties are altered by processes and events.

The effect of designs on performance will also be evaluated. Following the reassessment of performance, it may be determined that reallocation of the performance goals is desired. For instance, if the performance goal is only marginally achieved, it may be prudent to reallocate performance or change the design that was evaluated. If the performance goals can be achieved, then the designs evaluated will be proposed as part of the LAD. Additional verification activities may be required if, through the parametric analyses, it can be shown that a higher degree of confidence is required to achieve the performance goal. This higher degree of confidence can be achieved through laboratory, field testing, or both. A reassessment of the designs will be made using the data obtained through verification testing.

The strategy used in the sealing program to evaluate performance of sealing components is to use analytical solutions in a sensitivity analysis and, when appropriate a combination of numerical and analytical models. The numerical and analytical approaches used to date are in Section 6.4.3.1. It is anticipated that no new fluid-flow codes will be required specifically for use in the seal program. Rather, codes that are being developed, verified, and validated for use in other hydraulic performance analyses needed for the NNWSI Project will be used for sealing analyses. Input to verification and benchmark problems will be made by the seal program to ensure the applicability of the codes to the seal environment.

The following subtasks will be performed in evaluating the performance of the sealing system:

1. Develop the following matrices for the materials and designs specified in the advanced conceptual design report:
 - a. Events versus processes. (Which likely natural events initiate or enhance processes affecting seal system performance?)
 - b. Processes (static, dynamic, and man-induced) versus failure mechanisms. (Which processes contribute to specific failure mechanisms?)
 - c. Failure mechanisms versus potential materials and designs. (Which materials or designs will resist, partially resist, or will not resist specific failure mechanisms?)
2. Use the results from the following laboratory and field testing to develop models for use in assessing seal performance:
 - a. Laboratory tests to evaluate the following:
 - (1) Alteration of sealing materials (cementitious materials) in contact with tuff.

- (2) Consolidation behavior of mined tuff as a function of particle size distribution (this mined tuff will be obtained from the excavation of the exploratory shaft).
 - (3) Early curing behavior of cementitious materials.
 - (4) Durability of concrete emplaced on the ground surface.
- b. Field tests of the Topopah Spring Member and the tuffaceous beds of Calico Hills to evaluate the hydrologic behavior of these units (described in Section 8.3.1.2, geohydrology program).
- 3. Use the matrices developed in part (1) together with potential scenarios to predict the alteration of seal performance.
 - 4. Calculate the effect of the postclosure sealing system on radionuclide release. This effort will be coordinated with the total system performance assessments (Section 8.3.5.13) for a repository at Yucca Mountain.

Nuclear Waste Policy Act
(Section 113)

Section 8.3.5.12

Consultation Draft

**GROUND-WATER
TRAVEL TIME**

Site Characterization Plan

***Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

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***U.S. Department of Energy
Office of Civilian Radioactive Waste Management
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8.3.5.12 Issue resolution strategy for Issue 1.6: Will the site meet the performance objective for pre-waste-emplacement ground-water travel time as required by 10 CFR 60.113?

Regulatory basis for the issue

One of the NRC performance objectives for high-level waste repositories is stated in 10 CFR 60.113(a)(2) as

The geologic repository shall be located so that pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other time as may be approved or specified by the Commission.

The disturbed zone has been defined qualitatively in 10 CFR 60.2 as

That portion of the controlled area the physical or chemical properties of which have changed as a result of underground facility construction or as result of heat generated by the emplaced radioactive wastes such that the resultant change of properties may have a significant effect on the performance of the geologic repository.

The accessible environment has been defined in 10 CFR 60.2 to mean

- (1) the atmosphere, (2) the land surface, (3) surface water, (4) oceans, and
- (5) the portion of the lithosphere that is outside the controlled area.

The controlled area, defined in 40 CFR 191.12(g), means

- (1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system, and (2) the subsurface underlying such a surface location.

The current reference locations of the boundaries of the disturbed zone and accessible environment at Yucca Mountain are subject to change and are established now only to provide a planning basis for a site specific approach to resolution of this issue. Solely for the purposes of this discussion, a distance of 50 m below the midplane of the repository is used as the boundary of the disturbed zone (see Section 8.3.5.12.5 for discussion of plans for defining a more formal boundary of the disturbed zone). A preliminary definition of the boundary of the accessible environment, taken from Rautman et al. (1987), is shown in Figure 8.3.5.12-1. The final definition of the boundary of the accessible environment will be determined by Subactivity 1.6.3.1.2 (Section 8.3.5.12.3.1.2).

Activities within this issue will support a determination of the distribution of pre-waste-emplacement ground-water travel times along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment. Though water may move through the unsaturated zone in both liquid and vapor phases, this issue is concerned only with the travel time of liquid water. The direct effects on performance of vapor flux through the

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Figure 8.3.5.12-1. Preliminary definition of the boundary of the accessible environment (Rautman et al., 1987) and the location of section B-B', Figure 8.3.5.12-2.

unsaturated zone are addressed by Issue 1.1 (Section 8.3.5.13). Vapor flux through the unsaturated zone at Yucca Mountain may significantly influence both the magnitude and direction of liquid water flux and will therefore be considered in determining ground-water (liquid) travel time.

Within the following text for this issue, the relationship between the issue and the information needs is discussed, followed by a discussion of the issue resolution strategy, performance allocation, and the activities to provide data for the information needs.

Background

The present understanding of hydrogeologic conditions at Yucca Mountain is described in Chapter 3. The proposed repository will be located in the unsaturated zone, and liquid-phase releases of radionuclides to the accessible environment will probably occur in the saturated zone after migration downward through the unsaturated zone. This means that the flow paths of concern will have two parts: an approximately vertically downward portion through the unsaturated zone and a generally horizontal portion through the saturated zone (Figure 8.3.5.12-2).

The hydrologic characteristics along these general paths, as well as any other paths that may be identified during site characterization, will be tested during the characterization process to determine their physical characteristics. The hydrogeologic test plans are addressed in the geohydrology program (Section 8.3.1.2). An additional requirement for resolving Issue 1.6 is the refinement of current conceptual models for flow through the saturated and unsaturated zones at the site. Plans for development of these models are also described in the geohydrology program.

Current concepts generally distinguish two types of pathway types for ground-water travel through the unsaturated zone. These two general modes of ground-water movement are

1. Flow predominantly through pores in the rock matrix. In this mode, the time of water movement through a given volume of rock is dominated by near-steady, near-vertical flow through the small but abundant matrix pores of the tuffaceous rocks along the flow path. Current data on site characteristics and likely flux values beneath the repository depths suggest that this is the predominant mode of ground-water movement from the disturbed zone to the water table (Section 3.9.4). Although local regions of fracture flow may exist along significant fractions of any flow path (i.e., where the flux times the gradient exceeds the transmitting capabilities of the matrix pores), continuous fracture flow probably does not occur along the entire distance of any given flow path from the disturbed zone to the water table.
2. Continuous flow through fractures or faults. In this mode, the flow rate is relatively rapid because flow along one or more entire paths is constrained to the relatively large but sparse openings constituting a fracture network. Continuous fracture flow from the disturbed zone to the accessible environment may be caused by various sequences of events and may occur in only one general location or be

Figure 8.3.5.12-2. Conceptual hydrogeologic section from Solitario Canyon to well J-13. Section location shown in Figure 8.3.5.12-1 (modified from Scott and Bonk, 1984).

distributed throughout the site. This flow may be caused by episodic or continual lateral diversion of water toward a fault; by an average, sustained percolation rate higher than the values of matrix saturated conductivity; by periodic, high intensity infiltration events at the surface; or by other means (Section 3.9.4). The conditions necessary to induce and sustain fracture flow, as well as if and where such conditions exist at the Yucca Mountain site, are addressed by the geohydrology program, Sections 8.3.1.2.2 and 8.3.1.2.3. Continuous fracture flow beneath the potential repository is not considered likely at Yucca Mountain (Montazer and Wilson, 1984; Peters et al., 1986; Sinnock et al., 1984, 1986; Wang and Narasimhan, 1986). However, because implications of such flow include short travel times, this mode of flow will be considered in resolution of this issue.

The strategy for determining ground-water travel times is to reflect the current uncertainty about flow mechanisms that may occur at the site, as well as uncertainty about the spatial distribution of rock characteristics along flow paths and about boundary conditions. Therefore, site data are needed to reduce the current uncertainty about whether the likely ground-water flow paths include continuous fracture flow. Flow in both the matrix and fractures in the unsaturated zone will be considered on a probabilistic basis, unless site data unambiguously support a position that continuous fracture flow is not likely enough for serious consideration.

In the saturated zone also, the general pathway for water movement probably includes travel through alternating matrix blocks and fractures. For purposes of conservatively evaluating ground-water travel time, the saturated zone will probably be treated solely as an equivalent porous medium where fracture properties characterize the medium.

Approach to resolving the issue

The general approach to resolution of this issue, and others, is discussed in Section 8.2.2. Specifically, the strategy for resolving this issue entails the definition, characterization, and assessment of multiple barriers to ground-water flow. By dividing potential flow paths and flow processes into discrete categories, the DOE conceptually can establish multiple, quasi-independent natural barriers to which goals for ground-water travel time can be assigned. The multiple natural barriers are distinct hydrogeologic units that occur along potential flow paths. Within each unit different types of general flow processes may be distinguished, including dispersive and advective flow in rock pores, similar flow in fractures, and diffusion between and within the matrix and fractures. By considering each of these processes, in turn, beginning with the most conservative (i.e., non-diffusive, dispersive fracture flow) an additional set of multiple barriers is made available for consideration. This creates a matrix of hydrogeologic units and flow processes whereby each intersection on the matrix may be evaluated to see if it singly is capable of providing assurance that pre-waste-emplacment travel time will be at least 1,000 yr.

The strategy is based on current understanding of flow behavior in each of the hydrogeologic units and current assessments of the relative contribution of each process in each unit to flow velocities. Separate goals of

1,000 yr of travel time, with varying degrees of confidence, are assigned to the several hydrogeologic units under flow conditions dominated by the several processes. If any combination of a single unit and set of processes can be shown to meet the goal of 1,000 yr, the issue could be considered resolved. However, all units will be characterized and evaluated. If several units and associated processes meet their goals, confidence is significantly enhanced that the repository site, considered in the whole, will meet the 1,000 yr requirement. This defense-in-depth approach is designed to provide reasonable assurance that the site will comply with the NRC performance objective, even given the uncertainty about flow mechanisms and flow path characteristics that will remain after site characterization.

Specifically, resolution of Issue 1.6 requires several steps as shown schematically in Figure 8.3.5.12-3. The process for resolution (the center-line in Figure 8.3.5.12-3) is designed to account for both conceptual and parameter uncertainties (left and right lines, respectively, Figure 8.3.5.12-3). The first general step is performance allocation where relevant characterization needs are established through a five-part process:

1. Identifying all hydrogeologic units along potential flow paths to the accessible environment and identifying all potentially operating processes within each of these units.
2. Classifying hydrogeologic units and flow processes as primary, secondary, and auxiliary "barriers" to establish a defense-in-depth basis for reasonable assurance that flow time to the accessible environment is at least 1,000 yr.
3. Establishing measures of performance (i.e., travel time) and assigning goals in terms of the measures that allow comparisons of the flow behavior in each unit to the 1,000 yr flow time requirement.
4. Identifying relevant flow processes within each unit.
5. Identifying relevant parameters and associated levels of confidence that will be used to predict the travel time and associated uncertainty through each unit.

The second general step is performance assessment, which involves defining, constructing, and applying numerical models to make travel-time predictions. The final step, performance evaluation, entails comparison of predicted travel times to the goals for each unit, then comparing the travel times in all units in combination to the 1,000 yr requirement to assess the likelihood of compliance with the 1,000 yr travel-time performance objective. This final step includes some, as yet ill-defined, process for assessing the validity of the predictive models (Section 8.3.5.19). Each of the parts of performance allocation, the first step, is discussed in the immediately following pages. Current plans for the second step, performance assessment, are outlined in the succeeding discussion of Information Needs 1.6.2 through 1.6.4 (Sections 8.3.5.12.2 through 8.3.5.12.4). The third step, performance evaluation, is not explicitly addressed because the criteria for evaluating the degree of compliance with performance objectives are not yet known. A summary of the performance allocation process for this issue is provided in Table 8.3.5.12-1.

Figure 8.3.5.12-3. Schematic logic for resolution of Issue 1.6 (current alternative models of flow system acknowledge matrix and fracture dominated flow in unsaturated zone, seepage velocity, dispersion and diffusion) (Note: TSw = Topopah Springs welded unit; CHnv = Calico Hills nonwelded vitric unit; CHnz=Calico Hills nonwelded zeolitic unit. SZ = saturated zone, GWTT = ground-water travel time)

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

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

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

Hydrogeologic components ^a available	Allocation of reliance	Process	Performance measure	Performance goal (yr)	Needed confidence ^b	Performance parameters
Combination of all units			GWTT GWTT	1,000 10,000	Very high High	See Table 8.3.5.12-2

^aTSw = Topopah Spring welded; CHnv = Calico Hills nonwelded vitric; CHnz = Calico Hills nonwelded zeolitized; PPn = Prow Pass nonwelded; BFw = Bullfrog welded; BFn = Bullfrog nonwelded.

^bVery high goal lies at least three standard deviations below the mean of GWTT; 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).

^cDarcian 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.

^dIf a significant thickness of the unit occurs along the flow path.

^eGWTT = ground-water travel time along the fastest path of likely radionuclide travel.

First, a brief statement is needed about the purpose and limitations of this resolution strategy. The current purpose is to provide a basis for defining a characterization program that will lead to data of sufficient quantity and quality ultimately to allow findings of "reasonable assurance" (10 CFR 60.101(a)(2)) that the ground-water travel time at Yucca Mountain is or is not at least 1,000 yr. The criteria for defining reasonable assurance are not unambiguous; therefore the conditions of sufficiency for data are and will remain ambiguous until they are established during licensing proceedings. Nested within this arena of institutional and political indeterminism regarding the compliance criteria is a technical indeterminism regarding the relations among the uncertainties attached to individual parameters (item 5 above) and the consequent uncertainty in travel times (items 2 and 3 above). This latter indeterminism rests on two basic principles: (1) the predictability of flow processes in time depends on conceptualizations of these processes that cannot be objectively quantified in terms of degrees of correctness, and (2) the underlying mathematical structure of any valid conceptual approach does not permit unique solutions as to the relative influence of the uncertainty associated with any given parameter or parameter set. For these reasons, the elements of the resolution strategy outlined in the following pages are based firmly on professional judgments about a set of performance goals and site parameters that, if met and collected, will provide a reasonable basis for drawing reliable, albeit always somewhat uncertain, conclusions about the ground-water travel time at Yucca Mountain. The amount of uncertainty reduction needed, if any, relative to current understanding cannot be determined at this time.

Step 1. Flow system identification

The components of the natural setting that compose a portion of the Yucca Mountain geologic disposal system are shown in Table 3-17 (Section 3.9). These components are defined as hydrogeologic units (system components) that occur along potential ground-water travel paths between the disturbed zone and the accessible environment. There are seven units in the unsaturated zone: (1) Topopah Spring welded unit (TSw), (2) Calico Hills nonwelded vitric unit (CHnv), (3) Calico Hills nonwelded zeolitic unit (CHnz), (4) Prow Pass welded unit (PPw), (5) Prow Pass nonwelded unit (PPn), (6) Bullfrog welded unit (BFw), and (7) Bullfrog nonwelded unit (BFn). The saturated zone (SZ) in its entirety is defined as a separate, eighth unit. As site characterization progresses, it may be determined that the saturated zone needs to be subdivided into its distinct hydrogeologic units, to characterize more adequately the ground-water flow paths to the accessible environment.

Each of these hydrogeologic units can be subdivided into two types of physical elements that may be considered to define distinct pathways: matrix pores and fractures, whereby fractures, in turn, are considered to exist as two types: (1) distributed networks, and (2) fault zones. This classification, though unit specific, is designed to account for throughgoing fracture pathways, distributed throughout the rock mass or along fault zones, that may extend uninterrupted from the disturbed zone to the water table and along the saturated pathways to the accessible environment.

The spatial locations of flow paths from the disturbed zone to the accessible environment are generally through the unsaturated zone to the

water table and along a 5-km distance in an approximately down-gradient direction along the upper part of the saturated zone. Although a definition of the boundaries of the disturbed zone is not yet firm (Information Need 1.6.5, Section 8.3.5.12.5) a distance of 50 m below the midplane of the repository is used as the boundary for the purposes of this discussion. The hydrogeologic units that may be relied upon depend to a certain extent on where this boundary lies; however, the ability of the site to meet the 1,000-yr ground-water travel-time criterion probably is not affected much by moderate departures from this definition. The thickness of each unsaturated hydrogeologic unit between the assumed boundary of the disturbed zone and water table is shown in Figure 8.3.5.12-4.

Each of the two physical elements (fractures and matrix) of each hydrogeologic unit is considered a potential pathway for water flow. Several processes may be used to describe flow along each pathway. Darcian flow with dispersion in fractured porous media is the process that will be used as a baseline case to describe water movement through the unsaturated and saturated hydrogeologic units. Dispersion is a mixing and spreading process that should be considered to account for the times of first arrivals in a travel-time distribution. Dispersion is believed to be caused by small- to large-scale heterogeneities along a flow path. The dispersive effects of medium- to large-scale heterogeneities will be addressed by accounting for macroscopic property variations along flow paths, and small microscale effects may be addressed, if they are shown to accelerate significantly first arrivals, by assigning a dispersivity factor to each unit.

Diffusive processes, which would tend to lengthen travel times of an inert tracer, would be relied upon only if necessary to show 1,000 yr of travel time, as suggested in the draft position paper by Codell (1986). If diffusion of inert tracers between matrix pores and fracture openings is relied upon, the characteristics and limitations of the diffusive process must be adequately characterized. Because radionuclide travel may occur by particles larger than inert tracers (such as colloids), characterization of colloid formation and behavior is also planned. The diffusive characteristics of radionuclides and colloids will be investigated under the geochemistry program (Section 8.3.1.3). Issue 1.1 (Section 8.3.5.13) provides more discussion on the transfer of particles between the matrix and the fractures by a diffusive process.

Step 2. Selection by hydrogeologic units and flow process

If the current conceptual model for the unsaturated zone is valid, each of the hydrogeologic units listed previously is a barrier that, in and of itself, is likely to have travel times of at least 1,000 yr along some path of likely, radionuclide travel (Figure 8.3.5.12-5, top). Current analyses (Sinnock et al., 1986) indicate that the fastest path of likely radionuclide travel from the disturbed zone to the water table will probably occur beneath the east-northeast region of the proposed repository (Figure 8.3.5.12-5, bottom). Only two unsaturated units occur in this area; the Topopah Spring welded and Calico Hills zeolitic units (Figure 8.3.5.12-6). The saturated zone occurs along all potential paths of liquid water flow to the accessible environment, including those from the northeast part of the repository. Accordingly, a level of performance has been allocated to the Topopah Spring

Figure 8.3.5.12-4. Isopach contour maps of hydrogeologic units used for performance allocation: (A) Total thickness from disturbed zone to the water table; (B) Thickness of undisturbed Topopah Spring welded unit, TSw; (C) Thickness of the Calico Hills nonwelded vitric unit, CHnv; (D) Thickness of the Calico Hills nonwelded zeolitic unit, CHnz; (E) Thickness of the Prow Pass welded unit, PPw; (F) Thickness of the Prow Pass nonwelded unit, PPn; (G) Thickness of the Bullfrog welded unit, BFw; and (H) Thickness of the Bullfrog nonwelded unit, BFnn. Modified from Sinnock et al. (1986).

Figure 8.3.5.12-5. Travel-time plots: Top - cumulative frequency plots of current travel-time estimates through each hydrogeologic unit and through the total thickness of the undisturbed unsaturated zone; Bottom - isochron maps of mean total travel times in years. Cross-section A A' is shown in Figure 8.3.5.12-6. Modified from Sinnock et al. (1986).

Figure 8.3.5.12-6. Cross section at Yucca Mountain showing pinch-outs of unsaturated hydrogeologic units. Location of section line shown in Figure 8.3.5.12-5. (2 times vertical exaggeration)

welded, Calico Hills nonwelded zeolitic, and saturated zone hydrogeologic units (Table 8.3.5.12-1).

Sinnock et al. (1986) assumed one-dimensional steady-state, vertical flow through matrix and fractures of the unsaturated zone and concluded that the Calico Hills nonwelded zeolitic unit has travel times along the fastest paths much greater than 1,000 yr. Based on these analyses, this unit is allocated a high level of performance and is referred to as a primary barrier. The Topopah Spring welded unit and the saturated zone are considered secondary barriers, and are allocated lower levels of performance. The Calico Hills vitric unit, where present, is also thought to provide relatively long travel times, comparable to or greater than those in a similar thickness of the zeolitic facies of the Calico Hills tuffs, though this unit probably is very thin or absent below the northeast portion of the current facility design where the fastest flow paths to the water table are likely to occur.

Because of uncertainty regarding how to determine the "fastest path of radionuclide travel" (Codell, 1986), it is possible that flow from the entire disturbed zone boundary over the entire site may be included in the distribution of travel times relevant to this issue. In this instance, the vitric portion of the Calico Hills unit would also serve as a primary barrier, as indicated in Table 8.3.5.12-1. The Calico Hills vitric unit has a higher saturated hydraulic conductivity than the Calico Hills zeolitic unit and is therefore more likely to have drained to lower saturation and higher suction, particularly in view of its greater distance above the water table. Therefore, matrix-dominated flow can be assumed with more confidence in the vitric unit than in the more nearly saturated zeolitic unit. If the regulatory basis for defining the fastest path is restricted to geographical regions of least flow time, it might be prudent to modify the proposed location of the repository to ensure that at least a minimal thickness of vitric Calico Hills tuff occurs along all flow paths from the disturbed zone to the water table. In either event, the vitric unit is a significant barrier to flow from the disturbed zone and is considered a primary barrier.

Other units (e.g., BFW) will also contribute to a longer ground-water travel time; however, the different, sometimes zero, thicknesses of these units (Figure 8.3.5.12-4) for different flow paths requires that their role in resolving the issue be considered somewhat differently. For the purpose of this allocation, these units are termed auxiliary. This allocation strategy may change as additional data and understanding are obtained.

Flow through the unsaturated units of Yucca Mountain includes the possibility of localized sustained flow in fractures (Montazer and Wilson, 1984). If substantial, continuous fracture flow exists at the site, it probably will not occur throughout broad regions. Sustained flow in fractures is most likely to occur only along a major geologic structural feature such as the Ghost Dance fault or faults bounding the site to the east. This may occur if a sufficient flux of water is diverted laterally to the structural features where the water could then drain quickly through fractures along the fault to the water table (Rulon et al., 1986). Temporary or steady-state ponding of perched water near the structural features is presently considered possible within and above the nonwelded units. Therefore, if water moves as continuous flow in fractures to the water table, it

probably occurs in down-dip areas along the eastern portion of the site, where the Calico Hills vitric unit is thin or absent and the zeolitic unit is nearly saturated. Portions of the previously discussed pathways, particularly those at shallow depths, may experience fracture flow following episodic, high infiltration events.

If, during site characterization, continuous, rapid fracture flow is shown to be significant, then diffusion of nonsorbing tracers from the fractures to the matrix pores would be used to identify the fastest path of likely radionuclide travel. Transfer of nonsorbing tracers (identifying the paths of radionuclide travel) from fractures to matrix and vice versa would occur by advection and diffusion. Because of the large storage capacity in the partially saturated matrix pores where advection, dispersion, and diffusion would take place, accounting for diffusion would probably result in a significant increase in predicted travel times compared with those based solely on the seepage velocity in continuously flowing fractures. However, only in the event of likely, sustained fracture flow would diffusion be relied upon to complement Darcian flow with advection and dispersion in describing movement of inert tracers through the unsaturated and saturated zones.

The DOE strategy for assessing flow in the unsaturated zone, thus, rests firmly on the assumption that flow below the disturbed zone is essentially vertically downward. It is recognized that lateral diversion of water at some unit contacts is possible. If such paths are established as likely during site characterization, they would then be used as the basis for determining travel time. There is a credible possibility that, below the repository level, very little liquid water is moving in any direction (e.g., if flux $\ll 0.5$ mm/yr) and that a nearly static condition prevails (Roseboom, 1983). A significant possibility also exists that, in terms of quantities of water, downward flux of liquid water is less than the upward flux of vapor (Montazer and Wilson, 1984). These possibilities will be investigated during further development of the hydrologic model, as described in the geohydrology program. In lieu of more definitive information, the assumption of net, vertically downward movement of liquid flux probably is a conservative basis for calculating ground-water travel times.

An auxiliary facet of the strategy for assessing ground-water travel times involves the estimation of ground-water ages at different points along the flow paths. Geochronology using carbon, chlorine, and hydrogen isotopes in the ground water can provide a basis for estimating ground-water residence times. Results of such studies are generally subject to significant uncertainty regarding the identification of flow paths, mixing of waters of different ages, etc. However, data on residence times (ages) of water along the potential pathways are expected to be very useful for helping to interpret ground-water travel times calculated with numerical models. Standard hydrochemical data may also be used to help determine whether computed travel times are consistent with the isotopically determined ages (Section 8.3.1.2.2).

Step 3. Performance measure

The probability or frequency distribution of calculated ground-water travel times is the performance measure for each hydrogeologic unit. Ground-water travel time is an obvious choice because of its direct relationship to 10 CFR Part 60.113(a)(2) and because time is a fundamental quantity.

The measure of performance for each hydrogeologic unit will be expressed as a cumulative distribution curve. Figure 8.3.5.12-7 shows examples of a histogram and an associated cumulative distribution curve, for ground-water travel time through the total unsaturated zone based on the net effects of fracture and matrix flow, with no diffusion. Ground-water travel time is assumed to be the time that it would take inert tracer particles released at the boundary of the disturbed zone to reach the accessible environment. This travel time is often calculated by integrating the ratio of effective porosity to the Darcy velocity along the flow path from the disturbed zone to the accessible environment (Sinnock et al., 1986; Codell, 1986). Dispersion, diffusion, differences in flow path lengths, and other factors tend to spread travel times. As a result, a distribution of travel times exists along any path. This distribution is taken to be the measure of ground-water travel time.

As discussed in Step 1, dispersion caused by macroscopic heterogeneity of flow-controlling properties will be explicitly accounted for in calculations used to produce a travel-time distribution. This will be accomplished by randomly sampling the properties from an empirical probability distribution function that describes natural variability along the flow paths as well as uncertainty associated with that variability. Micro-dispersion may be included as a second-derivative dispersivity term in the calculations if it significantly accelerates early arrivals of inert tracers to the accessible environment. The effects of diffusion (between the fractures and the matrix) will be considered, only if necessary, in establishing a high likelihood of more than 1,000 yr of travel time. Finally, the uncertainty in the travel time caused by alternative conceptual models will be incorporated in the cumulative distribution curves, perhaps by subjective weighting of the alternatives based on peer review.

As a result of the incorporation of these various sources of spreading, the cumulative distribution curve of travel times is intended to encompass all relevant sources of uncertainty. This implies neither that all uncertainty will be objectively quantified nor that the cumulative distribution curve will be a measure of the true travel-time distribution. Rather, the curves will represent the uncertainty associated with parameter measurements as well as the uncertainty associated with many professional judgments about the likely effects of the various sources of parameter and conceptual uncertainty on flow mechanisms. Thus, the cumulative distribution curves will provide a performance measure that allows informed judgments about the likely range and uncertainty in the travel time from the disturbed zone to the accessible environment.

Step 4. Performance goals

The overall performance goal desired for the ground-water travel-time measure for the combination of all hydrogeologic units between the disturbed

Figure 8.3.5.12-7. Examples of ground-water travel-time distributions: top-histogram; bottom-cumulative distribution function showing x percentile of flow having travel times less than some specified value, T^* . Modified from Sinnock et al. (1986).

zone and the accessible environment is 1,000 yr at a very high level of confidence (Table 8.3.5.12-1). Assurance that the goal will be achieved should be very high to support a license application. To achieve the desired confidence in the total site, performance goals of 1,000 yr are set for several individual hydrogeologic units to establish multiple barriers and implement a strategy of defense-in-depth (Table 8.3.5.12-1). Performance goals of 1,000 yr are set to establish a direct basis for assessing compliance with the performance objective. Goals for 10,000 yr are included to provide a second point on the cumulative distribution curve to constrain the shape of the curve, thereby lending a degree of assurance that minor shifts in the whole curve (e.g., due to conceptual or parameter uncertainties) will not lead to significant differences in the likelihood of travel times less than 1,000 yr. Also, 10,000 yr goals, if met, provide a basis for a defense-in-depth strategy for resolution of Issue 1.1, which addresses releases of radionuclides over a 10,000-yr period. The confidence goals set for each unit for both 1,000-yr and 10,000-yr travel times are based on results of preliminary evaluations by Sinnock et al. (1986), exemplified in Figures 8.3.5.12-5 and 8.3.5.12-7.

The confidences indicated for the two travel-time goals for each individual unit range from very low to very high (Table 8.3.5.12-1). Five levels of confidence are assigned; very high, high, medium, low, and very low. Very high indicates that the goal lies at least three standard deviations below the mean of the ground-water travel time distribution; high indicates that the goal lies at least two standard deviations below the mean; medium, at least one standard deviation below the mean; low, less than the mean; and very low, less than one standard deviation above the mean. The differences in assigned confidences depend on such factors as saturation in each unit, frequency and apertures of fractures, thickness of each unit, and percentage of the repository area underlain by each unit. Confidence for the required travel time to the accessible environment would be high if the goal is met for various individual units, or (because of the redundancy among individual units) very high if goals are met for several of the various individual units.

The confidence desired for travel time through both Calico Hills units, CHnv and CHnz, is highest of all units, consistent with their designation as primary barriers. A confidence level of low was set for the TSw unit because only a short path length may exist below some portions of the disturbed zone and because of the greater likelihood of fracture flow through significant portions of this densely fractured and welded unit than through the CHn units. Confidence levels for the auxiliary Prow Pass and Bullfrog units (PPw, PPn, BFW, and BFn) are lower because they occur only beneath part of the repository area (Figures 8.3.5.12-4 and 8.3.5.12-6). The goal for the saturated zone, a secondary barrier, is assigned relatively low confidence based on current, conservative estimates of saturated zone flow times (DOE, 1986b).

Comparisons of calculated ground-water travel-time distributions (Figure 8.3.5.12-5) with the performance goals (Table 8.3.5.12-1) provide the basis for determining if each hydrogeologic unit meets its goal. This performance evaluation will be done after more data are available and new curves are calculated by determining from the cumulative distribution curves the likelihood that travel time is greater than the performance goal (e.g., 1,000 yr).

Step 5. Parameter needs

The parameters required to satisfy this issue are those that can establish a basis for reasonable assurance that the performance goals are met. This assurance can be achieved, in large part, if it can be demonstrated that water flows predominantly through the matrix rather than the fractures. This would occur if the water flows through a sufficient volume of matrix pores for at least some minimal portion of each unit to which a goal has been assigned. For each unit, the sufficient volume of pore space may be expressed as effective porosity, n . The minimum portion of each unit may be expressed for a given flux, q , as distance, d , along a flow path (generally equivalent to thickness of units in the unsaturated zone, assuming vertical flow). The condition of flow through the matrix may be expressed by a ratio of percolation flux to the saturated hydraulic conductivity of the matrix, q/K_s . If this ratio is less than some threshold value, generally taken to be somewhat less than one, a potential (expressed as suction pressure) for additional moisture retention will exist in the matrix materials and the entire flow volume will tend to move through the matrix. This, in effect, means that if flux exceeds matrix saturated conductivity, fracture flow is expected to occur. However, where flux is less than the conductivity, the resulting potential will tend to draw water from adjacent fractures into the matrix pores until pressure equilibrium is established between the matrix and fractures. The water that remains in fractures at this equilibrium pressure will occur in apertures generally equal in diameter to the largest saturated matrix pores or cling to asperities equal in radius to even larger unsaturated matrix pores holding water in minisci. Because an air-gap constrictivity generally occurs along fractures with apertures larger than the radius of partially saturated matrix pores (Wang and Narisimhan, 1985; Montazer, 1982), flow along fractures under suction pressures tends not to occur and flow across fractures may be considered an extension of matrix flow. As the ratio q/K_s decreases, the potential for moisture absorption by the matrix increases, assuming the matrix pores can drain (i.e., assuming they are not bounded downstream by a region where flux exceeds conductivity).

Because local heterogeneities in saturated conductivity can result in a chaotic distribution of regions where some have q/K_s values less than one and others have q/K_s values greater than one, particularly where flux is about equal to the mean of the probability distribution of conductivity, transitions may occur from fracture to matrix flow along any given path. Therefore, a sufficient portion of every flow path in each unit is sought where q/K_s is less than one in freely drained conditions. Given satisfaction of this inequality, seepage velocity can be assumed to equal the flux divided by the effective porosity of matrix materials, and travel time to equal the flow path distance divided by the seepage velocity. By allocating a required travel time (or times) to each unit, a combination of desired flux, effective porosity, and flow distance can be specified that cause the travel-time goal to be met. Further, if current conservatively estimated values for effective porosity and flux are defined as the desired conditions, then a minimum desired thickness of matrix flow can be defined for each unit. This process of quantifying desired parameter values was followed to define the values shown in the "performance parameter goal" column of Table 8.3.5.12-2, completing the performance allocation process for Issue 1.6.

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	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	0.01 to 0.2	> 0.5	Low	Low
	d ^e	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	0.15 to 0.45	> 0.2	Medium ^f	High
	d ^e	0 to 160 m	> 2.5 m (100%) > 25 m (80%)	Low ^f Low	High 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	0.2 to 0.4	> 0.2	Medium ^f	High
	d ^e	0 to 140 m	> 2.5 m (100%) > 25 m (80%)	Low ^f Low	High 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	0.015 to 0.35	> 0.1	Low	Medium
	d ^e	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	0.1 to 0.45	> 0.2	Low	Medium
	d ^e	0 to 140 m	> 2.5 m (50%)	Low	Medium

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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 goal ^d parameter	Current confidence	Desired confidence
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 ^e	0 to 70 m	> 5 m (20%)	Low	Medium
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 ^e	0 to 50 m	> 2.5 m (10%)	Low	Medium
Saturated zone	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 ^e	0 to 5000 m	1000 m	Low	Medium

^aTSw = 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.

^bq = flux; K_s = hydraulic conductivity of saturated matrix pores; n_e = effective porosity; d = distance along flow paths.

^cParenthetical values for d indicate the desired percentage of the repository area underlain by the indicated thickness.

^dLow 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.

^eBased on Section 3.9, Figure 8.3.5.12-4., and Sinnock et al. (1986).

^fA thickness of greater than 10 m for 100 percent of the area below the repository is based on a disturbed zone thickness much less than 50 m.

The values set as goals for the performance parameters, if realized, would establish a bounding basis for concluding with reasonable confidence that travel time in each unit would exceed 1,000 yr. However, knowing these goals were met would not be sufficient to calculate a cumulative distribution of travel time, especially if portions of some paths include fracture flow or if travel time, as expected, is influenced by variability of the parameters within ranges that are only bounded by the goals. Therefore, a set of supporting performance parameters based on elements of the general flow equations is identified in the next section, which describes Information Need 1.6.1. (Section 8.3.5.12.1). For these supporting parameters, no quantitative goals are set; rather, goals are defined in terms of relative confidence desired in the statistical properties of the spatially dependent probability distributions of the parameters. As a result, the total parameter needs for resolving this issue are separated into two categories: those identified here (Table 8.3.5.12-1) for establishing bounds on the travel time for comparison to goals, and those identified in the following section (Section 8.3.5.12.1) for developing a probabilistic performance measure expressed as a cumulative distribution function of travel time.

Interrelationships of information needs

The question raised by Issue 1.6 addresses whether the regulation for ground-water travel time, 10 CFR 60.113(a)(2), can be satisfied at the Yucca Mountain site. There are several distinct parts to the issue that must be resolved to answer the question. The distinct parts, expressed as questions, are as follows:

1. What site information, design concepts, and auxiliary information are needed to (1) identify the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment, and (2) determine the pre-waste-emplacement ground-water travel time along this path?
2. What calculational models of the hydrologic system will be used to identify the fastest flow path(s) and predict ground-water travel-time distributions along this path?
3. Based on the selected models, where is the fastest path(s) from the disturbed zone to the accessible environment, and what are the flow characteristics along this path?
4. What is the cumulative distribution of pre-waste-emplacement ground-water travel times along this path(s) based upon results of simulations using the calculational models and any other information resulting from answering the preceding questions?
5. Where are the boundaries of the disturbed zone?

Each of these questions has been designated as an information need. Questions 1, 2, 3, 4, and 5 are Information Needs 1.6.1, 1.6.2, 1.6.3, 1.6.4, and 1.6.5 (Sections 8.3.5.12.1 through 8.3.5.12.5), respectively. Information Need 1.6.1 summarizes the mathematical basis for calculating ground-water travel time and the associated set of site parameters needed to resolve this issue. Included in Information Need 1.6.1 is an indication of the

confidence desired for each parameter. Note that the required parameters and associated confidence levels apply to statistical moments of particular properties and not just to a single value for each property. Such statistical information will allow better quantification of uncertainty for a given conceptual model than will data limited to expressions of confidence in a single, target value for a given property.

Information Need 1.6.2 (Section 8.3.5.12.2) describes the planning basis for selecting calculational models that will help identify flow paths and analyze ground-water travel times along these paths. Direct measurements of ground-water travel time for demonstration of compliance with regulatory rules are not feasible. Therefore, resolution of this issue requires calculational models that can simulate ground-water flow at the site and predict flow paths and travel times from the disturbed zone to the accessible environment. These models also enable sensitivity analyses to be performed; such analyses indicate the relative importance of different parameters to travel-time distributions (values, moments, and spatial location), so that data acquisition plans can be focused in an iterative process on parameters that allow the greatest reductions in quantifiable uncertainty about ground-water travel time. The calculational models will be used to identify likely paths of radionuclide travel (Information Need 1.6.3) and to assess pre-waste-emplacement ground-water travel time along these paths (Information Need 1.6.4). Thus, the models selected under Information Need 1.6.2 are based on mathematical concepts addressed in Information Need 1.6.1 that establish the parameters needed to predict ground-water travel time. On the other hand, the confidence desired for each parameter is established by interpreting analyses done to satisfy Information Needs 1.6.3 and 1.6.4.

Information Need 1.6.3 (Section 8.3.5.12.3) addresses a basis for determining the fastest paths of likely radionuclide travel for both matrix- and fracture-dominated modes of water movement. As site characterization proceeds, new data will be analyzed to identify the likely flow paths. Ultimate selection of flow processes and paths used for analysis of travel time may be based, in part, on data or theories that are inadequate for unambiguous estimation of a probability or likelihood of occurrence and will require the judicial use of expert judgment and peer review.

Activities under Information Need 1.6.4 (Section 8.3.5.12.4) focus on determining pre-waste-emplacement ground-water travel times along the fastest path of radionuclide travel. Sensitivity and uncertainty analyses are also performed under Information Need 1.6.4 to establish the effects of uncertainty in parameter values and conceptual approaches on the ultimate confidence that may be placed in the predictions of travel-time. Results of prelicensing studies will be used to evaluate the sufficiency of the data base on which predictions are made, thereby identifying the proper focus of further site characterization to reduce most effectively the remaining sources of uncertainty in predictions of travel time.

Information Need 1.6.5 (Section 8.3.5.12.5) establishes a planning basis for determining the boundary of the disturbed zone. The current plans are based in part on the general guidance given by the U.S. Nuclear Regulatory Commission (Gordon et al., 1986). Thermal, mechanical, geochemical, and hydrologic analyses will be used to define the extent of disturbances expected from repository construction and heat generated by the waste.

Because Information Need 1.6.5 is fundamentally different from the previous information needs in this issue (in that the information required for Information Need 1.6.5 will address the postemplacement environment and will not be used directly to assess ground-water travel time) it is treated separately. Information Need 1.6.5 develops its own performance measures and goals, as well as the parameters required to assess the extent of repository-induced disturbances.

The schedule information provided for information needs in this section includes the sequencing, interrelationships, and relative durations of the activities in the information need. Specific durations and start/finish dates for the activities are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

8.3.5.12.1 Information Need 1.6.1: Site information and design concepts needed to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path

This information need summarizes the parameter needs required for analyses to be performed for assessing ground-water travel time. The information and data required for Information Needs 1.6.2 through 1.6.4 (Sections 8.3.5.12.2 through 8.3.5.12.4) are described here. Because defining the disturbed zone is distinct from calculating ground-water travel time, the parameters required for the disturbed-zone definition are addressed in Information Need 1.6.5 (Section 8.3.5.12.5). The parameter needs identified here apply only to pre-waste-emplacement conditions.

The specific parameters requested by Issue 1.6 are discussed later in the logic portion of this section and will provide information in the following four categories (Figure 8.3.5.12-8):

1. System geometry.
2. Material property values.
3. Initial and boundary conditions.
4. Model validation.

Information is required from each of these categories to calculate ground-water travel-time values in Information Need 1.6.4.

The specific parameters requested here (inner circle, Figure 8.3.5.12-8) rarely correspond to parameters directly measured in the field or laboratory (outer circle, Figure 8.3.5.12-8). A set of site characterization modeling activities (middle circle, Figure 8.3.5.12-8) is required to reduce the measured data to the parameters amenable for direct use in ground-water travel-time calculations. The logic that establishes how the actual measurements are used to produce the requested parameters is provided in Sections 8.3.1.2 (geohydrology) and 8.3.1.4 (rock characteristics).

Crucial information required by this issue are descriptions of the conceptual models and associated uncertainties for the unsaturated-zone and saturated-zone flow systems at the site. Though no specific parameter needs

K-5/13/87-FIGURE 8.3.5.12-8

Figure 8.3.5.12-8. Schematic flow of site information on system geometry, material properties, initial and boundary conditions, and model validation through data reduction modeling (Programs 8.3.1.2 and 8.3.1.4) to definition of performance assessment parameters (Table 8.3.5.12-2) for use in ground-water travel time calculations and model validation (Information Needs 1.6.2, 1.6.3, and 1.6.4).

are delineated here with regard to the validation of flow models, the means by which the flow models will be developed, as well as the plans that described how the requested specific parameter values will be obtained, are described within the geohydrology program (Section 8.3.1.2), and rock characteristics program (Section 8.3.1.4).

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Chapter 3 summarizes the current understanding of conceptual models of ground-water flow addressed by the general equations of flow discussed here. Chapters 1 and 2 provide the current data on the geologic and rock characteristics represented by parameters in the equations. Data on the thicknesses and extents of stratigraphic units also are contained in Chapters 1 and 2. Structural information about fracture and fault characteristics is provided in Chapter 1. Data on porosity are in Chapters 2 and 3, and data on permeability, saturation, pressure, and water table elevations are in Chapter 3.

Parameters

The parameter needs established for this information need are identified in Table 8.3.5.13-3. In general these parameters will be obtained from activities discussed in Section 8.3.1.2.

Logic

Parameter requirements cannot be made without using some conceptual model(s) as the basis. The phenomena relevant to predicting ground-water travel times at the site have been indicated in the issue resolution strategy of this issue and are more fully described in Section 3.9. The general concept for flow in the saturated zone postulates Darcian flow in a saturated, equivalent porous medium. The concept for flow in the unsaturated zone postulates near steady-state Darcian flow, with the possibility of flow in both the matrix and fractures. The mathematical equations that are formulated to describe the conceptual flow models are used to determine what parameter information is required. A significant aspect of site characterization is testing the validity of these models. The models will be periodically reevaluated and modified, if necessary, in light of the results of this testing.

Ground-water models generally are based on one or more governing equations. These equations are derived by combining mathematical statements for the conservation of mass and momentum with constitutive equations relating these statements to measurable quantities such as hydraulic head (pressure) and initial and boundary conditions.

The governing equation of three-dimensional flow in saturated porous media is generally expressed as follows:

$$S_s \frac{\partial h}{\partial t} - \nabla \cdot (\bar{K} \nabla h) + Q = 0 \quad (8.3.5.12-1)$$

where

S_s = specific storage

h = piezometric head

$\bar{K}$ = hydraulic conductivity

Q = volumetric discharge $\left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right)$

t = time

∇ = differential operator

For steady or nearly steady flow, the storage term can be neglected.

Flow in unsaturated porous media is generally expressed by variants of Richards' equation. The model for liquid water flow in unsaturated fractured porous media, as described in Section 3.9, can be formulated by an equation derived from a version of Richards' equation written for both the matrix and fracture systems and by assuming that, in a near-equilibrium condition, the pressure head in the fractures and the matrix is locally in equilibrium. This can be written in the form

$$\nabla \cdot [(\bar{K}_m(\psi) + \bar{K}_f(\psi)) \nabla (\psi + z)] = F \left(\frac{\partial \psi}{\partial t} \right) + Q \quad (8.3.5.12-2)$$

where

$\bar{K}_m(\psi)$ = the relative hydraulic conductivity for the unsaturated matrix system

$\bar{K}_f(\psi)$ = the relative hydraulic conductivity for the unsaturated fracture system

ψ = pressure head

z = elevation head

Q = sink/source term

and F involves the specific moisture capacity of matrix and fractures and the compressibility of water, the bulk rock, and the fracture system (Klavetter and Peters, 1986).

Once the pressure head distribution is established, seepage velocities (v) can be determined by

$$v = \left(\frac{K(\psi)}{n_e} \right) \left(\frac{\partial h}{\partial l} \right) \quad (8.3.5.12-3)$$

and ground-water travel time (GWTT) by

$$\text{GWTT} = \frac{D}{v} \quad (8.3.5.12-4)$$

where h is total head defined by an elevation head component, z , and a pressure head component, ψ , l is length along the pressure gradient, d is the flowpath length, and n_e is effective porosity.

K or $K(\psi)$, hydraulic conductivity is an empirical parameter that depends on properties of both the moving fluid and transmitting medium (i.e., on both water and rock properties). may be more fundamentally expressed as

$$K = \frac{\rho g k}{\mu} \quad (8.3.5.12-5)$$

where K , permeability, or $K(\psi)$, relative permeability, is a property of the rock (and moisture content in unsaturated material), g is the acceleration due to gravity, and μ , viscosity, and ρ , density, are properties of the fluid that depend on temperature and on chemical species present. Assuming little effect of chemistry on ρ and μ , in situ temperatures and intrinsic permeability are the parameters needed to derive K . In unsaturated materials, the value of $K(\psi)$ depends on moisture content and may differ (for transient behavior) depending on whether the material is becoming wetter (ψ increasing) or drier (ψ decreasing). This moisture dependency and hysteresis will be accounted for in modeling of the unsaturated zone (8.3.1.2.2).

Effective porosity is used here as a measure of the volume of space through which flow occurs. In the unsaturated zone, this property is taken to be the in situ moisture content less the residual moisture content. As understanding of unsaturated flow evolves, this definition may need to be modified to account for porous channeling or other phenomena.

Equations 8.3.5.12-1 through 8.3.5.12-5 are judged, based on the current understanding of the conceptual models of flow at the site (as described in Chapter 3), to be a suitable basis for generally describing the flow phenomena present in the saturated and unsaturated zones. These equations define the basic set of material-property parameters that must be available to calculate ground-water travel time and therefore resolve this issue. Additional information required to solve Equations 8.3.5.12-1 through 8.3.5.12-5 include the description of the system geometry (for both the saturated and unsaturated zones within the controlled area) and initial and boundary conditions for the models.

Parameters requested in Table 8.3.5.12-3 are divided into the four categories previously discussed: (1) system geometry, (2) material property values, (3) initial and boundary conditions, and (4) model validation. As described earlier, information is required from the first three categories to provide specific input for the solution of the general equations for ground-water travel time. To determine if those mathematical equations provide an adequate formulation for the calculation of ground-water travel time,

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							
<u>Initial and Boundary Conditions</u>							
Flux, percolation rate	Fault zones	R-area	UZ, TS _w 2, repository level	Mean	Medium	NA ^d	NA
	Fault zones	R-area	UZ, TS _w 2, repository level	SCor	Low	NA	NA
	Fault zones	R-area	UZ, TS _w 2, repository level	SDev	Low	NA	Low
	Fractures	R-area	UZ, TS _w 2, repository level	Mean	Medium	3.9.3	NA
	Fractures	R-area	UZ, TS _w 2, repository level	SCor	Low	NA	NA
	Fractures	R-area	UZ, TS _w 2, repository level	SDev	Low	NA	Medium
	Rock matrix	R-area	UZ, TS _w 2, repository level	Mean	High	3.9.3	NA
	Rock matrix	R-area	UZ, TS _w 2, repository level	SCor	Medium	NA	NA
	Rock matrix	R-area	UZ, TS _w 2, 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

8.3.5.12-30

CONSULTATION DRAFT

Table 8.3.5.12 3. 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 ^b	Needed confidence ^c	SCP Section where current estimate is discussed	Current confidence ^d
Porosity, effective	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
	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
	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							
<u>Initial and Boundary Conditions</u>							
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
<u>Material Properties</u>							
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
<u>System Geometry</u>							
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
<u>Validation of Model Concepts</u>							
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							
<u>Material Properties</u>							
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							
<u>Material Properties</u>							
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
Fracture frequency	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
	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 repository	SCor	Low	NA	NA
	Fractures	R-area	UZ, each hydro unit below repository	SDev	Low	NA	NA

^aSZ = saturated zone; UZ = unsaturated zone; GWTT = ground water travel time; C-area = controlled area; R-area = repository area; litho = lithological; hydro = hydrological.

^bMean = spatially dependent mean value; SDev = spatially dependent standard deviation; SCor = spatial correlation coefficient.

^cHigh = high confidence, highest priority; Medium = medium confidence, medium priority; Low = low confidence, low priority.

^dNA = not available.

information relevant to the fourth category, model validation, is also required.

Under each of the four categories in Table 8.3.5.12-3, specific parameters are requested for several distinct types of models. The parameters may be used primarily in direct calculations of the ground-water travel times in the unsaturated zone or the saturated zone; they may be used primarily in models to derive hydrologic properties of fractures, or they may be used primarily in models to define the basic spatial correlation structure of the rock mass. Table 8.3.5.12-3 is subdivided to show which parameters are used in each of these broad types of models.

The second column in the table, material type, indicates whether information on the requested parameter is required about their distributions in the rock matrix, in distributed fracture networks, as characteristics of a sufficiently large volume of rock (rock mass), or in fault zones. The third column, spatial location, indicates whether information is needed for the requested parameter in the repository area or the entire controlled area. The fourth column in the table, stratigraphic unit, indicates where in the vertical dimension that information is needed. In the unsaturated zone, because this issue is concerned primarily with downward water movement, most of the information is requested only for those units at the repository level or below. However, it is recognized that similar information may be required for units above the repository level (see Investigation 8.3.1.2.2) in order to infer some of the parameters requested in Table 8.3.5.12-3, such as percolation flux.

The fifth and sixth columns indicate, respectively, the statistical measures desired and confidence level set for each requested parameter. The measure desired is either one of the first two statistical moments (mean and standard deviation) for the parameter or the spatial correlation coefficient. The confidence level (low, medium, or high) indicates the relative confidence required in the parameter of interest, with a confidence level of high also indicating that the parameter value is of high priority, medium indicating a medium priority item, and low indicating a low priority item. These confidence levels are based on professional judgments about the relative importance of the various parameters and are not meant to imply any quantitative definition. The confidence levels apply to confidence that the location-dependent mean, standard deviation, and spatial correlation need to be known to the indicated levels. Generally, for the unsaturated zone, higher confidence is requested for matrix properties than for properties of fractures, faults, or the rock mass. This reflects current judgments that matrix flow dominates in the unsaturated zone. The relative confidence levels are also based, in part, on the estimated feasibility of obtaining reliable information for each of the parameters.

The seventh and eighth columns in Table 8.3.5.12-3 identify the section in the SCP where current values for each of the identified parameters are discussed, and the current confidence that the NNWSI Project has for each parameter.

Table 8.3.5.12-3 lists those site parameters considered necessary to support resolution of this issue. In general, values for parameters listed in the table under the categories of material properties and initial and

boundary conditions will provide the direct input necessary to calculate ground-water travel times from the mathematical formulations represented by Equations 8.3.5.12-1 through 8.3.5.12-5. However, some parameters in those equations are not requested by Table 8.3.5.12-3. For example, the viscosity and density of water and the value of the acceleration due to gravity were not requested because they can be readily obtained from scientific handbooks. The specific storage parameter in the first term on the left-hand side of Equation 8.3.5.12-1, which represents responses to transient, stressed conditions, is not requested because pre-waste-emplacement travel times will be calculated under steady or near steady conditions. Also, the parameter in Equation 8.3.5.12-2, representing the specific moisture capacity of the rock and compressibilities of fluid and rock, is not requested because it can be derived from values from a combination of the requested moisture retention curves and from values from literature sources.

The parameters in Table 8.3.5.12-3 related to fracture geometry in the unsaturated zone will be required if evaluation of flow in fractures is required. Values of these parameters for unsaturated units will be used to infer the hydrologic properties of fractures including relative permeability and associated effective porosity, perhaps in the manner of Wang and Narasimhan (1986), only if fracture flow below the disturbed zone is sufficiently widespread or probable to warrant analysis. Similarly, bulk density is listed as a contingency for preserving the option to consider diffusion of nonsorbing tracers in the event of significant fracture flow. The term involving diffusion of tracer particles between the matrix and the fractures is not shown in Equations 8.3.5.12-1 and 8.3.5.12-2 because these equations are ground-water flow rather than transport equations. If diffusion is to be considered then the transport equations developed in Issue 1.1 would apply (Section 8.3.5.13).

For both the unsaturated and saturated zones, the confidence levels set for individual parameters reflect current judgments of their relative importance to ground-water travel time. If the mean values currently available (Chapters 1 through 3) for the parameters listed in Table 8.3.5.12-3 are good estimates of the true values, then those values are probably adequate to show compliance with the performance goals set for this issue. In no instance is the current level of confidence high for any of the parameters listed.

The actual parameters requested are the first two statistical moments (mean and standard deviation) and the spatial correlation coefficients of each of the properties for each of the hydrogeologic units. Thus, the confidence levels apply to confidence that the three-dimensional location-dependent mean, standard deviation, and spatial correlation within each unit are known to the indicated level of confidence. Generally, more samples are required to obtain higher confidence levels for, respectively, means, standard deviations, and spatial correlations of individual properties. This is particularly true for geologic materials where properties are commonly treated as regionalized variables (Matheron, 1971). This strategy of assigning confidence goals to statistical parameters of distinct properties varies somewhat from the general approach for issue resolution discussed in Section 8.2.2 wherein target goals are requested for the value of a property with specified confidence or within specified intervals. Given the nonunique combination of property values that will satisfy the performance goal and the potentially large contribution of spatial and statistical variability of

properties to uncertainty in travel-time predictions (Codell, 1986; Sinnock et al., 1986), definition of the statistical characteristics of property distribution will more effectively and efficiently reduce uncertainties, at least for this issue, than specification of target values for the properties. Because spatial variability is a major source of uncertainty in predictions of ground-water travel time, it is prudent to characterize the spatially dependent statistical structure of the variables.

A large number of samples may need to be tested to obtain high confidence in some parameters over the entire repository site, particularly the spatial correlation. This is because the porous tuff formations are probably heterogeneous, with hydrogeologic properties varying in an irregular manner in space both horizontally and vertically. The heterogeneity can be characterized by the autocorrelation of the properties of interest as a function of spatial separation. This autocorrelation is referred to in the remainder of this section as spatial correlation. Different scales (sample separation differences) should be sampled reliably to assess the vertical and horizontal spatial structure of parameter statistics within each hydrogeologic unit. The scale over which a measurement averages flow parameters should be evaluated to estimate the proper hydraulic properties of the medium to use in modeling exercises. The laboratory and even field scales of property measurements are usually relatively small compared with the rock mass represented in numerical simulations. Modeling-scale properties of the fractured porous rock mass need to be developed, accounting for the uncertainty in both the fracture and matrix variability, by calibrating the modeling data with the actual measurements obtained from cores, in situ tests, and subsurface observations in the exploratory shaft. The effect of different scales on hydrologic property values will be investigated in Sections 8.3.1.2.2 and 8.3.1.4.3. Definition of the scale-dependency and spatial variability may require systematic, relatively dense sampling of the properties of interest (or their correlated surrogates).

To indicate the level of detail at which the information is required for resolution of this issue, a desired level of confidence, for example high, medium, or low, is indicated in Table 8.3.5.12-3. Because of the paucity of current information on hydrologic properties and characteristics, the requested levels of confidence are only qualitative. These qualitative levels relate to the width of the confidence interval for means and variances, with high indicating that the desired confidence interval for the value is smaller than the interval for a medium level of confidence. For spatial correlation, increasing confidence is taken to mean extending the spatial correlation coefficient (variogram) over a greater distance range, at a given level of confidence. Quantitative levels may be set as the hydrologic models are more completely defined and knowledge is improved about the effects of parameter distributions, interrelationships, and characteristics on uncertainty in ground-water travel time.

Confidence in means, standard deviations, and spatial correlations can be enhanced by defining the covariance coefficients among different parameters, within and between individual hydrogeologic units, and using the spatial distribution of one parameter to constrain the distribution of another. To be most effective, this approach should rely on measurements of correlated parameters on a single physical sample. Therefore, design of a

sampling and testing program should, to the extent practical, sequence measurements of different parameters on single samples.

Although little specific information is called out within Table 8.3.5.12-3 to define the conceptual hydrologic models, it is evident that definition of alternative conceptual hydrologic models and assessment of their relative likelihood for the unsaturated and saturated zones is an important requirement for evaluating ground-water travel times. Chapter 3 more explicitly addresses some of the sources of uncertainty about unsaturated-zone conceptual models, and these uncertainties are shared by this issue, including questions about coupling processes between matrix and fracture flow and about scaling laboratory and field measurements to a sufficiently large volume of rock for numerical modeling.

Hydrologic concepts and data needed to calculate ground-water travel times are provided by the site characterization programs 8.3.1.2 and 8.3.1.4. Calculation of the ground-water travel-time distribution will probably be made with versions of different calculational models. Calculational models are subject to refinement as conceptual understanding of flow in unsaturated and saturated, fractured porous tuff increases and as additional data are acquired from site characterization. The hydrologic parameters and confidence levels listed in this information need will probably be revised as the current versions of calculational models are refined.

No specific activities are defined for this information need. However, as more information about site data and geostatistical modeling becomes available, the data needs defined in this section will be continually reevaluated (see Section 8.3.5.12.4.1.1).

8.3.5.12.1.1 Application of results

The information called for in this information need is a summary of data about site characteristics required to satisfy Issue 1.6. As such, satisfaction of this information need will provide the input parameters for modeling activities described under Information Needs 1.6.2 through 1.6.4.

8.3.5.12.1.2 Schedule and milestones

There are no activities for Information Need 1.6.1. For this reason, a timeline figure is not presented in this section.

Information Need 1.6.1 supplies parameters to Information Needs 1.6.2 through 1.6.4, whereby models and codes for calculations of ground-water travel times are determined, likely paths of radionuclide transport are identified, and the fastest travel time along the most likely path is determined. Sections 8.3.1.2 (geohydrology program) and 8.3.1.4 (rock characteristics program) describe the logic for how the parameters required by this information need will be generated.

8.3.5.12.2 Information Need 1.6.2: Calculational models to predict ground-water travel times between the disturbed zone and the accessible environment

Issue 1.6 addresses the performance objective that pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 yr. Direct measurements of ground-water travel time are not feasible because the time and distance scales are too great for direct observation. Resolution of the issue will be demonstrated primarily by using numerical models to make quantitative estimates of the distribution of ground-water travel time and by comparing these estimates to the performance goals. Models that describe the appropriate physical processes are needed for estimating the ground-water travel times. Several types of calculational models are required to provide tools for determining the pre-waste-emplacement ground-water travel time.

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Currently available calculational models for ground-water travel time are alluded to in Section 3.9, and more comprehensively listed in Section 8.3.5.19. The conceptual basis for the current models and those that may be developed in the future is described in Section 3.9, and the basic mathematical formulations of current models is given in Information Need 1.6.1, Section 8.3.5.12.1.

Parameters

The following information must be available to select a set of calculational models for establishing ground-water travel time:

1. Site parameters described in Information Need 1.6.1 (Section 8.3.5.12.1) and listed in Table 8.3.5.12-3.
2. Conceptual models of water flow through the unsaturated and the saturated zones at the Yucca Mountain site. The conceptual models should consist of a description of the physical processes, including a definition of the limits of the processes, a listing of parameters believed to be relevant to the process, and a statement of the parameters that the model will predict.
3. A three-dimensional geometric model of site parameters alluded to in item 1. This geometric model should be capable of associating single values, multiple values, or variations of values for the hydrological and geochemical parameters with specific three-dimensional locations at the Yucca Mountain site.

Logic

The types of calculational models required depend upon the approaches used to resolve the ground-water travel-time performance objective, reflected in the technical basis described for resolving Information Needs

1.6.3 and 1.6.4 (Sections 8.3.5.12.3 and 8.3.5.12.4). A sufficient understanding of the flow behavior at Yucca Mountain, as well as interpretations of the available data, are needed to select an appropriate suite of models for resolving this issue. Once the physical processes of the flow system have been hypothesized (the issue resolution strategy, Section 8.3.5.12 and the geohydrology testing strategy, Section 8.3.1.2) and a proper set of variables (or data) has been identified (Section 8.3.5.12.1), mathematical and numerical models of the flow behavior can be formulated. Many alternative considerations are examined: What dimensionality and scale of modeling should be used? Can simplifying approximations to the physical processes be used? Should a homogeneous-parameter or heterogenous parameter model be used to quantify physical properties of discrete hydrogeologic units? What are the proper mathematical forms of the processes embodied by the models? What are the proper geometric and mathematical forms of boundary and initial conditions?

Ground water at the Yucca Mountain site flows through fractured porous tuff in both saturated and unsaturated conditions. Current conceptual models of Yucca Mountain postulate that flow takes place in matrix pores or in matrix pores in combination with fractures. The matrix porosity is made up of interconnected microscopic pores within tuff blocks bounded by fractures. The fracture porosity is made up of joints and fault zones. Indeed, the many fractures can be envisioned as homogeneous within the framework of continuum models at an appropriately large scale. Faults may serve as specific discontinuities, boundaries, zones of high permeability, etc., but they may be too few and too influential to justify a continuum approach. The different types of calculational models that may be used to simulate the flow through fractured, porous systems are discussed in the following paragraphs.

The equivalent porous medium type of model (Bear, 1972) is based on representative elemental volume concepts and on the assumption that any flow through fractures is Darcian. The equation of flow is described by the conservation of mass, including terms for advection, storage, dispersion, diffusion, and sinks and sources. The underlying assumption is that physical quantities such as porosity, conductivity, and pressure can be averaged over large blocks of rock containing a large number of fractures. There is no well-defined method for computing the equivalent porous medium parameters even if the fractures are completely described, although several models are being constructed to generate unsaturated porous-media properties from detailed structural and physical concepts. When available, these methods may be applied to the unsaturated zone. Equivalent porous medium models are generally taken to be the most realistic way of calculating regional scale and local scale (repository area) saturated ground-water flow. Thus, this type of model will be used for saturated flow simulations used to calculate travel times. The parameters needed for this model are hydraulic conductivity, effective porosity, specific storage, the flux and head at the model boundary, and initial head conditions within the model area.

The double porosity type of model (Barenblatt et al., 1960) lumps all the matrix blocks into one continuum and all the fractures into another continuum and develops a coupling term between the two continua. The rock matrix continuum is commonly characterized by low permeability and high storage, while the fractured continuum is usually characterized by high permeability and low storage. Therefore, the rock matrix often controls the

late time response of the system to pressure or stress transients, while the fractured continuum controls the early time response of the system. This system can be described by two mass conservation equations, one for each continuum. If flow is highly dominated by either matrix or fractures, the need for two continua is questionable and reasonable approximations can be obtained by a single equivalent porous medium approach. The parameters needed for the saturated zone are the effective porosity, hydraulic conductivity, and the pressure for both matrix and fracture continua; the flux of water; and a coupling function representing the transfer of fluid between rock matrix and fractures, including, as appropriate, hysteretic behavior of relative hydraulic conductivity and effects of mineral coatings on fracture-to-matrix conductivity. Physical parameters, such as porosity and permeability, associated with the fracture continuum are obtained from fracture properties such as aperture width, spacing, and orientation. This approach probably will not be used in the studies currently planned because of the current beliefs that flow in the unsaturated zone is predominantly constrained to the matrix pores and in the saturated zone to the fractures.

A special case of the double porosity model, called a composite medium model (Klavetter and Peters, 1986), can be derived by adding the two continuum equations, assuming the potential fields for the two systems (matrix and fractures) are in equilibrium. The validity of this fundamental assumption will be tested by the site characterization program for geohydrology (Program 8.3.1.2). Such superposition is practical in the representative elementary volume approach for saturated flow but has not been demonstrated to be applicable to unsaturated flow. As for the double porosity model, the composite medium model is only applicable under the steady or nonsteady conditions where both matrix pores and fractures are involved in the flow. This model will be provisionally accepted to describe unsaturated flow under transients that cause fracture flow. The parameters required for unsaturated conditions are the relative permeability and saturation as a function of pressure head, effective porosity, and initial conditions; all these parameters are required for both the matrix and fractures (Table 8.3.5.12-3). This type of model will be used primarily to investigate local behavior of fracture and matrix flow within and between units under variable flux conditions to help generate representative concepts, parameters, and flow paths for use in site scale models.

Another approach to investigating the relations between matrix and fracture flow involves discrete fracture models that treat fractures and discontinuities individually rather than as a continuum. The drawback to a discrete fracture model for site scale applications is the amount of detail that is required as input for a large number of fractures and the accompanying difficulties in modeling the discrete fractures throughout a large volume. For small scales, an efficient approach can be applied by using statistical descriptions of fracture characteristics to generate synthetic fractures sets, then simulating the flow through the fractures and between the matrix blocks and the fractures (Long et al., 1982; Wang and Narasimhan, 1985, 1986). Microfractures, which are too numerous to simulate discretely, may be included within the hydraulic properties of the fracture or matrix continuum, as is true for any modeling approach accounting for dual porosity effects. This type of model will be used to augment a composite medium model to establish proper generalized parameters for use in simpler site-scale

models. Of particular interest are the potential for channeling of fracture flow and other complications that may result in generalizing the characterization of the fractures.

The phenomena of flow in fractured porous tuff are complicated, especially in the unsaturated zone. In particular, the mathematically nonlinear description of permeability changes caused by saturation changes (flux transients) in the differential equations of flow become very difficult to solve, especially where material property contrasts occur between matrix blocks and fractures or across unit contacts. If the spatial variability of properties within units is considered, the difficulties of numerical convergence are increased many fold. To attempt to overcome some of these numerical difficulties, development of simplified models that avoid iterative, convergent solutions of the mass-balance differential equations will be pursued. Current ideas point toward direct kinematic or direct simulation models that calculate velocity, simply, as flux divided by moisture content, where flux is treated as an independent boundary condition. For example, the velocity of ground water in unsaturated flow may be approximated in one-dimensional analysis by dividing percolation flux by the moisture content in the matrix pores. If the flux is greater than the saturated hydraulic conductivity, the travel time is calculated from the velocity of flow through fractures (Sinnock et al., 1986). This, or similar simplified models, will be used to the extent it can be demonstrated as reliable or conservative for site-scale calculations of travel-time distributions. Currently, it is believed that there is a possibility of lateral diversion at some unit contacts or within single units. In this case, one-dimensional vertical flow may be an oversimplification and horizontal components might need to be accounted for in defining a set of one-dimensional flow lines. The computing efficiency associated with such one-dimensional kinematic models allows available computing power to be focused on resolution of the effects of spatial heterogeneity.

As currently planned, a stochastic type of model that generalizes flow processes while enhancing spatial resolution of property variations will serve as the primary site-scale model. Using this approach, ground-water travel time can be treated as a random variable rather than as a fixed quantity through any given distance (Codell, 1986). One source of the variability of ground-water travel time is caused by spatial heterogeneity of the parameters. Irreducible uncertainty about site characteristics with regard to spatial and temporal variabilities will always lead to uncertainty in ground-water travel time. To account for the spatial variability and uncertainty of parameters (e.g., hydraulic conductivity and effective porosity for both the matrix and fractures, and for initial and boundary conditions), many random realizations of the parameter sets will be used to estimate a travel-time probability distribution that reflects parameter uncertainties that are themselves expressed as probability distributions. Such a procedure is known as a Monte Carlo simulation and will be applied to estimate the ground-water travel-time distributions for comparison with the travel-time goals set in Section 8.3.5.12. A preliminary application of this approach was used to generate the cumulative distribution functions for travel time (Sinnock et al., 1986) in Sections 3.9.4 and 8.3.5.12. A more direct stochastic method is to treat numerically the parameters and dependent variables of the governing equations as random processes rather than as deterministic quantities. The partial differential or kinematic equations

describing flow are solved in terms of means and variances of the dependent variables. The direct stochastic method of modeling has been rapidly developing in recent years (Mantoglu and Gelhar, 1985; Yeh et al., 1985). A good estimate of input covariances of the hydrogeologic parameters is required for such stochastic modeling. If feasible, this direct stochastic approach may be used to supplement or supplant reliance on Monte Carlo simulations. •

The proper application of each type of model is determined by its role in building confidence that the flow time can be adequately simulated and that uncertainty can be adequately accounted for. The level of complexity of the phenomena included in the model depends on the purpose for which the model is intended. A flow-system model will be developed to incorporate spatial variability, temporal variability, and uncertainty. Once a modeling concept has been developed to some level of sophistication, a period of evolution begins, wherein the important features of the model are retained and inconsequential features are eliminated. This occurs by comparing the results of simulations using various approaches, modifying the models to test the assumptions, calibrating and validating the models, performing sensitivity analyses and uncertainty analyses, and incorporating new data into the analyses. The correctness of results predicted by the model will be tested against analytical solutions of a similar model and against laboratory and field data. When discrepancies appear, the models may undergo modification and further modeling tests may be performed until a self-consistent model of the flow system is built.

In summary, the calculational models required to estimate ground-water travel times from the disturbed zone to the accessible environment include (1) local (small scale) models for both the unsaturated zone and saturated ground-water flow to establish the proper processes to consider in the flow description at the site, (2) a travel-time model to determine ground-water travel time based on simplifications of the flow processes established by the local scale models, and (3) a statistical model to incorporate the uncertainty in the input information into the travel-time model and to provide a probabilistic estimate of ground-water travel time.

8.3.5.12.2.1 Activity 1.6.2.1: Model development

The objective of this activity is to develop calculational models for predicting pre-waste-emplacement ground-water travel time. Two subactivities are involved in this activity.

8.3.5.12.2.1.1 Subactivity 1.6.2.1.1: Development of a theoretical framework for calculational models

Objectives

The objective of this subactivity is to assess conceptual and mathematical representations of unsaturated flow phenomena in fractured porous media

and adopt a set or sets of equations for use in calculating ground-water travel time.

Description

This subactivity will assess the concepts and hydrologic mechanisms governing fluid flow in partially saturated fractured porous tuff at Yucca Mountain. Section 8.3.1.2.2, under the geohydrology program, will describe the unsaturated zone hydrologic system at Yucca Mountain. This activity will work in conjunction with plans described in Section 8.3.1.2.2 to develop one or more mathematical representations of the hydrology at the site that are suitable for use in the calculation of ground-water travel time.

8.3.5.12.2.1.2 Subactivity 1.6.2.1.2: Development of calculational models

Objectives

The objective of this subactivity is to develop computer algorithms for calculational (numerical) models to estimate ground-water travel time.

Description

This subactivity will refine existing computer algorithms or develop new ones that embody (1) local flow models for investigating the mechanisms of flow in the unsaturated and saturated zones, (2) travel-time models for estimating ground-water travel time, and (3) statistical models for incorporating the uncertainty in a probabilistic manner. This subactivity will modify present calculational models by comparing them with other models incorporating different levels of sophistication, field test results from the geohydrology program about the conceptual assumptions within the models, and the results of sensitivity analyses. These calculational models will be developed in cooperation with related efforts in Section 8.3.1.2.2.

8.3.5.12.2.2 Activity 1.6.2.2: Verification and validation

The objective of this activity is code verification and model validation. Two subactivities are involved in this activity.

8.3.5.12.2.2.1 Subactivity 1.6.2.2.1: Verification of codes

Objectives

This subactivity will ensure that the computer algorithms making up the codes correctly perform the intended numerical operations.

Description

The numerical accuracy of the calculational models used in analysis of flow will be verified by tests including comparison to analytical solutions and benchmarking against other codes. Currently, the NNWSI Project is participating in HYDROCOIN, an international effort to verify and support validation of computer codes to be used in assessments of environments related to nuclear waste disposal. The NNWSI Project has also instituted a formal code verification activity, CQVE, for all performance assessment codes used by the project. For more information, refer to Sections 8.3.5.19 and 8.3.5.20.

8.3.5.12.2.2.2 Subactivity 1.6.2.2.2: Validation of models

Objectives

The objective of this subactivity is to ensure that the conceptual models and their mathematical and numerical representations correctly account for the physical processes relevant to determining ground-water travel time.

Description

The correctness of theoretical and mathematical models in the simulation of flow phenomena relevant for assessing travel time will be addressed by model validation. The validation tests will involve, to the extent possible, comparisons of model predictions with laboratory experiments and field data or comparisons with other models already validated. The correctness of results predicted by a model will be tested against similar models (verification) and against appropriate laboratory and field data (validation). If discrepancies occur, the models may undergo modification and further verification and validation until the code predicts observed behavior with acceptable accuracy or the range of uncertainty associated with code predictions will be extended. For more information, refer to Section 8.3.5.19. Plans for the subactivity listed below are under development to provide laboratory test data to help validate the flow codes.

This subactivity will perform laboratory experiments that will provide direct observations of flow behavior in unsaturated media that can be compared with code predictions and used to support validation of mathematical models describing unsaturated fluid flow. Integrated sets of laboratory data will be obtained and the hydrologic properties of the samples used in the validation experiments will be measured. This subactivity is divided into two separate parts. The first is responsible for designing and performing the validation experiments. The second is responsible for ensuring that the hydrologic property values required by the mathematical flow models have been determined for the samples used in the validation experiments.

The specific process for validation has not been developed. General factors to be considered in model validation are described in Section 8.3.5.19 and include laboratory experiments. Computer codes that embody the unsaturated flow model(s) have been developed and are continuing to be developed. This activity will work closely with the work described in

Sections 8.3.5.19 and 8.3.5.20 by providing experiments appropriate for validating unsaturated flow models; however, this activity will not itself validate the models.

Under the first part of this subactivity, laboratory hydrologic experiments will be designed and performed to support comparison of unsaturated flow models to laboratory observations. The mathematical models to be validated are those whose predictions will be used in Issue 1.1 (Section 8.3.5.13) and in this issue. The computer codes in which those models are embodied and the factors involved in the general validation process are summarized in Section 8.3.5.19.

The validation process is currently at a very immature stage. A primary effort within this subactivity will be to design hydrologic experiments that can be sufficiently controlled to produce integrated sets of data such that every relevant component of the model is addressed. Some experiments may address single components of the model and others may address the composite response of the entire model. Although the time frame of the experiments generally will not be comparable to the time period desired for the application of the model, the loads imposed in the experiments will be as comparable to those expected in situ as possible, perhaps accounting for time and distance scaling factors. In general, the experiments will be designed to monitor water movement (either wetting or drying processes) in laboratory-scale samples under tightly controlled boundary conditions. Materials may range from tuff samples of various kinds to synthetic or natural materials such as sand. The main parameters to be measured will include pressure, saturation, boundary conditions of pressure, saturation, and temperature profiles, and time.

Two experiments have been designed at this time: One is an imbibition (wetting) experiment and the other is a drying experiment. Laboratory scoping experiments of both imbibition and drying processes have already been performed on a welded tuff sample of cylindrical geometry to develop the necessary instrumentation. In the imbibition experiment, a dry sample of cylindrical geometry will be placed within a core holder and pressure vessel. Pressure conditions will be monitored. One-dimensional water movement will be induced by initiating a constant water flux at one end. The transient saturation profile along the sample will be monitored using a (nonintrusive) gamma-beam attenuation technique. The experiment will be terminated after full saturation is reached. The sample will be tested initially under isothermal conditions.

The drying experiment will use the same sample and experimental apparatus used in the imbibition experiment. A dry gas stream will be passed over one or both ends of the saturated sample. The saturation along the sample will be monitored as a function of time as the sample dries out.

The purpose of the second part of this subactivity is to characterize the hydrologic properties of the samples used in the model validation experiments. The parameters determined will be those required by the unsaturated flow model to be validated. The general unsaturated flow model (e.g., Section 8.3.5.12.1, Equation 8.3.5.12-2) requires the following input parameters: hydraulic conductivity as a function of pressure head, saturation as a function of pressure head, and porosity. The first two parameters

are often referred to as characteristic curves of the material. The curves should be determined under the same water movement process (either wetting or drying) as took place in the validation experiment.

This subactivity will cooperate with the work performed under Investigation 8.3.1.2.2 to characterize the hydrologic properties of the tested samples. The results will be documented and supplied to the Scientific and Engineering Property Data Base for use in the validation process.

Although no validation of models will occur under this subactivity, the experimental efforts will be closely coordinated with work described in Sections 8.3.5.13, 8.3.1.2, and 8.3.5.19 to ensure that appropriate and sufficient laboratory hydrologic experiments are performed to support model validation.

Methods and technical procedures

The methods and technical procedures for Subactivity 1.6.2.2.2.1 are given in the following table.

Method	Technical procedure		Date
	Number	Title	
Imbibition/drying characterization using gamma-beam attenuation	TBD ^a	Determination of fluid saturation in unsaturated consolidated porous material using gamma-beam attenuation	TBD
Other methods to be determined as required	TBD	The methods and procedures used will be those that are determined by the prototype testing within Activity 8.3.1.2.2.3.1., (matrix hydrologic properties testing), to be the most appropriate to measure property values for the desired parameters	TBD

^aTBD = to be determined.

8.3.5.12.2.3 Application of results

The information provided by satisfaction of this information need will be used in Information Need 1.6.3 (description of ground-water flow paths) and Information Need 1.6.4 (calculation of pre-waste-emplacement ground-water travel time).

8.3.5.12.2.4 Schedule and milestones

This information need contains two ongoing activities: 1.6.2.1 (model development) and 1.6.2.2 (verification and validation). In the figure that follows, the schedule information for these activities is presented in the form of timelines. The timelines extend to the issuance of the final products associated with each activity. Summary schedule and milestone information for these activities can be found in Section 8.5.2.2.

Both of the activities in this information need proceed in parallel with the other information need activities in this issue. The activities are not seriously constrained by other program elements. Groups of subactivities, however, are required to be sequential: initial concept verification and model validation must be performed before the models can be used; preliminary modeling efforts must be completed prior to final verification and validation efforts.

The activity numbers corresponding to the timelines are shown on the left of the following figure. The points shown on the timelines represent major events or important milestones associated with the activity. Solid lines represent study durations and dashed lines show interfaces. The data input and output at these interfaces are shown by circles and described in the numbered notes.

CONSULTATION DRAFT

The points on the timeline and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone P650. Issue report on concepts of flow in partially saturated tuff.
2	Report on concepts of flow and transport in tuff available to Information Needs 1.6.3 and 1.6.4.
3	Update of conceptual, mathematical, and numerical models (codes) for use in identification of fastest flow path (Information Need 1.6.3) and calculation of ground-water travel time (GWTT) (Information Need 1.6.4). Activity to be reported in Milestone M183, Information Need 1.6.4.
4	Final codes and models developed and selected for use in calculations of GWTT for the draft environmental impact statement (DEIS) and license application. Activity to be reported in Milestone P652, Information Need 1.6.4.
5	Results of final code and model development supplied as input to Information Need 1.6.4.
6	Milestone R073. Development of verification and validation strategies.
7	Milestone P227. Verification of codes and validation of models used for identification of fastest path and calculation of GWTT for DEIS and license application.

8.3.5.12.3 Information Need 1.6.3: Identification of the paths of likely radionuclide travel from the disturbed zone to the accessible environment and identification of the fastest path

Descriptions of flow paths in both the unsaturated and saturated zones are required to determine the proper pathways for assessing pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment; this information is used in Information Need 1.6.4 (Section 8.3.5.12.4). In addition, the flow paths, velocities, fluxes, boundary conditions, and initial conditions throughout the site will be developed as input to predict the cumulative curies transported to the accessible environment under normal conditions for Information Needs 1.1.4 and 1.1.5 (Sections 8.3.5.13.4 and 8.3.5.13.5).

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Current information on flow paths at the Yucca Mountain site is discussed in Chapter 3 and Section 8.3.1.2.

Parameters

The results obtained from Information Need 1.6.2 (calculational models) together with a hydrogeologic model of the Yucca Mountain ground-water flow system are needed to satisfy this information need.

Logic

Compliance with the ground-water travel-time performance objective requires (1) identifying the pre-waste-emplacement environment and its potential spatial and short-term temporal variabilities, (2) calculating flow paths in the flow domain, and (3) identifying the fastest path of likely radionuclide travel. At Yucca Mountain, the flow paths pass through both the unsaturated and saturated zones. A general conceptual model of flow in the unsaturated zone was presented in Section 3.9. This general conceptual model is flexible enough to accommodate various alternative hypotheses that are based on current understanding of the hydrogeologic characteristics at the site. Several alternative conceptual models can be derived by assuming different hypotheses. Each of the alternative conceptual models may produce different likely paths for radionuclide travel. Alternative interpretations of regulatory intent for defining "fastest path" and "likely radionuclide travel" also introduce difficulty in identification of the fastest path. Currently the cumulative distribution functions of travel time (CDF) have been generated in the following two ways:

1. By combining the random travel times of each of the likely paths throughout the site into a single CDF. The fastest path is then defined as a geometrically ambiguous set of travel times representing some fraction of these random times. The variance of the total suite of travel times is the indicator of uncertainty of the travel time along the "fastest path."
2. By generating a CDF from the expected (e.g., mean of a CDF for each discrete flow tube) travel times of all the paths. The fastest path is then defined as some set of these paths (flow tubes) having an identified geographic location and specified, maximum expected travel time. The variance of travel time along these geometrically defined fastest paths is the indicator of uncertainty of travel time.

Numerical modeling based on alternative conceptual models will provide quantitative predictions of flow fields and flow tubes (pathways). The flow paths that are currently hypothesized, as well as any that may be identified by field observations during characterization, will be numerically modeled to predict pressure head distributions and define flow fields. These models will evolve as new data become available during the characterization process. Using one or more models of the hydrology of the unsaturated and saturated zones at Yucca Mountain, the range of likely flow paths will be determined. Because current concepts include the possibility of lateral diversion of flow in the unsaturated zone, determination of flow paths in the unsaturated zone will entail two-dimensional calculations. The definition of flow paths will be coordinated with activities under the geohydrology program, Section 8.3.1.2.

Once the flow field is established, the velocity and travel time along individual flow tubes will be calculated. These travel times will be plotted as maps and cumulative distribution functions from which the fastest paths can be identified. If the formal definition of a fastest path of likely radionuclide travel incorporates flow from the entire disturbed zone boundary, then the fastest paths will be identified as those originating at that boundary and the vitric Calico Hills unit will be a primary barrier. If the fastest path is defined as the geometric location of the fastest flow tubes, then the facility location could be changed, if necessary, to ensure adequate thickness of specific hydrogeologic units to provide high confidence of 1,000 yr travel times along the fastest flow tube.

8.3.5.12.3.1 Activity 1.6.3.1: Analysis of unsaturated flow system

The objective of this activity is to determine which flow paths or sets of flow paths of likely radionuclide travel in the unsaturated zone will be used in ground-water travel time calculations.

8.3.5.12.3.1.1 Subactivity 1.6.3.1.1: Unsaturated zone flow analysis

Objectives

The objective of this subactivity is to determine pre-waste-emplacement unsaturated flow paths from the disturbed zone to the water table. This description of flow paths will be performed in conjunction with Activity 8.3.1.2.2.10.3. The fastest path of likely radionuclide travel through the unsaturated zone will be identified.

Description

Concepts of the behavior of fluid flow in fractured, unsaturated tuff media will be used in conjunction with Study 8.3.1.2.2.6.3 to develop and apply two-dimensional numerical models of unsaturated flow. Flow paths in the unsaturated zone will be simulated. Likely paths of radionuclide travel will be identified.

8.3.5.12.3.1.2 Subactivity 1.6.3.1.2: Saturated zone flow analysis

Objectives

The objective of this subactivity is to determine which flow paths or set of paths of likely radionuclide travel in the saturated zone will be used in ground-water travel time calculations.

Description

The local region around Yucca Mountain will be modeled in conjunction with studies described in Section 8.3.1.2.3 by two-dimensional finite-element

analysis to support the ground-water travel-time calculations. The inverse problem, in which the head field will be predicted based on a set of conductivity fields, will be performed iteratively, and boundary head values will be interpreted from the regional model developed under Section 8.3.1.2.3.3. The finite-element mesh will be drawn to follow known or suspected geologic features that may influence fluid flow. Flow paths will be simulated in the saturated zone. This activity will be coordinated with the saturated zone modeling performed in Section 8.3.1.2.3.3.3. Part of this activity will entail defining the boundary of the accessible environment based on the direction of ground-water flow in the saturated zone.

8.3.5.12.3.2 Application of results

The information provided for the satisfaction of this information need will be used in the following areas:

1. Input to Information Need 1.6.4 (Section 8.3.5.12.4) to determine pre-waste-emplacement ground-water travel time.
2. Input to Information Needs 1.1.4 and 1.1.5 (Sections 8.3.5.13.4 and 8.3.5.13.5) to use in prediction of radionuclide transport to the accessible environment under nominal conditions.
3. Input to Information Need 1.6.5 (Section 8.3.5.12.5) to use in the definition of the disturbed zone.

8.3.5.12.3.3. Schedule and milestones

This information need contains one ongoing activity: 1.6.3.1, analysis of unsaturated zone flow system. In the figure that follows, the schedule information for this activity is represented in the form of a timeline. The timeline extends to the issuance of the final product associated with the activity. Summary schedule and milestone information for this information need can be found in Section 8.5.2.2.

The modeling work undertaken in this information need proceeds in parallel with activities listed under Information Need 1.6.2 and 1.6.4. Parameters required by the activity are provided through Information Need 1.6.1 from data generated through the studies in Section 8.3.1.2. Results of this activity provide data to Information Need 1.6.4, where ground-water travel times along the fastest path of likely radionuclide migration are determined.

The activity number and title corresponding to the timeline is shown on the left of the following figure. The points shown on the timeline represent major events or important milestones associated with the activity. Solid lines represent activity durations and dashed lines show interfaces. The data input and output at these interfaces are shown by circles and described in the numbered notes.

PERFORMANCE
ASSESSMENT
ACTIVITY

1.6.3.1
Analysis
of unsatu-
rated zone
flow
system

8351233-VB

The points on the timeline and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Receive input from Information Need 1.6.2 on concepts of flow in partially saturated tuff.
2	Identification of the fastest path of likely radionuclide travel for use in preliminary calculation of pre-waste-emplacement ground-water travel time (GWTT). Activity to be reported in Milestone M181, Information Need 1.6.4.
3	Update of conceptual, mathematical, and numerical models of flow and transport for calculation of ground-water travel time from Information Need 1.6.2.
4	Update of identification of fastest path of likely radionuclide travel for use in the interim calculation of GWTT. Activity to be reported in Milestone M183, Information Need 1.6.4.
5	Identification of fastest path of likely radionuclide travel for use in calculation of GWTT for draft environmental impact statement and license application. Activity to be reported in Milestone P652, Information Need 1.6.4.

8.3.5.12.4 Information Need 1.6.4: Determination of the pre-waste-
emplacement ground-water travel time along the fastest path of
likely radionuclide travel from the disturbed zone to the
accessible environment

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Chapter 3 provides information on current estimates of ground-water travel time.

Parameters

This information need is a rollup of the previous information needs under this issue. Therefore, the output from these information needs will be used as the basis for determining the pre-waste-emplacement ground-water travel time.

Logic

The determination of the pre-waste-emplacement ground-water travel time should account for spatial and temporal variabilities and uncertainties in the data and models. The difficulty of quantifying uncertainty in the performance measure for the ground-water travel-time objective is recognized by the NRC (Codell, 1986). As yet, the NRC has not indicated the specific basis under which a ground-water travel-time modeling approach would be judged adequate in accounting for such uncertainty.

Ground-water travel time is considered a random variable because the hydrologic properties (such as effective porosity and permeability) are spatially distributed heterogeneous quantities, and because uncertainty is associated with both conceptual models and measurement of properties. The heterogeneity is characterized by a length scale that approximately expresses the spatial correlation of hydrologic properties. Uncertainty will always exist about the representative values for effective porosities, hydraulic conductivities, and moisture contents of the various rock units at Yucca Mountain, particularly in unsampled regions. Conservative assumptions will be adopted to compensate for the inherent uncertainty in the data and models. Spatially dependent means and variances of the parameter values can be estimated and used with a Monte Carlo approach to account for the uncertainty caused by heterogeneity. If spatially varying parameters (represented by a covariance matrix) can be estimated, then stochastic models or conditional simulations will be applied. Statistical estimates of parameter values from results of well-designed drilling, sampling, and testing programs in conjunction with defensible conceptual models based on appropriate field tests will provide a quantified ground-water travel-time distribution function that incorporates most, if not all, sources of uncertainty.

Ground-water travel-time values are, of course, highly dependent upon the conceptual hydrologic models (to be determined within Section 8.3.1:2) for both the unsaturated and saturated zones. The conceptual hydrologic models are the bases for the formulation of the mathematical models to be

used in predicting future hydrologic behavior of the site. In the calculation of the ground-water travel-time distribution function required for resolution of this issue, uncertainties in the conceptual model will be addressed. The uncertainties to be addressed include variations in the possible modes (or paths) of water movement (i.e., matrix versus fracture flow), the hydrologic initial and boundary conditions, the geometry of the flow paths (e.g., the possibility of lateral water movement), the hydrologic property values and their intercorrelation, and the methods used to calculate the distribution function itself. These uncertainties will be investigated within this issue and the geohydrology program (Section 8.3.1.2).

Currently, travel-time distributions have been estimated only by simplified one-dimensional modeling (Sinnock et al., 1986). The simplifying one-dimensional assumptions will be modified to account for the dependence between outflow locations, travel times, and quantities. Such dependence and interaction are likely to occur in the actual multidimensional flow system. Therefore, analyses that either directly or indirectly account for two-dimensional or three-dimensional flow are required to incorporate the uncertainty. Adaptation of one-dimensional equations to account indirectly for multidimensional flow will be attempted, perhaps by applying a "random walk" or a related technique. A probabilistic analysis of ground-water travel time accounting for alternative conceptual models, as appropriate, and based on such modified one-dimensional equations will

1. Calibrate the flow models by using geostatistical results together with field-measured heads or saturations in a parameter estimation technique.
2. Determine the parameter estimation errors (e.g., the covariance matrix) as a part of the model calibration.
3. Use the parameter estimation errors and the calibrated flow model to generate a large number of hydrogeologic parameter values and the associated realizations of head or saturation.
4. Calculate a pore water velocity field and fluid flow paths with associated travel times from the disturbed zone to the accessible environment for each realization.
5. Determine the pre-waste-emplacement ground-water travel time.

In summary, the technical basis for determining the ground-water travel time will be developed further and expanded in considerable detail during site characterization.

8.3.5.12.4.1 Activity 1.6.4.1: Calculation of pre-waste-emplacement ground-water travel time

The objective of this activity is to define performance measures and perform related analyses of pre-waste-emplacement ground-water travel time. This activity includes two subactivities.

8.3.5.12.4.1.1 Subactivity 1.6.4.1.1: Performance allocation for Issue 1.6

Objectives

The objective of this subactivity is to continually evaluate and, if necessary, update performance allocation for Issue 1.6.

Description

Analyses will be conducted to calculate quantitative estimates of ground-water travel time. The predicted values can be compared directly with the performance goals defined for issue resolution. The strategy for issue resolution outlined in Section 8.3.5.12 will be updated if necessary.

8.3.5.12.4.1.2 Subactivity 1.6.4.1.2: Sensitivity and uncertainty analyses of ground-water travel time

Objectives

The objective of this subactivity is to determine the sensitivity and uncertainty of ground-water travel time.

Description

Sensitivity analyses will be performed to determine how the ground-water travel time changes as a function of changes in input parameters and conceptual models. Complementary uncertainty analyses will be done to determine how much confidence may be placed in a predicted output parameter based on uncertainties in input parameters.

8.3.5.12.4.1.3 Subactivity 1.6.4.1.3: Determination of the pre-waste-emplacement ground-water travel time

Objectives

The objective of this subactivity is to determine pre-waste-emplacement ground-water travel time at the Yucca Mountain site for comparison with the performance objective in 10 CFR 60.113(a)(2).

Description

Pre-waste-emplacement ground-water travel time will be calculated along the fastest path of likely radionuclide travel. This will be done in accordance with the description given in the logic section for this information need.

8.3.5.12.4.2 Application of results

The information will be used in determining if the pre-waste-emplacement ground-water travel time meets the 1,000-yr flow time requirement of 10 CFR 60.113(a)2 in the environmental impact statement and safety analysis report.

8.3.5.12.4.3 Schedule and milestones

This information need contains one ongoing activity: 1.6.4.1, calculation of pre-waste-emplacement ground-water travel time. In the figure that follows, the schedule information for this activity is presented in the form of a timeline. The timeline extends to the issuance of the final products associated with the activity. Summary schedule and milestone information for this information need can be found in Section 8.5.2.2.

The modeling work undertaken in this information need proceeds in parallel with work described in Information Needs 1.6.2 and 1.6.3. Data for this information need is supplied through Information Need 1.6.1 from data generated through the studies described in Section 8.3.1.2. The activity is not seriously constrained by other program elements; most of the work described interacts in an iterative fashion with the studies in Section 8.3.1.2 and with other activities in Section 8.3.5.12.

The activity number and title corresponding to the timeline is shown on the left of the following figure. The points shown on the timeline represent major events or important milestones associated with the activity. Solid lines represent activity duration and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.

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The points on the timeline and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Receive input from Information Need 1.6.2 on concepts of flow in partially saturated tuff.
2	Receive input from Information need 1.6.3 on locations and characteristics of fastest flow paths and from Information Need 1.6.5 on location of disturbed zone boundary.
3	Milestone M181. Report on pre-waste-emplacement ground-water travel time (GWTT) based on initial site characterization data.
4	Receive input on concepts of flow and transport in partially saturated tuff from Information Need 1.6.2.
5	Receive input on locations and characteristics of fastest flow paths from Information Need 1.6.3.
6	Milestone M183. Issue report on GWTT based on interim site characterization data.
7	Provide information on GWTT to Information Need 1.6.5 for definition of disturbed zone boundaries.
8	Receive input on concepts of flow and transport in partially saturated tuff from Information Need 1.6.2.
9	Receive input on locations and characteristics of fastest flow paths from Information Need 1.6.3.
10	Receive input on location of disturbed zone boundary from Information Need 1.6.5.
11	Milestone P652. Calculation of pre-waste emplacement ground-water travel time in support of the draft environmental impact statement (DEIS) and calculation of post-emplacement ground-water travel time (1.6.5.1).
12	Update of GWTT calculations for final environmental impact statement (FEIS) and license application.

8.3.5.12.5 Information Need 1.6.5: Boundary of the disturbed zone

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Chapters 6 and 7 provide design data for current estimates of the disturbed zone. Chapters 1, 2, 3, and 4 provide information on site characteristics that might change after repository development.

Logic

This information need deals with determining the boundary of the disturbed zone. Because the location of the boundary of the disturbed zone depends on repository-induced changes in physical or chemical properties that may have a significant effect on the performance of the geologic repository, it is different from the remainder of the information needs under this issue which deal only with pre-waste-emplacement conditions.

In 10 CFR Part 60.2, the NRC defines the disturbed zone as "the portion of the controlled area the physical or chemical properties of which have changed as a result of underground facility construction or as a result of heat generated by the emplaced radioactive wastes such that the resultant change of properties may have a significant effect on the performance of the geologic repository." The definition poses two questions:

1. What physical or chemical changes can have a significant effect on the repository's performance?
2. What constitutes a significant effect on the repository's performance?

The NRC staff addressed these questions in a draft generic technical position (GTP): "Interpretation and Identification of the Disturbed Zone in the High Level Waste Rule; 10 CFR Part 60" (NRC, 1986b). The NRC staff proposed that the disturbed zone be defined "by the zone of significant changes in intrinsic permeability and effective porosity caused by construction of the facility or by the thermal effects of the emplaced waste." This position presumes that permeability and porosity changes are appropriate surrogates for changes in performance. The NRC staff further considers "that the pre-waste-emplacement ground-water travel time will still be an appropriate measure of the overall geologic setting performance for the purpose of licensing." In an earlier version of the draft GTP (April 1985, page 8), the NRC staff explained what constitutes a significant change in intrinsic permeability and effective porosity; "the meaning of 'significant' in this context is considered to be about a factor of two change in effective porosity, which would generally correspond to about an order of magnitude change in intrinsic permeability." Coupling the NRC definition with the NRC staff's guidance, the NNWSI Project will determine the size of the disturbed zone in the following manner:

1. The likely paths of ground-water travel in the pre-waste-emplacement environment will be identified (Information Need 1.6.3, Section 8.3.5.12.3).
2. Ground-water travel time along these paths will be taken as a primary indicator of performance, as related to the definition of the boundary of the disturbed zone. Because of the general importance of effective porosity and intrinsic permeability in calculating travel times, changes in these two properties along the

paths (probably confined to the matrix, not the fractures) will be taken as measures used to define the boundary of the disturbed zone.

3. Repository-induced changes to effective porosity and intrinsic permeability will be determined along the identified likely paths of ground-water travel. Because the likely paths are presently expected to be matrix-dominated and vertically downward in the unsaturated zone, only the matrix properties will be considered at this time. The disturbed zone is presumed to be contained entirely within the unsaturated zone. The point(s) along the paths where effective matrix porosity would decrease more than two times relative to the pre-waste-emplacement conditions or matrix permeability would decrease by a factor of 10 times will mark the outer boundary of the disturbed zone.

As more information becomes available regarding possibilities of fracture flow, lateral ground-water flow and paths of likely ground-water travel (Sections 8.3.1.2.2 and 8.3.1.2.3), the present basis for defining the boundary of the disturbed zone will be reevaluated. If site information indicates that the likely path is one of fracture-dominated flow, changes in intrinsic fracture properties rather than intrinsic matrix hydrologic properties will be used to determine the boundary of the disturbed zone.

Several of the hydrogeologic units within the unsaturated zone may be considered in calculations that investigate how the repository changes the ground-water flow field. Properties and conditions in some of these units, particularly those more than 50 to 100 m from the waste, will probably be needed only to provide accurate boundary conditions for analyses. Only the unsaturated Topopah Spring, the unsaturated Calico Hills vitric, and the unsaturated Calico Hills zeolitic units have performance measures and goals associated with delineation of the disturbed zone boundary. The present concepts of ground-water flow and design of the repository suggest that the boundary of the disturbed zone probably will be contained within the Topopah Spring welded unit. The unsaturated Calico Hills vitric unit and Calico Hills zeolitic unit are assigned goals because future design changes could increase the areal power density of the repository enough to cause significant property changes in them, particularly temperature-induced mineral alterations. In determining an approach to fulfilling this information need, the following guidance from the most recent NRC draft technical position paper (June 20, 1986) was considered:

A disturbed zone of five diameters for circular openings, 5 opening heights for noncircular openings, or 50 meters, whichever is largest, from any underground opening, excluding surface shafts and boreholes, may be the minimum appropriate distance for use in calculations of compliance with the pre-waste-emplacement ground-water travel-time criterion.

The reference design for the Yucca Mountain repository calls for underground openings approximately 25 ft (8 m) wide and 22 ft (7 m) high (Chapter 6). Five times the maximum dimension is 40 m and is less than 50 m, therefore, by the NRC staff guidance, the disturbed zone should have a minimum value of 50 m.

Using this guidance and the expectation that significant effects on the performance of the repository will be caused by changes in the hydrologic properties within the Topopah Spring welded unit, site specific information will determine the extent of the disturbed zone. For convenience in determining what this information should be, the following discussion uses the performance allocation terms (performance measures and goals) developed for the issue resolution strategy (Section 8.2). The performance goals assigned in this discussion, if met, will ensure that the disturbed zone is less than, and perhaps much less than, 50 m in extent.

Some differences exist between the NNWSI Project and the NRC draft GTP in the approach used to define the boundary of the disturbed zone. The GTP states that the disturbed zone is "the zone of significant changes in intrinsic permeability and effective porosity" where "significant changes" was suggested to be about a factor of two change in effective porosity or an order of magnitude change in permeability. 10 CFR 60.2 states that the disturbed zone is "that portion of the controlled area the physical or chemical properties of which have changed...such that the resultant change of properties may have a significant effect on the performance of the geologic repository." The NNWSI Project believes 10 CFR Part 60 offers a more concrete definition of the disturbed zone. The guidance in the GTP infers that changes in the intrinsic permeability of the rock mass are appropriate surrogates for one quantity, ground-water travel time, which itself is an appropriate surrogate for total repository performance. In the unsaturated zone, there will probably not be such a direct correspondence between the intrinsic permeability of the rock mass and ground-water travel time. An order-of-magnitude change in permeability or a factor-of-two change in porosity of either the matrix or fractures will probably cause less than an order-of-magnitude change in the ground-water travel time. The definition for a significant change in intrinsic hydrologic properties may be different for the Yucca Mountain site.

The GTP suggests a minimum distance of 50 m for the disturbed zone boundary based largely upon considerations of stress redistribution around openings. The GTP states that the no-stress-change contour (at which presumably changes in permeability will be eliminated) could be conservatively estimated to be about five times the opening height for noncircular openings or five times the diameter for circular openings. Using 10 m as the appropriate length, a value of 50 m was obtained. However, the NNWSI Project believes that the distance to a contour of minimal changes in permeability is more likely to be two to three diameters (Rautman et al., 1987). This could place the boundary of the disturbed zone at much less than 50 m.

Because the NNWSI Project considers the boundary of the disturbed zone to be at a distance dictated by effects on the performance of the repository, that boundary may be significantly less than the 50-m boundary suggested by the NRC GTP. Ground-water travel time is acknowledged by the DOE as strongly associated with the overall performance of the repository. Effective porosity and permeability are tentatively accepted as reasonable surrogates for ground-water travel time. For this reason, all performance measures for this information need are related to induced changes in matrix permeability and effective porosity. The changes in matrix properties are of primary concern because the movement of water is currently thought to be primarily through the tuff matrix.

Table 8.3.5.12-4 lists the processes of concern in defining the boundary of the disturbed zone; they are processes that could, in principle, change the intrinsic hydrologic properties of the rock. The processes listed in the table are based on the NRC draft technical position paper, which suggested the following processes be considered in determining the boundary of the disturbed zone: (1) stress redistribution, (2) construction and excavation, (3) thermomechanical processes, and (4) thermochemical processes. The first three of these processes could change the permeability of the matrix. Because ground-water flow is expected to be dominantly through the matrix, stress redistribution, which primarily affects fracture hydrologic properties, is not expected to affect the location of the disturbed zone boundary. "Fracture activation caused by mining and heating," is listed in Table 8.3.5.12-4 to represent the first three processes. The fourth process, thermochemical processes, is addressed by the remaining four entries in the table, one for each of the hydrogeological units that are within about 100 m of the repository horizon.

Matrix porosity and permeability are listed explicitly as performance measures only for the Topopah Spring welded unit because it is the only unit along the expected path of ground-water flow from the repository to the water table in which it is thought there could be significant changes in hydrologic properties. Until "significant change" in matrix porosity and permeability is defined for the Yucca Mountain site, the disturbed zone will be approximated by the extent of (1) increases in matrix permeability of more than an order of magnitude, and (2) decreases in matrix porosity of more than a factor of 2.

A temperature limit is used as a performance measure for the remainder of the units. The associated performance goal of 115°C was set to limit mineral alteration and dehydration. This goal is indirectly related to changes in intrinsic porosity and permeability. At this time, this goal is also expected to limit the changes in intrinsic hydrologic properties to values no greater than those used as a performance goal for the Topopah Spring welded unit. This assumption will be tested as part of the geochemistry program described in Section 8.3.1.3.

Because the definition of the disturbed zone is not governed by any direct numerical regulatory criteria, and because it is expected that the ability to show compliance with the 1,000-yr ground-water travel-time performance criterion will not be very sensitive to the quantitative definition of the disturbed zone boundary (Issue 1.6.5), the confidence level for each performance goal in Table 8.3.5.12-4 is set qualitatively as "medium."

Parameters

The information required to address Information Need 1.6.5 is listed in Table 8.3.5.12-5. These information items are required under the assumption of matrix-dominated flow. If this assumption is shown to be invalid, the current strategy will be modified and additional fracture flow characteristics may be required. However, those additional parameters are already called for by Information Need 1.6.1 (Section 8.3.5.12.1) and it is believed that no new testing would be required by this information need.

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	

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

Table 8.3.5.12-5. Parameter needs for defining the disturbed zone
(Page 1 of 2)

Item number	Information item description
1	Location of the likely ground-water flow path and mode of flow from the repository to the water table
2	Predicted average travel time and bounds on the travel time along the fastest unperturbed path from the repository location to the accessible environment
3	Reference underground facility designs (including borehole spacing and spacing waste canisters within the emplacement holes)
4	Thermal decay characteristics of the waste package
5	In situ temperature conditions
6	Bulk density
7	Altitude of the hydrogeologic unit contacts
8	Location and displacements of faults within approximately 0.5 km of the outer repository boundary
9	Altitude of the water table
10	Location of any perched-water zones
11	Thermal properties of the rock as a function of saturation (including thermal conductivity and heat capacity) thermal expansion
12	Saturation (and moisture content) values as a function of depth and lateral spatial location
13	Pressure head values as a function of depth and lateral spatial location
14	Thermohydrologic response of test under nonisothermal test conditions
15	Fracture and matrix saturated permeability
16	Relative permeability for the fracture network and matrix as a function of temperature

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Table 8.3.5.12-5. Parameter needs for defining the disturbed zone
(Page 2 of 2)

Item number	Information item description
17	Gas relative conductivity for the fracture network and matrix as a function of temperature
18	Moisture retention curves for wetting and draining
19	Effective porosity and porosity of the fracture network, fault zones, rock mass, and matrix
20	Changes in porosity and permeability of matrix due to construction and heat from waste emplacement
21	Ground-water percolation flux at the top of TSw2 (portion of Topopah Spring welded unit proposed for repository unit)

The following steps will be used to define and provide supporting evidence for the boundary of the disturbed zone:

- Step 1. Obtain information on the likely ground-water flow path and mode of travel from the repository to the water table environment before waste emplacement. Determine the values of intrinsic matrix permeability and effective matrix porosity along this path. If continuous fracture flow becomes the likely ground-water flow path, reevaluate the present strategy used to determine the boundary of the disturbed zone. The locations of the likely ground-water flow paths and modes of flow from the repository to the water table are needed to make this decision.
- Step 2. Obtain predictions of matrix hydrologic-porosity changes (porosity and permeability) under expected repository conditions. Matrix porosity and permeability changes as a result of geochemical alteration are needed to complete this step.
- Step 3. Evaluate the extent and duration of repository-induced changes along the flow path of interest by performing thermohydrologic analyses using data that bound the expected site characteristics (i.e., include the repository-induced changes in site characteristics).

- Step 4. Determine quantitatively what would be considered a significant change in the intrinsic hydrologic properties by considering how the ground-water travel time before repository construction and waste emplacement compares with what could be expected after repository construction and waste emplacement in the portion of the rock that has been changed. The original range and mean of the matrix hydrologic properties will also be considered in determining a quantitative value for a significant change in hydrologic properties. The results of step 3 will be needed to complete this step.
- Step 5. Review the repository-induced changes in ground-water flow to determine whether there are other repository-induced changes identified in step 3 that could significantly change the ground-water travel time from the repository to the accessible environment. Evaluate whether a new strategy for determining the boundary of the disturbed zone should be initiated.
- Step 6. If necessary, revise the preliminary estimate of the boundary of the disturbed zone using the new predictions of matrix hydrologic property changes and the quantitative definition of significant property changes determined in Step 4.

8.3.5.12.5.1 Activity 1.6.5.1: Ground-water travel time after repository construction and waste emplacement

Objectives

The objective of this activity is to predict the ground-water travel time to the water table using the hydrologic properties changed as a result of repository construction and waste emplacement for comparing pre- and postemplacement travel times to establish the extent of the disturbed zone.

Description

Using a combination of (1) a two-phase, nonisothermal flow code with the region of significant temperature changes, and (2) an unsaturated isothermal code outside that region with boundary conditions determined from a thermal-conduction calculation, the movement of gas and liquid along with the temperature distribution in the near-field region as a function of time will be predicted. The following information will be used to help determine the geometry and boundary conditions for the problem: (1) reference underground facility designs, (2) distribution of rock properties, (3) temperature at the water table and the surface, (4) geothermal gradient, (5) location of the water table, and (6) initial pressure head and saturation conditions. The following information will be used as input for the calculations: (1) initial pressure head and saturation conditions, (2) hydrologic properties of the rock units before and after repository construction and waste emplacement (items 16 through 21 from the parameter list), (3) thermal properties of the

rock units (the Topopah Spring as well as surrounding rock units), (4) bulk density, (5) hydrologic and thermomechanical unit contacts, and (6) location of perched-water zones.

8.3.5.12.5.2 Activity 1.6.5.2: Definition of the disturbed zone

Objectives

The objective of the activity is to reevaluate the definition of the disturbed zone.

Description

This activity will reevaluate and, if necessary, refine the boundary of the disturbed zone using the following information: (1) preliminary definition of the boundary of the disturbed zone, (2) the NRC guidance, (3) the average and fastest likely path of a nonsorbing radionuclide, (4) predicted bounds on the travel time along the average and fastest unperturbed path from the repository location to the accessible environment, and (5) changes in hydrologic rock characteristics that are significant. Although this activity is identified only once, it may be a recurring one. The possibility of recurrence depends on changes in NRC guidance and the understanding of the changes in properties caused by the repository.

8.3.5.12.5.3 Application of results

The resolution of Issue 1.6 will use the boundary of the disturbed zone.

8.3.5.12.5.4 Schedule and milestones

This information need contains two ongoing activities: 1.6.5.1 (ground-water travel time after repository construction and waste emplacement) and 1.6.5.2 (definition of the disturbed zone). In the figure that follows, the schedule information for these activities is presented in the form of timelines. The timelines extend to the issuance of the final products associated with the activities. Summary schedule and milestone information for this information need can be found in Section 8.5.2.2.

Work described under this information need is not seriously constrained by other program elements; some iterative interaction will occur with Information Needs 1.6.2 (which supplies information to 1.6.5) and 1.6.4 (which is the recipient of the results of 1.6.5).

The activity numbers and titles corresponding to the timelines are shown in the following figure. The points shown on the timelines represent major events or important milestones associated with the activities. Solid lines represent activity durations and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.

The points on the timeline and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone M111. Issue preliminary report on the effect of heat and excavation on water flow in the vicinity of the waste package.
2	Milestone M188. Issue report on the detailed analysis of the effect of heat and excavation on water flow in the vicinity of the waste package.
3	Milestone M107. Issue report on the preliminary definition of the disturbed zone.
4	Output information to Information Need 1.6.4 on the preliminary location of the disturbed zone boundary.
5	Receive information from Information Need 1.6.4, Milestone M183 on pre-waste emplacement ground-water travel time from the repository to the water table.
6	Milestone Z090. Issue report on the definition of the disturbed zone.
7	Information on the location of the disturbed zone boundary supplied to Information Need 1.6.4.

Nuclear Waste Policy Act
(Section 113)

Section 8.3.5.13

Consultation Draft

**TOTAL SYSTEM
PERFORMANCE**

***Site Characterization
Plan***

***Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

Volume VII

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***U.S. Department of Energy
Office of Civilian Radioactive Waste Management
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8.3.5.13 Issue resolution strategy for Issue 1.1: Will the mined geologic disposal system meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13?

Regulatory basis for the issue

The regulation that governs this issue is given in Section 60.112 of 10 CFR Part 60. The proposed conforming amendment to 10 CFR Part 60 gives this requirement as:

The geologic setting shall be selected, and the engineered barrier system and the shafts, boreholes and their seals shall be designed:

- (a) So that, for 10,000 years following permanent closure, cumulative releases of radionuclides to the accessible environment from all significant processes and events that may affect the geologic repository shall:
 - (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated in accordance with 10 CFR 60.115.
 - (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated in accordance with 10 CFR 60.115.

The proposed 10 CFR 60.115 gives, in table form, the radionuclide release limits that shall be used to make the calculations referred to in paragraph (a) of 10 CFR 60.112. These limits, expressed as curies (Ci) per 1,000 MTHM, are the maximum allowable cumulative releases to the accessible environment for 10,000 years after disposal, and are as follows:

Americium-241 or 243	100
Carbon-14	100
Cesium-135 or 137	1,000
Iodine-129	100
Neptunium-237	100
Plutonium-238, 239, 240 or 242	100
Radium-226	100
Strontium-90	1,000
Technetium-99	10,000
Thorium-230 or 232	10
Tin-126	1,000
Uranium-233, 234, 235, 236 or 238	100
Any other alpha-emitting radionuclide with a half-life greater than 20 years	100
Any other radionuclide with a half-life greater than 20 years that does not emit alpha particles	1,000

These limits are identical to those in Table 1 in Appendix A of 40 CFR Part 191; the notes guiding its use in proposed amendments of 10 CFR Part 60 are

essentially identical with the notes for guiding applications of Table 1 in Appendix A of 40 CFR Part 191.

The DOE understands the term "accessible environment" to mean (1) the atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, and (5) all the lithosphere that is beyond the controlled area. Likewise, the DOE understands the term "controlled area" to mean (1) a surface location, to be identified by passive institutional controls, that encompasses no more than 100 km² and extends horizontally no more than 5 km in any direction from the outer boundary of the underground facility, and (2) the subsurface underlying such a surface location.

The phrase "significant processes and events that may affect the geologic repository" is interpreted as meaning likely natural events and such other processes and events that could affect a geologic repository and are sufficiently credible to warrant consideration. Significant processes and events that may affect a geologic repository may either be natural processes and events or processes and events initiated by human activities other than those licensed under 10 CFR Part 60. Processes and events initiated by human activities may only be found to be sufficiently credible to warrant consideration if it is assumed that: (1) the monuments provided for by this part are sufficiently permanent to serve their intended purpose; (2) the value to future generations of potential resources within the site can be assessed adequately under the applicable provisions of this part; (3) an understanding of the nature of radioactivity, and an appreciation of its hazards, has been retained in some functioning institutions; (4) institutions are able to assess risk and to take remedial action sufficient to prevent persistent or systematic releases resulting from human-induced disruptions of a repository; and (5) relevant records are preserved, and remain accessible, for several hundred years after permanent closure.

Overview of the performance assessments for this issue

The DOE plans to demonstrate compliance with the total system performance objective by conducting performance assessments. Consistent with the requirements of 10 CFR 60.21(c)(1)(ii)(C), these performance assessments will (1) identify all significant processes and events that may affect the geologic repository, (2) evaluate the effects of these processes and events on the release of radionuclides to the accessible environment, (3) combine estimates of these effects to the extent practicable into an overall probability distribution displaying the likelihood that the amount of radioactive material released to the accessible environment will not exceed the specified values, and (4) compare the numerical predictions with the performance objective, evaluating the importance of any uncertainties on conclusions from this comparison.

The significant processes and events to be taken into account in these performance assessments will be identified by developing scenarios that specify a sequence of processes and events potentially resulting in significant impacts on the variables of the systems important to waste isolation. Scenarios will be developed for undisturbed conditions (those conditions caused by likely natural events) and for disturbed conditions that are sufficiently credible to warrant consideration. In addition to providing an approach to organizing the information regarding significant processes and

events for this issue, these scenarios provide a vehicle for the evaluation of the favorable and potentially adverse conditions of 10 CFR 60.122 for the resolution of Issue 1.8 (Section 8.3.5.17).

The proposed section 60.115 of 10 CFR Part 60, when taken together with Note 6 guiding the application of Table 1 in Appendix A of 40 CFR 191 referenced by that section, is sufficient to establish a performance measure (M) for the total disposal system.

$$M = \sum_i \frac{Q_i}{L_i} \quad (8.3.5.13-1)$$

where

M = normalized release from the total system

Q_i = cumulative radioactivity of the i^{th} radionuclide released to the accessible environment in the 10,000 yr period following permanent closure (C_i)

L_i = release limit for the i^{th} radionuclide as specified in the regulations (C_i/MTHM) (see proposed 10 CFR 60.115 or 40 CFR Part 191, Appendix A).

The EPA containment standard, 40 CFR 191.13(a), on which proposed 10 CFR 60.112 and 60.115 are based, explicitly recognizes that estimates of the normalized release (M) will have considerable associated uncertainty, and consequently M must be treated as a distributed quantity (i.e., a quantity to which a cumulative distribution function (CDF) must be attached). However, the containment standard advocates demonstrating compliance in terms of the complementary cumulative distribution function (CCDF), which is one minus the CDF. In terms of the CCDF, the containment standard reads

$$\Pr\{M > 1.0\} < 0.1$$

$$\Pr\{M > 10.0\} < 0.001$$

where $\Pr\{e\}$ stands for the probability that the statement " e " is true. Note that the term "containment," as applied in the EPA standard, is the same as the term "isolation," as applied by the NRC and in this document.

The remainder of this section discusses a methodology for the development of the CCDF suitable to define the information needs for the resolution of this issue. These information needs are defined in terms of the particular methodology outlined in the discussion. The methodology that will actually be used in preparing the license application may differ from the methodology proposed here. For example, information developed during the site characterization may suggest a different approach that may be more efficient in conveying the assessment of the repository. However, it is the judgment of the DOE, based upon the available information, that the proposed

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approach will lead to the information needed for the DOE to present its case for the Yucca Mountain site, whichever methodology is chosen.

The following discussion addresses five topics:

1. Discussion of CCDFs and significant processes and events.
2. A preliminary selection of release-scenario classes for the Yucca Mountain repository site.
3. Technical discussion of the release-scenario classes.
4. A preliminary performance allocation for Issue 1.1.
5. Summary of licensing and issue resolution strategy for Issue 1.1.

To enable the reader to understand the strategy for resolving this issue, the following discussion presents an interpretation of "all significant processes and events that may affect the geologic repository" mentioned in the proposed 10 CFR 60.112 and an outline of a method for making practical calculations of the CCDF. Definitions are presented first, then the CCDF is discussed, and finally the treatment of significant processes and events to be incorporated in the CCDF is discussed.

1. Discussion of CCDFs and significant processes and events

Definitions

A waste disposal system, like any complex system that evolves in time, can be described by a finite number of dependent variables (here called performance measures) that, in turn, are functionally dependent upon a finite number of independent variables (here called state variables or determining variables). These state variables may be prescribed functions of time; and it is helpful to imagine all state variables being collected into a vector in N-dimensional space (where N is the number of state variables required to determine the system), the "tip" of which traces out a trajectory in that space with the passage of time. For the system being considered in this report, examples of state variables would be the spatially averaged percolation flux at a given depth in the Topopah Spring welded unit and the radionuclide inventories at the time of closure; many other examples of state variables are given in the section entitled "a systems-level model for release along water pathways."

With noted exceptions, the following definitions of terms will be used throughout the remainder of this section: A scenario will mean a sequence of definite types of processes and events that occur with prescribed intensities, for prescribed durations, or at prescribed epochs, in a prescribed order. In other words, a scenario can be represented by a single trajectory traced out by the state-variable vector of the system during a prescribed interval of time. A scenario class (or class of scenarios) will mean the set of all scenarios that involve the same types of processes and events acting in a definite time interval. In other words, a scenario class can be represented by a bundle of trajectories in the state-variable space. In this section, the consequences of a scenario will always mean the contribution that the scenario would make to the performance measure defined by Equation

8.3.5.13-1, if the scenario were realized. Thus, consequences of a scenario may be viewed, in mathematical language, as mappings from the function space of the state variables to subsets of the real number line.

Construction of a complementary cumulative distribution function

In a draft position paper on licensing assessment methodology (NRC, 1984b), the NRC staff suggested that the CDF could be calculated using the following expression:

$$\Pr\{M \leq m\} = \sum_j \Pr\{M \leq m | S_j\} \Pr\{S_j\} \quad (8.3.5.13-2)$$

where

M = normalized release from the total system (Eq. 8.3.5.13-1)

m = independent variable measuring normalized releases (m is always greater than zero; critical values are $m = 1$ and $m = 10$, according to proposed 10 CFR 60.112)

S_j = designator for the j^{th} scenario

$\Pr\{S_j\}$ = probability that S_j is realized

$\Pr\{A|B\}$ = probability that statement A is true, given that statement B is true.

A scenario is defined in the appendix of the position paper as "an account or sequence of a projected course of action or events." However, the DOE understands the term scenario in this position paper to mean scenario class in the sense defined earlier and Equation 8.3.5.13-2 to be a symbolic expression of the way a CDF could be calculated. The validity of Equation 8.3.5.13-2 depends on the S_j s being exhaustive and mutually exclusive.

The DOE proposes to calculate a CDF by numerical simulation of the performance measure of the total system as a function of system response to randomly occurring significant events and processes, using simplified (but ultimately validated) mathematical models of system response. The following formalism is compatible with numerical simulation and is equivalent to Equation 8.3.5.13-2 as long as the state variables over which the expectation (to be defined) is taken are exhaustive and mutually exclusive:

$$\Pr\{M \leq m\} = E[u(m - M)] \quad (8.3.5.13-3)$$

where

M = normalized release from the total system (Eq. 8.3.5.13-1)

$u(x)$ = unit step function ($u(x) = 0$ if $x < 0$ and $u(x) = 1$ if $x \geq 0$)

$E[\bullet]$ = mathematical expectation of the quantity in square brackets.

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If the vector of all state variables sufficient to describe the occurrence and intensity of all significant processes and events is denoted by

$$\vec{V} = (v_1, v_2, v_3, \dots, v_N)$$

then the mathematical expectation operation is explicitly

$$E[\bullet] \equiv \int_{v_1} \int_{v_2} \dots \int_{v_N} [\bullet] f(\vec{V}) dv_1 dv_2 \dots dv_N \quad (8.3.5.13-4)$$

where

$f(\vec{V})$ = the joint probability distribution of the components of $\vec{V}$.

Each integration is taken over the entire range of its indicated variable v_N . Two points need to be made concerning this formalism.

The first point is that the formalism requires numerical simulation. Even with a modest number of state variables and relatively simple mathematical models of system response to events or processes, the CDF in Equations 8.3.5.13-3 and 8.3.5.13-4 would not be efficiently calculated by numerical integration; a more efficient method would be performing the calculation using the Monte Carlo technique combined with some efficient sampling technique such as Latin Hypercube Sampling (Iman and Conover, 1982). In fact, a major incentive for the development of Monte Carlo methods was the problem of making numerical estimates of the value of multiple integrals of large dimension (Hammersley and Handscomb, 1964) such as the expression in Equation 8.3.5.13-4.

There are practical limitations to the Monte Carlo technique, however, and these limitations can be overcome only if efforts are made to limit the dimensions of the total-system's state-variable space, to screen scenario classes so as to limit the number of distinct models of system response, to consider simplified approaches to constructing the models of system response, and to construct efficient computer codes implementing those models so as to limit computation time. Time-dependent and spatially-dependent state variables are particularly troublesome with regard to minimizing state-variable-space dimension and model simplicity. For example, a time-dependent state variable can always be approximated by a piecewise-linear function, as shown in Figure 8.3.5.13-1, or a piecewise-constant function; however this turns one component of the state-variable vector into at least $C > 1$ components, where C is the number of intervals into which the 10,000-year performance period is partitioned. The possibility of making realistic but simplified models of system response, of course, depends upon the analyst's skill and the resources available for validating and verifying the simple models against predictions made with more complex computational models of system response.

Secondly, the formalism can be applied to a decomposition into classes of scenarios. This application will prove useful later when measures must be devised with which to compare the relative importance of events and processes that could cause potentially adverse changes in system performance. That is,

Figure 8.3.5.13-1. Representation of a time-dependent state variable. The hypothetical case shown is of percolation flux in the Topopah Spring welded unit as a function of time. The solid curve is the predicted flux history; the dotted curve is a discrete approximation to solid curve. Subdivisions of the ordinate show possible exceedance intervals for the percolation flux. The cells defined by the subdivisions of the ordinate and abscissa form an M by N matrix for the definition of exceedance probabilities; the notation $P(m,n)$ stands for the probability that percolation flux in the m^{th} interval is exceeded in the n^{th} time interval.

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the future performance of the repository system can be conceptually decomposed into an exhaustive set of mutually exclusive scenario classes, if then the total performance measure, M , can be expressed in the following manner:

$$M = \sum_j M_j \quad (8.3.5.13-5)$$

where

j = index of the subset of scenario classes being considered (the context of the discussion will be relied on to make the specific meaning of this index clear)

M_j = partial performance measure for the j^{th} scenario class.

M_j is defined mathematically by

$$M_j = \sum_i \frac{Q_{ij}}{L_i} \quad (8.3.5.13-6)$$

where

Q_{ij} = the cumulative release of radioactivity (per 1000 MTHM) released to the accessible environment in the 10,000-yr period following disposal, in the form of the i^{th} radionuclide species, through the realization of one or more scenarios included in the j^{th} scenario class (Ci)

L_i = release limit (per 1000 MTHM) for the i^{th} radionuclide as specified in the regulations (Ci) (see proposed 10 CFR 60.115 or 40 CFR Part 191, Appendix A).

Q_{ij} , though uncertain, is commonly predicted by deterministic mathematical models to make point estimates of M_j . Such estimates may be regarded as estimates of the expected partial performance measure (EPPM) for the scenario class under consideration (i.e., estimates of $E[M_j]$ where $E[\bullet]$ is defined by Equation 8.3.5.13-4). The EPPMs do not account for uncertainties in the consequences of a given scenario class and, therefore, are not sufficient to establish the overall probability distribution in themselves. Nevertheless, they provide useful measures to focus the testing during site characterization on the information needed for this overall probability distribution and are therefore used here as simple surrogates for the full CDFs associated with the scenario classes.

A treatment of significant processes and events

Significant processes and events include both natural processes and events and those initiated by human activities. The DOE intends to take into account all those natural processes and events that are sufficiently credible to warrant consideration in the calculation of the CCDF for the normalized release of radiation. Generally, categories of natural processes and events that can be shown to have a likelihood of less than one chance in 10,000 of occurring in the first 10,000 yr after permanent closure would not be taken into account in CCDF. Furthermore, categories of natural processes and

events whose contribution to the overall probability distribution can otherwise be shown to be insignificant would not be included in the detailed assessments. Likewise, any particular combinations of categories of natural processes and events that meet either of these two criteria would not be incorporated into the CCDF. That is, particular scenario classes involving a sequence of categories of events or processes which, in combination, can be shown to have a probability of occurrence in the 10,000-yr period following permanent closure of less than one chance in 10,000 or which otherwise can be shown to make a negligible contribution to the overall probability distribution would not be evaluated in detail.

Impacts of processes and events initiated by human activities will also be considered in the system performance assessments with regard to this issue. Repository construction and waste emplacement, as they affect the conditions in the geologic repository, will be taken into account in the evaluating of the CCDF for normalized releases. However, it may not be practical to treat the effects of human activities not related to repository construction or waste emplacement (such as direct human intrusion into the repository) in the same way. That is, because quantitative estimates of the absolute probability of human activities such as resource exploration and development in the distant future may not be feasible, it may not be possible to incorporate the impacts of such activities into the overall probability distribution. In these instances, it will be necessary to consider such effects in separate evaluations. However, even in such instances, the treatment of such events and processes will follow an approach similar to that used for the natural processes and events. The approach that will be used by the DOE in this case will be to (1) evaluate the effects of potentially adverse human activities such as those identified in the examination of the potentially adverse conditions of 10 CFR 60.122, (2) develop scenario classes of categories of processes and events that are initiated by human activities and that result in potentially significant impacts on normalized releases, and (3) estimate relative probabilities and consequences for these scenarios taking into account the factors and the assumptions given previously in the regulatory basis for this issue. The scenarios and scenario classes associated with human activities are often highly speculative and often do not involve significant impacts on the variables important to waste isolation. Therefore, the specification of highly speculative, low impact human activity-related scenarios and scenario classes, the development of the methods to analyze these classes, and the identification of data to support these analyses will not be allowed to dominate the testing program.

One or more scenario classes may be developed for undisturbed performance of the geologic repository, depending on the number of legitimate, distinguishable alternate conceptual models that are supported by the available information. By undisturbed performance, the DOE means the predicted behavior of a geologic repository, taking into account the uncertainties in predicted behavior, and considering only likely natural events. In this instance, natural events refers to those natural processes and events that are reasonably likely to occur in the 10,000-yr period following permanent closure. The judgments of which natural processes and events are likely to occur during this period will be based on the assumption that those processes operating in the geologic setting during the Quaternary will continue to operate, but with construction of the repository or the presence of emplaced radioactive waste some perturbation will occur.

Scenario classes will also be developed for sequences of categories of events and processes initiated by human intrusion and the occurrence of unlikely natural events. Only those human activities and unlikely natural events that are sufficiently credible and could lead to potentially significant impacts will be considered. Impacts will be evaluated in terms of effects on the variables needed to calculate the normalized releases for a specified scenario class.

To describe the system ideally, the set of scenario classes should be exhaustive and the classes should be mutually exclusive. That is, the set of scenario classes should provide a partitioning of all the physically realizable futures for the repository system and the set should be constructed so that the consequences of some effect are not counted more than once. In practice it will be difficult to provide such an ideal representation of the significant processes and events. For example, it will be difficult to distinguish between the low probability, extreme site characteristics taken into account in the undisturbed performance scenario classes and the site characteristics resulting from unlikely processes and events that are taken into account in the disturbed performance scenario classes. Care will be necessary to ensure that the respective representations are as realistic as possible. Nevertheless, it is recognized that the ability to rigorously identify a completely unambiguous set of scenarios may not be practicable.

It will also be difficult to ensure that every physically realizable future is represented in the set of scenario classes, particularly those that may be associated with unlikely processes and events. One of the undisturbed scenario classes is assumed to account not only for the likely processes and events explicitly specified in the description of the scenarios, but also for all unlikely processes and events that have no impact on repository performance. This scenario class is termed the "nominal" performance scenario class. Again, effort is needed to ensure that the nominal case scenario class provides a reasonable representation for these conditions.

Within each scenario class it will be possible to specify one or more release modes. For example, release of radionuclides may occur by way of water pathways (*w_p*) in which dissolved radionuclides are transported by water, by way of gas pathways (*g_p*) in which the radionuclides are transported in gaseous form and not with the moving water, and by direct pathways (*d_p*) in which the radionuclides are transported directly to the accessible environment by mechanical means such as by magmatic extrusion or human recovery. Provided that the interactions among these modes can be conservatively neglected (for example, the depletion of radionuclide inventory by one pathway being neglected in the evaluation of another), the partial performance measure (M_j) can be decomposed into measures for each mode:

$$M_j = M_{w_{pj}} + M_{g_{pj}} + M_{d_{pj}} \quad (8.3.5.13-7)$$

In some instances, the scenario class will be defined with a particular release mode in mind; for example, for some scenario classes such as drilling scenarios, the *d_p* mode may be considered to dominate.

2. A preliminary selection of release-scenario classes for the Yucca Mountain repository site

The identification of potentially disruptive scenarios for any system in which failure modes are possible is ultimately a matter of professional judgment. Methods that have been used to identify scenarios were recently reviewed with the following conclusion: "Three different approaches have been proposed to identify scenarios for performance assessments of high-level waste repositories: simulation, event trees, and judgment. Simulation models require large amounts of hard-to-obtain input data. Event trees tend to produce extremely large numbers of scenarios. Most published performance assessments rely on judgmental methods" (Ross, 1986b). To this fair appraisal might be added the observation that construction of meaningful simulation models or event trees also requires judgment. Observational and experimental evidence should be used to screen out insignificant effects before attempting to construct simulation models; similarly, efficient construction of event trees can proceed only after there has been a thorough examination and interpretation of the evidence concerning phenomena that might affect the system. The DOE will use professional judgment to guide the program for identifying scenario classes that have significance. At this point, it is appropriate to summarize specific efforts to identify release scenarios for a waste disposal system at the Yucca Mountain site.

The decision aiding methodology study

A panel of experts assembled by the DOE (1986g) proposed 15 generic, potentially significant scenarios (Table 8.3.5.13-1) and assessed the significance of these generic scenarios for a repository at Yucca Mountain, Nevada, using professional judgment and information from the Yucca Mountain site environmental assessment (DOE, 1986b). The panel judged that scenarios 3, 4, and 12 of Table 8.3.5.13-1 are not sufficiently credible to warrant consideration and that realization of scenarios 5 through 9, 13, and 14 would not entail consequences more severe than the nominal case (scenario 1). Scenario 1 (the nominal case), scenario 2 (unexpected features), and scenarios 10a through 11 were regarded by the panel as being potentially significant at Yucca Mountain.

The unexpected-features scenario (scenario 2) was actually broken down into six categories of features: (1) repository-induced subsidence or uplift, (2) undetected fault zones, (3) undetected significant lateral variations, (4) undetected dikes or sills, (5) undetected vertical heterogeneity (perching of water), and (6) "other"--a category of unspecified features. The panel stated that "The impacts of extreme conditions that result from unexpected features could lead to releases that could be as much as 10 times greater than those for the nominal case" (DOE, 1986a). After making evaluations the panel concluded that the most important releases would be by ground water; consequently no scenarios were developed for gas-phase releases (i.e., carbon-14 as carbon dioxide).

Survey of disruptive scenarios for Yucca Mountain

Ross (1986a) has made a survey of potentially disruptive scenarios for the Yucca Mountain repository site, and has identified 84 different sequences of processes and events that could influence the performance of one or more

Table 8.3.5.13-1. Potentially significant scenarios^a

Scenario	Description
1	Nominal case (expected conditions)
2	Unexpected features
3	Repository induced dissolution of the host rock
4	Advance of a dissolution front
5	Movement on a large fault inside the controlled area but outside the repository
6	Movement on a large fault within the repository
7	Movement on a small fault inside the controlled area but outside the repository
8	Movement on a small fault within the repository
9	Movement on a large fault outside the controlled area
10a	Extrusive magmatic event that occurs during the first 500 yr after closure
10b	Extrusive magmatic event that occurs 500 to 10,000 yr after closure
11	Intrusive magmatic event
12	Large-scale exploratory drilling
13	Small-scale exploratory drilling
14	Incomplete sealing of the shafts and the repository

^aSource: Table 3.2 in DOE (1986a).

Table 8.3.5.13-2. Categories of sequences affecting barrier performance^a

Category number	Description or end result	Barriers affected
1	Direct releases	All
2	Repository flooding	Unsaturated zone, canisters, fuel cladding
3	Colloids	Geochemical retardation
4	Widespread increase in percolation	Unsaturated zone, waste form
5	Localized increase in percolation	Unsaturated zone, canisters, waste form
6	Wetting of waste form	Canisters, fuel cladding, waste form
7	Accelerated waste dissolution	Waste form
8	Accelerated cladding corrosion	Cladding
9	Accelerated canister corrosion	Canister
10	Canister breakage	Canister
11	Fracture flow without increased flux	Unsaturated zone
12	Reduced sorption in the Topopah Spring unit	Topopah Spring welded unit
13	Water-table rise	Unsaturated and saturated zones
14	Fracture flow in the Calico Hills unit	Calico Hills nonwelded unit
15	New discharge points	Saturated zone
16	Faster saturated flow	Saturated zone

Table 8.3.5.13-2. Categories of sequences affecting barrier performance^a
(continued)

Category number	Description or end result	Barriers affected
17	Acceleration of pre-existing fracture flow	Topopah Spring welded unit

^aSource: Ross (1986a).

of the engineered or natural barriers. Ross chose to group the 84 sequences in 17 categories on the basis of similar end results (Table 8.3.5.13-2). Ross (1986a) did not explicitly consider disruptive sequences that involve release and transport of gas-phase carbon-14.

The categories described by Ross (1986a) (Table 8.3.5.13-2) can be aggregated in four supercategories according to potential impacts on barriers of the geologic repository: A, direct releases (number 1 of Table 8.3.5.13-2); B, categories in which only engineered barrier system (EBS) components are affected (numbers 6 to 10); C, categories in which only the unsaturated zone barriers are affected (numbers 2 to 5, 11 to 14, and 17); and D, categories in which the saturated zone barrier is affected (numbers 3, 15, and 16). A fifth supercategory, E, undisturbed or nominal performance of all barriers, is implicit in the aggregation, and can be treated as a single scenario class; the models associated with this class and the parameter values specifying anticipated conditions are described later in this section, in Section 6.4.2 of the Yucca Mountain environmental assessment (DOE, 1986b), and by Sinnock et al. (1986). The present description of this nominal scenario class is broad enough to encompass all the undisturbed performance conceptual model alternatives considered in Chapter 3; therefore, the terms "nominal case" and "undisturbed case" can be used interchangeably for this categorization of scenarios.

The supercategories can each be delineated in terms of particular kinds of impacts on the respective barriers. These groupings of the scenarios are listed in Table 8.3.5.13-3. An examination of the scenarios in supercategory A discloses two types of disturbed scenario classes: A-1, direct releases in an extrusive magmatic event and A-2, direct releases associated with inadvertent human activities. Class A-1 may be significant because an upper bound on estimates of the probability of volcanism on the Yucca Mountain site (Crowe et al., 1982) in 10,000 yr appears to exceed the 0.0001 probability cutoff and the consequences of realized, onsite volcanism could be large in comparison with other modes of release. Class A-2 cannot be eliminated on the basis of objective estimates of the probability of realization and--according to results of a simple bounding calculation shown later in this section--would have relatively large consequences if realized.

Table 8.3.5.13-3. Supercategories 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 water table attending increased flux from sources above the repository;
- 2) accelerated releases to the water table attending a rise in the water table (foreshortening of unsaturated zone);
- 3) accelerated releases to the water table 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)

^aNo independent, potentially significant classes have been associated with this supercategory.

The scenario classes in supercategory B that are considered relevant to the system performance objective are judged to occur concurrently with scenarios in supercategories C or D or to be part of the uncertainty associated with nominal performance of EBS components (i.e., container and cladding degradation rates or waste form dissolution rates and solubilities under various likely conditions). Thus, no independent, potentially significant scenario classes associated with supercategory B appear in Table 8.3.5.13-3.

Scenario classes in supercategory C (partial failure of unsaturated zone barriers) appear to be of three types: (1) ones in which the global or local percolation flux through the repository is increased, owing to the appearance of sources above the repository (e.g., those involving climatic change or local flooding from surficial sources); (2) ones in which the thickness of the unsaturated zone is decreased, for example, by a rise in the water-table level under the site; and (3) ones in which there are adverse changes in unsaturated-zone rock hydrologic properties or the geochemistry of the unsaturated zone. The logic of this organization follows from the fact that the appearance of any one of the factors (increased flux, decreased unsaturated-zone thickness, decreased saturated matrix conductivity or decreased geochemical retardation properties) could lead to an increase in the rate at which dissolved radionuclide-bearing compounds are transported from the repository to the water table. Depending upon the events and processes associated with these factors, each factor could appear singly or in combination, i.e., correlated with either or both of the other two factors.

Scenario classes in supercategory D (partial failure of the saturated zone) may be organized in a similar fashion, but because of the nature of saturated flow (which is not dominated by vertical flow as is the flow in the unsaturated zone), the factor "increased flux through the saturated zone" would be connected either with rises in the water-table level (considered in C-2) or increased linear water velocity (considered in D-2).

The categories in Table 8.3.5.13-3 serve as the basis for the information needs for this issue. That is, scenarios within a category are defined by the category of process or event that initiates the scenario and by the potential impacts associated with the category; these factors define the parameters needed to evaluate and take that scenario class into account in the assessment. For example, a scenario class associated with increased flux in the unsaturated zone (category C-1) may be initiated by climatic change. Parameters associated with the effect of the climatic change on the flux in the unsaturated zone can be developed to address this scenario class.

In addition, information needs can be identified for scenario classes involving combinations of the categories. For example, a scenario class initiated by faulting may modify the rock hydrologic properties in the unsaturated zone units (category C-3) and affect the ground-water flow in the saturated zone (category D-2). Parameters associated with the relation between the initiating event and the various impacts can be identified as well.

The categorization in Table 8.3.5.13-3 is considered adequate to define the investigations needed for both the nominal (undisturbed) performance and the disturbed performance of the geologic repository at the Yucca Mountain

site. That is, this categorization, in that it appears adequate to address the preliminary scenario classes of Ross (1986a), is suitable to address the current understanding of all significant processes and events at the site. Potential initiating events for disturbed performance scenario classes are discussed later.

Favorable and potentially adverse conditions of 10 CFR 60.122

Issue 1.8 addresses the need to obtain information to investigate and evaluate the site characteristics relevant to the siting criteria of 10 CFR 60.122. The evaluation required by the rule includes an assessment of the impacts of certain favorable and potentially adverse conditions on waste isolation. For efficiency in developing the site characterization program, the scenario classes developed to evaluate the ability of the geologic repository to meet the system performance objective have been defined in such a way that these favorable and potentially adverse conditions can be addressed.

The method for accomplishing this definition was to compare the scenario classes, developed for the potentially significant, site-specific processes and events, with each favorable and potentially adverse condition of 10 CFR 60.122. This comparison then led to an attempt to ensure that each potentially adverse condition is addressed by one or more scenario classes. Further, the set of relevant scenario classes has been organized and defined with the purpose of making clear the association of each of the potentially adverse conditions and appropriate favorable conditions with a subset of the scenario classes. The association of the favorable and potentially adverse conditions with particular scenario classes is discussed in Section 8.3.5.17.

3. Technical discussion of the release-scenario classes

This section describes the conceptual models of the release-scenario classes listed in Table 8.3.5.13-3, and discusses those physical and mathematical concepts associated with the conceptual models that are believed to be important to the development of an issue resolution strategy.

Nominal case (E): water-pathway releases

A representation of the present hydrologic setting at Yucca Mountain is shown in Figure 8.3.5.13-2, which also shows the abbreviations to be used for the hydrogeologic units. The proposed location of the repository is in the Topopah Spring welded unit (TSw). The TSw units includes TSw1 and TSw2 units shown on Figure 8.3.5.13-2. Conceptual models of present hydrologic conditions are described in Chapter 3 and Section 8.3.5.12 of this document. Briefly, it is believed that, within each unsaturated-zone rock unit, water will flow downward and mainly in the matrices of the rock units, with spatially averaged percolation flux not exceeding 0.5 mm/yr. Some lateral diversion of flux may occur at the interfaces between distinct hydrologic rock units (e.g., the interface between units TSw2 and CHnv-CHnz below the repository, and the interface between units PTn and TSw1 above the repository). This diverted water may be directed down dip along the interface (as matrix flow, given the present recharge rates) to the water table or to downward drainage points in the highly faulted zone southeast from the edge of the emplacement zone. Water reaching the water table will then flow in a

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Figure 8.3.5.13-2. General hydrogeologic cross section at Yucca Mountain. The wavy arrows show the flow paths, as assumed in this report, from a potential repository through the unsaturated zone to the water table and along the upper portion of the saturated zone toward the accessible environment (5 km away). Modified from Sinnock et al. (1986).

roughly horizontal direction to the accessible environment boundary to the southeast of the controlled zone.

Those radionuclide-bearing compounds which might be released in the liquid phase as water percolates through the host rock (TSw2) could be transported along these water pathways, and may eventually reach the accessible environment boundary. The subsurface portion of this boundary may be imagined as a vertical, curved sheet that is everywhere located up to 5 km from the edge of the waste emplacement. The amount of radioactivity released to the accessible environment, expressed in curies (Ci)_{th} in a 10,000-yr period, in the form of the *i*th radionuclide, for the *j*th scenario class involving water pathways, is calculated by the following expression:

$$Q_{ij} = \alpha_i \int_0^{10,000 \text{ yr}} \left[\int_A (\bar{F}_m^i + \bar{F}_f^i) \bullet d\vec{A} \right] dt \quad (8.3.5.13-8)$$

where

Q_{ij} = radionuclide release (Ci)

α_i = specific activity of the *i*th radionuclide (Ci/kg)

$\bar{F}_m^i$ = local mass flux of the *i*th radionuclide in the matrix of the saturated zone (kg/m² [rock]yr)

$\bar{F}_f^i$ = local mass flux of the *i*th radionuclide in the fracture system of the saturated zone (kg/m² [rock]yr)

t = time (yr)

$d\vec{A}$ = an outwardly-directed area element on the accessible environment boundary.

Note the *j*-dependence of quantities on the right of Equation 8.3.5.13-8 has been suppressed for simplicity. Each mass flux is assumed to be the sum of an advective flux and a dispersive-diffusive flux:

$$\bar{F}_m^i = C_m^i \bar{q}_m - \theta_m \overline{D_m^i} \bullet \nabla C_m^i \quad (8.3.5.13-9A)$$

$$\bar{F}_f^i = C_f^i \bar{q}_f - \theta_f \overline{D_f^i} \bullet \nabla C_f^i \quad (8.3.5.13-9B)$$

where

C_m^i = mass concentration of the *i*th radionuclide-bearing chemical species in matrix pore water (kg/m³ [water])

C_f^i = mass concentration of the *i*th radionuclide-bearing chemical species in fracture pore water (kg/m³ [water])

$\bar{q}_m$ = specific discharge through the matrix system (m³ [water]/m² [rock]yr)

$\bar{q}_f$ = specific discharge through the fracture system
(m^3 [water]/ m^2 [rock]yr)

θ_m = mobile moisture content in the matrix system (m^3 [water]/ m^3 [rock])

θ_f = mobile moisture content in the fracture system
(m^3 [water]/ m^3 [rock])

$\overline{\overline{D}}_m^i$ = effective dispersive-diffusive tensor in the matrix system
(m^2 [rock]/yr).

$\overline{\overline{D}}_f^i$ = effective dispersive-diffusive tensor in the fracture system
(m^2 [rock]/yr).

The dispersive-diffusive tensors are the sums of two tensors, one describing molecular diffusion and the other describing hydrodynamic dispersion (Freeze and Cherry, 1979). Note that, in the following development, the contribution of the longitudinal component of molecular diffusion to the dispersive-diffusive fluxes will be ignored because the Peclet numbers for the flows that are likely to result in significant releases of radioactivity will be about 10 or greater. Furthermore, the dispersive component of mass flux will be implicitly included in the specific discharges ($\bar{q}_m$ and $\bar{q}_f$) by assuming the latter are random fields (see Sinnock et al., 1986).

To calculate the mass fluxes ($\bar{F}_m^i$ and $\bar{F}_f^i$) one must first solve partial differential equations expressing the transport of dissolved mass from the vicinity of the repository to the accessible environment boundary; a solution of the transport problem gives the mass concentrations (C_m^i and C_f^i) as functions of time and space, and requires the specific discharges ($\bar{q}_m$ and $\bar{q}_f$) and the moisture contents (θ_m and θ_f) as input quantities from a separate calculation of the flow fields in the medium. The mathematical models of flow that have so far been used to predict the hydrologic regime at Yucca Mountain will not be reviewed here; Section 8.3.5.12 and Klavetter and Peters (1986) describe the development of a Richards' equation that incorporates composite-porosity concepts for flow through fractured, porous rock. The following partial differential equations for the transport of dissolved mass are consistent with the flow model of Klavetter and Peters and are adopted from Wilson and Dudley (1987):

$$\frac{\partial C_m^i}{\partial t} = -\bar{v}_m^i \cdot \nabla C_m^i - \lambda^i C_m^i + \lambda^{i-1} \left(\frac{R_m^{i-1}}{R_m^i} \right) C_m^i + \frac{1}{\theta_m R_m^i} (\Lambda_1 + \Lambda_2^i) (C_f^i - C_m^i) \quad (8.3.5.13-10A)$$

$$\frac{\partial C_f^i}{\partial t} = -\bar{v}_f^i \cdot \nabla C_f^i - \lambda^i C_f^i + \lambda^{i-1} \left(\frac{R_f^{i-1}}{R_f^i} \right) C_f^i - \frac{1}{\theta_f R_f^i} \Lambda_2^i (C_f^i - C_m^i) \quad (8.3.5.13-10B)$$

where

λ_i = decay rate of the i^{th} nuclide species (yr^{-1})

$\bar{v}_m^i$ = effective transport velocity for the i^{th} species in the matrix system (defined below) (m [rock]/yr)

$\bar{V}_f^i$ = effective transport velocity for the i^{th} species in the fracture system (defined below) ($\text{m}[\text{rock}]/\text{yr}$)

R_m^i = adsorptive retardation factor for the i^{th} species in the matrix system (defined below)

R_f^i = adsorptive retardation factor for the i^{th} species in the fracture system (defined below)

Λ_1 = advective coupling constant ($\text{m}^3[\text{water}]/\text{m}^3[\text{rock}]\text{yr}$)

Λ_2^i = diffusive coupling constant ($\text{m}^3[\text{water}]/\text{m}^3[\text{rock}]\text{yr}$).

The numbering of nuclides is such that nuclide $i-1$ decays into nuclide i . The nuclide at the beginning of the chain, nuclide 1, would not have a parent, so λ^0 has a value of zero by definition.

$\bar{V}_m^i$ and $\bar{V}_f^i$, the effective transport velocities for the i^{th} species, are defined by

$$\bar{V}_m^i = \frac{\bar{q}_m}{R_m^i \theta_m} \quad (8.3.5.13-11A)$$

$$\bar{V}_f^i = \frac{\bar{q}_f}{R_f^i \theta_f} \quad (8.3.5.13-11B)$$

R_m^i and R_f^i , the adsorptive retardation factors for the i^{th} radionuclide species, are defined by

$$R_m^i = 1 + \frac{\rho_b K_d^i}{\theta_m} \quad (8.3.5.13-12A)$$

$$R_f^i = 1 + \sigma_f \frac{K_a^i}{\theta_f} \quad (8.3.5.13-12B)$$

where

K_d^i = distribution coefficient of the i^{th} species ($\text{m}^3[\text{water}]/\text{kg}$)

ρ_b = bulk density of rock ($\text{kg}/\text{m}^3[\text{rock}]$)

σ_f = fracture surface area per unit volume of rock ($\text{m}^{-1}[\text{rock}]$)

K_a^i = distribution coefficient of the i^{th} radionuclide species expressed on a per-unit-surface-area basis ($\text{m}^3[\text{water}]/\text{m}^2[\text{rock}]$).

Some typical values for K_d and estimated values of R_m^i for the various radionuclides in spent fuel are shown in Table 8.3.5.13-4. Because fracture surface areas are usually much smaller than pore surface areas and because

Table 8.3.5.13-4. Typical distribution coefficients and approximate retardation factors for welded and nonwelded Yucca Mountain hydrogeologic units

Element	Distribution coefficient, ^a K_d (ml/g)		Retardation factor, ^b R_m	
	Welded	Nonwelded	Welded	Nonwelded
Americium	1,200	4,600	28,000	24,000
Carbon	0 ^c	0 ^c	1	1
Curium	1,200	4,600	28,000	24,000
Cesium	290	7,800	6,700	41,000
Iodine	0 ^c	0 ^c	1	1
Neptunium	7	11	160	58
Protactinium	64 ^d	140 ^d	1,500	740
Lead	5 ^d	5 ^d	120	27
Plutonium	64	140	1,500	740
Radium	25,000 ^e	25,000 ^e	580,000	130,000
Tin	100 ^d	100 ^d	2,300	530
Strontium	53	3,900	1,200	21,000
Technetium	0.3 ^d	0 ^c	8	1
Thorium	500 ^d	500 ^d	12,000	2,600
Uranium	1.8 ^d	5.3 ^d	27	45
Zirconium	500 ^d	500 ^d	12,000	2,600

^aUnless otherwise indicated, distribution coefficients were taken from Table 6-25 (DOE, 1986b) or were inferred from the sorption ratios quoted by Daniels et al. (1982).

^bCalculated using values of moisture content of 10 and 28 percent and bulk densities of 2.33 and 1.48 g/cm³ for welded and nonwelded tuff.

^cNo data available; assumed to be zero.

^dInferred from the midrange retardation factor for tuffs in compilation in Table 7-1 in National Research Council (1983).

^eBarium used as a chemical analog.

chemical equilibrium may not be reached in rapid fracture flows, the adsorptive retardation in fracture flow R_f^i can be regarded as a number of the order of unity (Sinnock et al., 1984b) (i.e., sorption in fractures may be ignored).

Equations 8.3.5.13-10A and 8.3.5.13-10B would be the standard transport equations (Freeze and Cherry, 1979), without dispersive-diffusive terms, except for the presence of the coupling terms proportional to $C_f^i - C_m^i$ on their right-hand sides. In particular, the reciprocal of the quantity Λ_f^i is a measure of the time required for the concentrations in the fracture pore water (C_f^i) to come to equilibrium with its counterpart in the slowly moving

matrix pore water (C_m^i). Wilson and Dudley (1987) show that these coupling constants have the forms

$$\Lambda_1 = \frac{\partial \theta_m}{\partial t} + \nabla \cdot q_m \quad (8.3.5.13-13)$$

$$\Lambda_2^i \cong \frac{\pi^2 \theta_f |\overline{D}_m^i| R_f^i}{R_m^i a^2} \quad (8.3.5.13-14)$$

a = one-half of the mean spacing between fractures (m[rock])

$|\overline{D}_m^i|$ = absolute magnitude of the effective dispersive-diffusive tensor in the matrix (m^2 [rock]/yr).

Note that lateral diffusion is accounted for in these coupling terms.

Several of the possible cases of transport of dissolved radionuclides through Yucca Mountain rocks can be qualitatively analyzed by means of Equations 8.3.5.13-10A, 8.3.5.13-10B, and 8.3.5.13-14:

1. Partially saturated flow. In this case, percolation flux does not exceed the saturated matrix hydraulic conductivity so the flow is predominantly through the rock matrix, and only Equation 8.3.5.13-10A applies. This is believed to represent present hydrologic conditions at Yucca Mountain. Under these conditions, the unsaturated-zone rocks will act as barriers to the release of liquid-phase contaminants because water flows predominately in the rock matrix, and matrix flow promotes rather long ground-water travel times (GWTT) to the water table, as shown in Table 8.3.5.13-5. Retardation of many elements is likely to be large under these circumstances (see Table 8.3.5.13-4).
2. Fracture flow with weak coupling. In this case, the coupling constants are small compared with the reciprocal of typical transport times in fracture flow ($L/\bar{V}_f^i$ where L is the unit thickness), and Equations 8.3.5.13-10A and 8.3.5.13-10B both apply. The radionuclide concentrations spread out through the matrix and fracture systems separately, with the fracture-system concentrations usually "outracing" the matrix-system concentrations. This situation could arise in a discharge through a saturated structural feature (Class C-3, Table 8.3.5.13-3).
3. Fracture flow with strong coupling. In this case, the coupling constants are larger than or comparable to the reciprocal of typical transport times in fracture flow, and the concentrations of radionuclides in both systems come to equilibrium. Wilson and Dudley (1987) show that in this case a single transport equation for the equilibrium concentration applies, and that the effective transport velocity in the advective term of this equation after equilibrium has been reached has the form

$$V^i = \frac{\bar{q}}{\theta_m + \theta_f + \rho_b K_d^i} \quad (8.3.5.13-15)$$

Table 8.3.5.13-5. Estimates^a of ground-water travel time, predominately matrix flow^{b,c}

Unit	Percentage of total repository area underlain by the unit	Mean (yr)	Standard deviation (yr)
Topopah Spring welded unit	98.5	4,765	1,920
Calico Hills vitric unit	95.3	11,000	7,760
Calico Hills zeolitized unit	94.5	13,695	8,145
Prow Pass welded unit	83.2	3,915	1,710
Prow Pass unwelded unit	63.1	15,020	8,025
Bullfrog welded unit	25.6	6,800	4,085
Bullfrog nonwelded unit	7.5	5,445	3,525
Estimated total ^d		43,265	12,765

^aEstimates are for the entire unsaturated zone underlying the disturbed zone. Variability in unit thickness is taken into account.

^bPercolation flux = 0.5mm/yr.

^cSource: Sinnock et al. (1986).

^dTotal is not a sum of the individual columns but represents the quantities for total ground-water travel time through the entire unsaturated zone.

Since θ_m is almost always much greater than θ_f , the effective transport velocity is virtually the same as that for an equivalent porous medium with an effective porosity equal to θ_m and an adsorptive distribution coefficient equal to K_d . Thus, we shall say that models of equivalent-porous-medium transport apply when concentrational equilibrium is reached (or closely approached), and Equation 8.3.5.13-15 approximately applies. Under these circumstances, it is easy to see that for percolation flux up to 5 mm/yr, transport times for nonsorbing species through a 50-m section of unsaturated-zone rock would equal or exceed one thousand years, and transport times for sorbing species would exceed ten thousand years.

The third-case stated above is likely to apply to those water-pathway scenario classes involving repository-wide failure of the unsaturated zone barriers: i.e., classes C-1, C-2, and C-3 in Table 8.3.5.13-3. Of most interest, though, is whether it would apply in the saturated zone. Since the

rocks in the saturated zone are known to be highly fractured and it is known that flow through fractures may be orders of magnitude faster than matrix flow, it has previously been assumed that the saturated zone would not be an effective barrier against releases. In Table 6-19 of the EA (DOE, 1986b), the ground-water travel time along a 5-km path to the accessible environment boundary is estimated to be approximately 170 yr, which is brief compared with the times shown in Table 8.3.5.13-5; the effective porosity used in these estimates was 0.0001, a value of fracture porosity attributed to Sinnock et al. (1984b). But if equivalent-porous-medium transport models are applicable to the saturated zone, the transport times for nonsorbing species would be larger than 170 yr by a factor of 100 to 400 (the estimated ratio of matrix porosity to fracture porosity) (i.e., 17,000 to 68,000 yr) and once coupled, sorbing species would be practically immobile in the saturated zone. Thus, whether the saturated zone is an effective barrier against releases to the accessible environment will depend on whether equivalent-porous-medium models apply there (i.e., whether advective-dispersive coupling can be achieved along the flow paths between the repository area and the accessible environment boundary).

According to the Wilson-Dudley model, the saturated zone may provide a good barrier to transport of nonsorbing and some weakly sorbing species, but would not reduce by much the releases of strongly sorbing species which, nevertheless, could be strongly retarded in the unsaturated zone. To see this, note that according to Equations 8.3.5.13-10B and 8.3.5.13-14, an estimate of the time constant governing establishment of concentrational equilibrium between fracture and matrix flows is

$$t_c = \frac{R_m^i a^2}{\pi^2 |D_m^i|} \quad (8.3.5.13-16)$$

Assume that the parameters in this expression take the following values in the saturated zone: fracture spacing ($2a$) equal to 30 cm ($CH_{nv} + CH_{nz}$ from Table 1 of Klavetter and Peters, 1986), an effective diffusivity ($\overline{D_m^i}$) equal to 1.0×10^{-2} m/yr and adsorptive retardation factors (R_m^i) equal to the values given in Table 8.3.5.13-4 for nonwelded tuff. Then, using these assumptions, the following are the time-constant (t_c) estimates: (1) for nonsorbing species, 0.23 yr; (2) for uranium, 10.4 yr; (3) for plutonium, 170 yr; and (4) for americium, 5,520 yr. In the Wilson-Dudley model (Wilson and Dudley, 1987), the effect of weak coupling on concentrations of strongly sorbing species in fracture flows is easily seen from Equations 8.3.5.13-10A and 8.3.5.13-10B. Transport of these species is at the fracture-flow velocity, and weak coupling may at best only increase the effective decay rate for concentrations of strongly sorbing species. Thus, using plutonium-239 as an example, one could assign an effective half-life of 0.693 times 170 yr (118 yr) instead of the usual 24,400-yr half-life against radioactive decay. In the saturated zone, where water travel times in fracture flow are also about 170 yr, the effective "decay" of concentration would only reduce cumulative discharge of plutonium-239 by a factor of about $1/e$, or about 37 percent.

The Wilson-Dudley model (Wilson and Dudley, 1987) may prove to be overly conservative in the sense that it overestimates the time required to couple mass concentrations in fracture flows with mass concentrations in matrix flows, thereby leading to larger discharges of strongly sorbing species at

the accessible-environment boundary than would be predicted by equivalent-porous-media transport calculations (i.e., calculations using a single mass concentration that moves with the effective transport velocity in Equation 8.3.5.13-15). Other investigators (Rasmuson and Neretnieks, 1981; Sudicky and Frind, 1982) seem to reach a different conclusion regarding the dependence of the time constant (t_c) governing coupling on the retardation factors (R_m^i). Although it is difficult to see in their analysis, Rasmuson and Neretnieks (1981) appear to predict a time constant of the form

$$t_c = \frac{r^2}{15|D_m^i|} \quad (8.3.5.13-17)$$

where r is the radius of a matrix block (which is assumed to be spherical and is the same order of magnitude as a in the Wilson-Dudley model (1987 - see Eq. 8.3.5.13-14). Similarly, the work of Sudicky and Frind (1982) suggests that the time constant should be

$$t_c = \frac{a^2}{3|D_m^i|} \quad (8.3.5.13-18)$$

where a is now one-half the uniform spacing between fractures which are assumed to be planar and parallel. Note that each of the last two forms of time constant are independent of the retardation factor and, apart from factors of 2 or 3, are of the same magnitude as the time constant for coupling nonsorbing species in the Wilson-Dudley model (Eq. 8.3.5.13-16).

These different estimates of the time required to couple mass concentrations in fracture and matrix flows illustrate the need for validated conceptual and mathematical models of transport of solutes through the actual (i.e., not idealized) fractured, welded and nonwelded tuffs of Yucca Mountain. Investigations to produce such validated models are described in Chapter 4 and in Section 8.3.1.3 (Geochemistry Program). The Wilson-Dudley model (Wilson and Dudley, 1987) is undoubtedly conservative relative to the models of Rasmuson and Neretnieks (1981) and Sudicky and Frind (1982); but it is not clear that the first or the third of these models are conservative because each assumes that the permeabilities and constrictivity-tortuosity factors of the surfaces separating fracture void space from matrix void space are the same as the permeability and constrictivity-tortuosity factor of the matrix. Rasmuson and Neretnieks (1981) do postulate an arbitrary mass-transfer coefficient for the interface between matrix and fracture void spaces but they then assume it is the same as internal mass transfer coefficients for their calculations. Such an assumption could be wrong if relatively impermeable mineral coatings or mineral-grain occlusions occur over a large fraction of the fracture surfaces. In such circumstances, the effective area for entry into the matrix per unit volume of rock could be reduced by several orders of magnitude, with the effect of reducing the effective diffusivity in the formulae for coupling time given above.

A systems-level mathematical model has been developed for predicting the partial performance measure M_j for those scenario classes involving releases along water pathways (e.g., classes in supercategories E, C, and D in Table 8.3.5.13-3). The model to be presented applies to the nominal

(undisturbed) case and to many of the disturbed-case scenario classes, but is discussed here under the nominal case for the sake of convenience. Discussion of this model will serve several purposes in this section:

1. It will illustrate the feasibility of and level-of-detail required for the "simplified" models mentioned in the preceding section (Construction of a CCDF) as being necessary for a calculation of the CCDF.
2. It will show, in a way that may be clearer than the preceding discussion of radionuclide transport theory, why certain data and information concerning (a) hydrologic and geochemical properties of Yucca Mountain rocks and (b) probabilities and intensities of events or processes initiating a scenario class are needed to resolve this issue.
3. It will partially document the basis for the largely nonquantitative reasoning so far used to make preliminary assessments of the relative magnitudes of the EPPMs for scenario classes involving releases along water pathways.

This last purpose should be emphasized: the model to be presented here is preliminary and has at least three serious limitations (the assumptions (1) through (3) given in the next paragraph) that could lead to underestimates of the partial performance measure. These limitations will be remedied by further model development and validation in the future. Most of the detailed development of the following model can be found in Section 3.0 of Sinnock et al. (1986).

Assume that (1) coupling between mass concentrations in matrix and fracture flows is always strong enough to justify the assumption of equivalent-porous-media transport in both the unsaturated and saturated zones (UZ and SZ), (2) all radionuclides can be treated as single-member decay chains, (3) the process of longitudinal molecular diffusion can be ignored, and (4) mass release rates from the EBS can be calculated with the formulae given in Section 3.1.1 of Sinnock et al. (1986). Then, making a slight extension of Equation 40 in Sinnock et al. (1986), one can show that the partial performance measure for the j^{th} scenario class involving releases along the water pathway may, in most cases, be approximated by the following expression:

$$M_j = \frac{N}{N_T} \sum_i \frac{a_i}{L_i} \cdot \frac{\tau_i}{(\tau_i + \lambda_i)} e^{-\lambda_i t} \cdot e^{\lambda_i \tau_i} [1 - e^{-(\lambda_i + \tau_i)\tau_i}] u(\tau_i) \quad (8.3.5.13-19)$$

where

N = number of waste packages involved in the release scenario

N_T = total number of waste packages in the repository at closure

a_i = inventory of the i^{th} radionuclide species at time of closure
(Ci/MTHM)

L_i = release limit (per MTHM) for the i^{th} radionuclide as specified in proposed 10 CFR 60.115 and 40 CFR Part 191, Appendix A (Ci)

r_i = fractional mass release rate of the i^{th} radionuclide species from any one of the waste packages involved in the release scenario (yr^{-1})

t = regulatory period of performance (10,000 yr)

λ_i = decay constant for the i^{th} radionuclide species (yr^{-1})

τ_i = a time interval to be described below (yr)

$u(x)$ = unit step function, ($u(x) = 1$ if $x > 0$, and $u(x) = 0$ if $x < 0$).

Table 8.3.5.13-6 provides values for decay constants, radionuclide inventories, release limits, and calculated values for the normalized inventory at risk (a_i/L_i) for the radionuclide species of concern. The following discussion will clarify the meaning of these variables and the equation in general. Note that the subscript j applies to certain variables appearing on the right-hand side, but has been suppressed to simplify the expression. The j -dependence of each variable will be noted below.

With the exception of t , N_T , λ_i , and L_i , all the variables appearing on the right-hand side of Equation 8.3.5.13-19 may be regarded as random variables in the sense that uncertainties dictate that they be treated as distributed quantities (examples will be mentioned later). Thus, M_j is also a random variable whose statistical properties must usually be evaluated by simulation.

The number of waste packages involved in the release scenario (N) depends on scenario class S_j and on the nature and intensity of the process or event that initiates a realization of the release scenario (e.g., the number of packages intercepted by flow through a fault zone). In every case, $0 < N < N_T$.

The fractional mass release rate (r_i) applies only to release in a liquid phase from bare waste form, and is estimated in Section 3.1.1 of Sinnock et al. (1986) by

$$r_i = \frac{q_u A \bar{S}_i}{M_o} \quad (8.3.5.13-20)$$

where

q_u = magnitude of specific discharge of water near a waste package ($\text{m}^3/\text{m}^2 \text{ yr}$)

A = effective water-intercept area of a waste package (m^2)

M_o = mass of waste matrix per package (kg)

$\bar{S}_i$ = effective solubility limit (kg/m^3).

Table 8.3.5.13-6. Reference inventory used in system-level models (page 1 of 2)

Nuclide	Decay constant λ_i (yr ⁻¹)	Assumed inventory at closure, a_i (Ci/MTHM)	10 CFR 60.115 ^a limit, l_i (Ci/MTHM)	Normalized inventory at risk, a_i/l_i
Cm-246	1.26×10^{-4}	3.5×10^{-2}	0.1	3.5×10^{-1}
Cm-245	7.45×10^{-5}	1.8×10^{-1}	0.1	1.8×10^0
Am-243	8.72×10^{-5}	1.4×10^1	0.1	1.4×10^2
Am-242	4.56×10^{-3}	1.0×10^1	1.0	1.0×10^1
Am-241	1.51×10^{-3}	1.6×10^3	0.1	1.6×10^4
Pu-242	1.83×10^{-6}	1.6×10^0	0.1	1.6×10^1
Pu-240	1.05×10^{-4}	4.5×10^2	0.1	4.5×10^3
Pu-239	2.84×10^{-5}	2.9×10^2	0.1	2.9×10^3
Pu-238	8.06×10^{-3}	2.0×10^3	0.1	2.0×10^4
Np-237	3.24×10^{-7}	3.1×10^{-1}	0.1	3.1×10^0
U-238	1.54×10^{-10}	3.2×10^{-1}	0.1	3.2×10^0
U-236	2.90×10^{-8}	2.2×10^{-1}	0.1	2.2×10^0
U-235	9.76×10^{-10}	1.6×10^{-2}	0.1	1.6×10^{-1}
U-234	2.81×10^{-6}	7.4×10^{-2}	0.1	7.4×10^{-1}
U-233	4.28×10^{-6}	3.8×10^{-5}	0.1	3.8×10^{-4}
Pa-231	2.13×10^{-5}	5.3×10^{-6}	0.1	5.3×10^{-5}
Th-232	4.95×10^{-11}	1.1×10^{-10}	0.1	1.1×10^{-9}
Th-230	8.66×10^{-6}	4.1×10^{-6}	0.1	4.1×10^{-5}
Th-229	9.44×10^{-5}	2.8×10^{-8}	0.1	2.8×10^{-7}
Ra-226	4.33×10^{-4}	7.4×10^{-9}	0.1	7.4×10^{-8}
Pb-210	3.11×10^{-2}	7.0×10^{-10}	1.0	7.0×10^{-10}
Cs-137	2.31×10^{-2}	7.5×10^4	1.0	7.5×10^4
Cs-135	2.31×10^{-7}	2.7×10^{-1}	1.0	2.7×10^{-1}
I-129	4.36×10^{-8}	3.3×10^{-2}	1.0	3.3×10^{-2}

Table 8.3.5.13-6. Reference inventory used in system-level models (page 2 of 2)

Nuclide	Decay constant λ_i (yr ⁻¹)	Assumed inventory at closure, a_i (Ci/MTHM)	10 CFR 60.115 ^a limit, l_i (Ci/MTHM)	Normalized inventory at risk, a_i/l_i
Sn-126	6.93×10^{-6}	4.8×10^{-1}	1.0	4.8×10^{-1}
Tc-99	3.22×10^{-6}	1.3×10^1	10.0	1.3×10^0
Zr-93	7.29×10^{-7}	1.7×10^0	1.0	1.7×10^0
Sr-90	2.39×10^{-2}	5.2×10^4	1.0	5.2×10^4
Ni-59	8.66×10^{-6}	3.0×10^{-2}	1.0	3.0×10^{-2}
C-14	1.21×10^{-4}	1.5×10^0	0.1	1.5×10^1
SUM =				1.7×10^5

^aFrom the proposed amendments to 10 CFR Part 60.

$\bar{S}_i$ is expressed mathematically as

$$\bar{S}_i = \min(S_i, S_m)$$

where

S_i = solubility limit for the chemical species carrying the i^{th} radionuclide (kg/m^3)

S_m = solubility limit for the bulk waste form (kg/m^3).

The fractional mass release rate (r_i) depends on the scenario class and the nature and intensity of initiating events or processes through its dependence on q_u and $\bar{S}_i$ (which are also dependent on the nature and intensity of initiating events and processes). In future formulations of Equation 8.3.5.13-19, r_i may be replaced with empirically determined fractional release rates as a function of time and specific discharge (q_u) near a waste package. Determination of actual release rates from waste packages under different repository hydrologic conditions is part of the investigations associated with Issues 1.4 and 1.5.

The quantity τ_i appearing in Equation 8.3.5.13-19 is defined by

$$\tau_i = t - [\max(T_c, T_d) + T_u^i + T_s^i] \quad (8.3.5.13-21)$$

where

t = regulatory period of performance (10,000 yr)

T_c = waste package containment time (yr)

T_d = total delay time (yr)

T_u^i = the unsaturated zone transport time for the i^{th} radionuclide species (yr)

T_s^i = the saturated zone transport time for the i^{th} radionuclide species (yr).

The waste-package containment time (T_c) is actually either the waste-package containment time or the time during which waste package temperature exceeds 95°C , whichever is greater. T_d , the total delay time, measured after closure and before the onset of a release, is defined by

$$T_d = T_c + t_p \quad (8.3.5.13-22)$$

where

T_c = waiting time, after closure, before the first occurrence of an initiating event or process that may lead to a release (yr)

t_p = time interval representing the delay between the occurrence of the initiating event or process and the epoch when releases begin (yr):

Examples of T_e are: (1) the epoch at which motion occurs along a fault zone that is sufficient to divert substantial amounts of down-dip flow through the repository (t_p would then be the delay between the event, "fault motion," and the event "flow in fault reaches the repository level"); and (2) the epoch at which a large surface-water impoundment is formed near the controlled area (t_p would then be the delay between the event, "formation of impoundment," and the event "wetting front from impoundment reaches repository level"). Clearly, T_e and t_p depend on the scenario class (j) and the nature and intensity of the initiating events or processes.

The unsaturated zone (UZ) transport time for the i^{th} radionuclide species (T_u^i) is the time required for a molecule of a chemical species carrying the i^{th} radionuclide, which is released from the repository in the liquid phase, to reach the water table. If it is assumed that coupling between mass concentrations in matrix and fracture flows is strong in the UZ, then the effective transport velocity is given by Equation 8.3.5.13-15 and

$$T_u^i = \int_z^y \frac{ds}{|\vec{V}_u^i|} = \int_z^y \frac{1}{q_u} (\theta_m + \theta_f + \rho_b K_d^i) ds \quad (8.3.5.13-23)$$

where

z = any point in that part of the repository affected by flows associated with the j^{th} scenario class and the event or process initiating the flow

y = a point on the water table connected to z by a flow pathway through the UZ

ds = an element of length along the pathway from z to y .

The saturated zone (SZ) transport time for the i^{th} radionuclide species (T_s^i) is defined in a manner similar to the UZ transport time. Again, if strong coupling in the SZ is assumed, then

$$T_s^i = \int_y^z \frac{ds}{|\vec{V}_s^i|} = \int_y^z \frac{1}{q_s} (n_m + n_f + \rho_b K_d^i) ds \quad (8.3.5.13-24)$$

where

q_s = specific discharge in the saturated zone ($\text{m}^3/\text{m}^2 \text{ yr}$)

n_m = effective matrix porosity in the saturated zone

n_f = effective fracture porosity in the saturated zone

z = a point on the accessible environment boundary connected to (defined above) by a flow pathway through the saturated zone.

Finally, the quantity $u(\tau_i)$ appearing in Equation 8.3.5.13-19 is the unit step function: $u(\tau_i) = 1$ if $\tau_i > 0$, and $u(\tau_i) = 0$ if $\tau_i < 0$. Since this function appears as a multiplicative factor in each term of the sum in Equation 8.3.5.13-19, it is clear that if any one of the T s in Equation 8.3.5.13-21 exceeds 10,000 yr, or if the sum of the T s exceeds 10,000 yr, that term will make no contribution to the sum in Equation 8.3.5.13-19. Thus, the various T s (T_c , T_e , T_u and T_s), are sensitive quantities in the determination of the magnitude of the partial performance measure (M_j) and warrant special discussion. Before beginning this discussion, it is appropriate to reiterate the claim made earlier that, with few exceptions, the variables in Equation 8.3.5.13-19 are distributed variables; it is therefore appropriate to refer to the distribution of the T s, rather than specific values that the T s may take.

The distribution of waste-package containment time (T_c) is not known. Estimates in the Yucca Mountain site environmental assessment (DOE, 1986b) suggest that $3,000 \text{ yr} < T_c < 30,000 \text{ yr}$, but no distribution was attached to this range. Current studies proposed for determining the distribution of T_c are outlined in Section 8.3.5.9.

The waiting times after closure until first occurrence of the process or event that initiates a release (T_e) will be distributed differently according to the process or event and scenario class to which it pertains (in this nominal case, $T_e = 0$). In most cases, and particularly for events, waiting times are assumed to be exponentially distributed with a given annual probability of occurrence. For example, consider the scenario class C-1 (Table 8.3.5.13-3) and the initiating event, "episodic offset on faults creates new pathways for drainage of water through the repository"; in this instance T_e may be exponentially distributed with an annual probability less than $10^{-5}/\text{yr}$ (an expected recurrence time of 100,000 yr).

If the waiting time to first occurrence of an event is exponentially distributed with mean annual probability less than $10^{-8}/\text{yr}$, then the probability that T_e is less than 10,000 yr would be less than one chance in ten thousand. In other words, the event would be expected to occur at most once during a simulation of many tens of thousands of runs and even on occurrence the consequences might be zero if other time delays were finite. To make a significant contribution to the CCDF, the consequences (the sample value of M_j) attending the occurrence of such a low-probability event would have to exceed 10,000, with little delay between the event and a release to the accessible environment. Events or processes associated with releases along water pathways fulfilling these conditions are inconceivable, although some events attending direct releases (e.g., scenario class A-1) may come near to fulfilling them.

The time delay (t_p) between the occurrence of an initiating event or process and the epoch when releases from the engineered barrier system attending that event or process begins may in certain contexts be highly sensitive in the determination of the magnitude of the partial performance measure. Generally speaking, $t_p > 0$ for those scenario classes involving hydrologic response to changed boundary conditions on the flows through

either the UZ or SZ (scenario classes in supercategories C and D). Though few calculations of the dynamic response of flows to changed boundary conditions have yet been made, the preliminary studies that have been documented indicate that t_p for events affecting flows in the UZ tends to be long (1,000 to 10,000 yr), while t_p for events affecting flows in the SZ tends to be relatively short (tens to hundreds of yr). Our current tools for investigating hydrodynamic response times are the hydrodynamics module of the Total System Performance Assessment Code (TOSPAC) for the UZ (under development, but refer to Peters et al. (1986) or Klavetter and Peters (1986) for the physical basis of TOSPAC's hydrodynamics), and the ISOQUAD code (Barr and Miller, 1987) for the SZ. The calculation of t_p for different scenario classes and different initiating events or processes will in general require the use of these or similar, phenomenological codes. In those cases where the calculation proves difficult or time consuming, t_p may conservatively be set to zero.

The transport times (T_u^i and T_i^i) are probably the most sensitive quantities determining the performance measure, Equation 8.3.5.13-19. From Equations 8.3.5.13-23 and 8.3.5.13-24, it is seen that the distributions of T_u^i and T_i^i apparently must be inferred by calculating the distributions of space integrals whose arguments contain quantities that are themselves distributed in space (e.g., the product $\rho_b K_d^i$ is expected to be spatially distributed with different mean values, variances and autocovariances pertaining to each rock unit). Such a calculation would be time-consuming in a systems-level model. However, considerable simplification is possible using extensions of the analytic methods proposed in Appendix A of Sinnock et al. (1986). Sinnock et al. (1986) show that distributions of ground-water travel time can be conservatively represented by a normal distribution, and analytic methods are developed therein for calculating the mean and variance of the GWTT distributions; these analytic methods can be applied to the calculation of the mean and variance of the transport times (T_u^i and T_i^i). For example, the mean of the UZ transport times can be estimated by

$$\bar{T}_u^i = \sum_k [\bar{\theta}_m + \bar{\theta}_f + \bar{\rho}_b \bar{K}_d^i]_k \cdot \bar{l}_k [\bar{q}_u^{-1}] \quad (8.3.5.13-25)$$

where

$\bar{\theta}_m$ = mean mobile moisture content in the matrix system
(m³ [water]/m³ [rock])

$\bar{\theta}_f$ = mean mobile moisture content in the fracture system
(m³ [water]/m³ [rock])

k = index labeling rock geohydrologic units in the unsaturated zone below the repository horizon

$\bar{l}_k$ = thickness of the k^{th} geohydrologic unit that intervenes between the repository floor and the water table in the repository area (m).

A bar over a quantity denotes the mean value or spatial average for a spatially varying quantity.

Note that $\bar{l}_k = 0$ if a water-table rise completely submerges the k^{th} unit.

Similarly, the mean of the SZ transport times can be estimated by

$$\bar{T}_s^i = \sum_s [\bar{n}_m + \bar{n}_f + \bar{\rho}_b \bar{K}_d^i]_s \cdot \bar{d}_s [\bar{q}_s^{-1}] \quad (8.3.5.13-26)$$

where

- $\bar{n}_m$ = mean effective porosity in matrix
- $\bar{n}_f$ = mean effective porosity in fractures
- s = index labeling rock geohydrologic units in the saturated zone
- $\bar{d}_s$ = flow-path length through the s^{th} unit (m).

The sum of the individual $\bar{d}_s$ is a total flow-path length from a given point on the water table under the repository to any point on the accessible-environment boundary. The formulae for estimating the variances of the transport times (T_u^i and T_s^i) will not be quoted here; it will suffice to say that evaluation of these formulae will require the same mean values of the quantities that appear on the right-hand sides of Equations 8.3.5.1.3-25 and 8.3.5.13-26, and in addition, the spatial variances and autocovariance lengths for, and correlation coefficients among, all these quantities. In short, given estimates of the statistical parameters associated with the natural distributions of rock hydrologic and geochemical parameters associated with each geohydrologic unit, one can estimate the distribution of the transport times (T_u^i and T_s^i). Note that estimates of each statistical parameter will intrinsically be uncertain because of practical limitations on both the analytical methods used to ascertain values of those parameters, and on the number of the data units (field samples or measurements) that can be obtained for use in those analytical methods. Data that could be used to infer these statistical parameters are presently sparse or nonexistent.

Considerable insight into the sensitivity of the transport times for the determination of the partial performance measure $\bar{M}_j$ can be gained by study of the expressions for the mean value of those variables (i.e., Equations 8.3.5.13-25 and 8.3.5.1.3-26). Since fracture porosities are almost always much less than matrix porosities, order-of-magnitude estimates of the mean transport times can be made from

$$\bar{T}_u^i \cong \frac{\bar{n}_m}{\bar{q}_u} \bar{R}_m^i \cdot \bar{l} \quad (8.3.5.13-27A)$$

$$\bar{T}_s^i \cong \frac{\bar{n}_m}{\bar{q}_s} \bar{R}_m^i \cdot \bar{d} \quad (8.3.5.13-27B)$$

where all barred quantities on the right-hand sides now denote spatial averages over the entire UZ or SZ as appropriate. Again, it is emphasized that these estimates apply only if the assumption of strong coupling between mass concentrations in matrix and fracture flows is valid.

For the UZ, one may take $\bar{n}_m$ equal to 0.2 (Figure B-1 in Sinnock et al., 1986), values for $\bar{R}_m^i$ from column 5 of Table 8.3.5.13-4, and l equal to 250 m (Figure 4(A) in Sinnock et al. (1986)). Using these values, one finds that at $\bar{q}_u = 5$ mm/yr, the mean UZ transport time for nonsorbing species (where $\bar{R}_m^i = 1$) is just about 10,000 yr, and much longer for sorbing species (e.g., uranium's mean transport time through the UZ would be 270,000 to 450,000 yr). The SZ mean transport times can be estimated by taking $\bar{n}_m$ and $\bar{R}_m^i$ as in the UZ case, but $\bar{q}_s = 3.2 \times 10^{-2}$ m/yr and $\bar{d} = 5000$ m (Table 6-19 in DOE, 1986b). One finds that the mean transport time in the SZ for nonsorbing species is about 30,000 yr, and for sorbing species, a term longer by the factor $\bar{R}_m^i$.

Estimates such as these show why it may be possible to ignore the contributions of sorbing species to the sum in Equation 8.3.5.13-19, provided that the standard deviations (i.e., the square root of the variances) of the transport times are small compared with the mean, and also why the variances of the transport times are important in determining the relative contributions of all species to the sum in Equation 8.3.5.13-19. These estimates also show why a solution to the problem of coupling times for the transfer of mass concentrations between fracture and matrix flows is badly needed, particularly for flows in the SZ. If coupling times are short then, as indicated, transport times for all species in the SZ may exceed 30,000 yr and the SZ becomes the primary barrier to releases through the water pathways (indeed, those scenario classes involving water-pathway releases would make little if any contribution to the complementary cumulative distribution functions in this alternative). On the other hand, if coupling times are long compared with the estimated 170-year ground-water travel time in the SZ, the SZ barrier could only modestly reduce the magnitude of 10,000-yr cumulative releases, and the UZ barrier would become the primary barrier to releases.

Nominal case (E): gas-phase releases

Release of radionuclides by gas pathways also applies to both undisturbed-case and disturbed-case scenario classes, but, again, this discussion is given here under the nominal case for convenience. A few of the radionuclides in spent-fuel waste forms, namely tritium, carbon-14, krypton-85, and iodine-129, could be released from waste packages as gases or in compounds that form gases. Of these, the only important one appears to be carbon-14, in the form of carbon dioxide. The half-lives of tritium and krypton-85 (12.3 yr and 10.7 yr, respectively) are short, and elemental iodine is extremely reactive and likely to be released in a liquid or solid phase. The source of gas-phase carbon-14 "is thought to be removal of carbon from the oxidized skin of the Zircaloy cladding by reaction of the oxygen in the atmosphere with carbon in the cladding oxidation layer to release carbon dioxide" (Oversby and McCright, 1985). Oversby and McCright believe that as much as one percent of the carbon-14 inventory in spent fuel may be available for rapid release from the breached waste packages in the form of carbon dioxide during the first 100 to 1,000 yr following closure (see Section 8.3.5.9). After the 1,000-yr containment period, the amount of C-14 available for rapid release from the breached waste packages would be very small because of slow oxidation rate of C-14 to carbon dioxide due to low temperatures and gamma fluxes (see Section 8.3.5.10). C-14 in nongaseous forms will be released slowly, probably in a liquid phase.

Rapid release of one percent of the carbon-14 inventory to the accessible environment would not alone violate the proposed rule (10 CFR 60.115). An upper-bound estimate of the expected partial performance measure (EPPM) for this scenario (assumed to be nominal case) is 0.15, assuming a normalized inventory of 15 for carbon-14 (see Table 8.3.5.13-6) at closure time and prompt transfer of one percent of the carbon-14 to the atmosphere above the repository. Carbon-14 dioxide originating in the waste form would, of course, not be promptly transferred to the atmosphere, but would have finite and possibly long residence times in partially saturated pore spaces of the repository's overburden during which times the carbon-14 could decay. In addition, some of the released carbon-14 dioxide would diffuse downward and presumably become dissolved in water in pore spaces of rock below the repository horizon. The effect of long residence times and downward diffusion would be to reduce the time-integrated flux of carbon-14 to the atmosphere above the repository; that is, reduce considerably the upper-bound estimate of the EPPM.

The time-dependent surface flux of carbon-14 originating in the waste form may, in principle, be estimated by first constructing a conceptual model of transport of carbon-14 dioxide through the partially saturated overburden units at Yucca Mountain and, second, solving the system of transport equations rising from the conceptual model. The remainder of this discussion is devoted to a description of one possible conceptual model of transport of carbon-14 dioxide and the site-specific data needed to verify that conceptual model and implement a solution of the associated transport equations.

The conceptual model for the transport of carbon-14 dioxide through the partially saturated overburden has three principal features:

1. Gas-phase carbon-14 dioxide moves upward through air-filled pores and fractures of the unsaturated tuffs by molecular diffusion and by advection in a thermally-driven air convection cell. Analyses to date do not permit either of these processes to be neglected.
2. An isotopic equilibrium exists between carbon dioxide in the gas phase, which is mobile, and dissolved bicarbonate, which is immobile. Advection of dissolved bicarbonate almost certainly may be neglected.
3. Precipitation of calcite, if it occurs, irreversibly removes carbon-14 from the system. The chemical controls on calcite precipitation are not yet understood.

To describe this system, three sets of equations are required:

1. Equations for the movement of carbon-14 and its transfer among phases.
2. Equations that determine the chemical environment, insofar as it is not directly observable.
3. Equations for the velocity of air flow.

The following discussion describes the preliminary model for releases along gas pathways. Thorstenson et al. (1983) point out that each isotopic

species of CO_2 within unsaturated-zone gas diffuses according to its own concentration² gradient. Advective transfer also will depend on the local concentration of any given species, independent of the presence of other isotopes. Mass transfer among phases can, however, depend on the concentrations of other isotopic species.

With these considerations in mind, a governing equation for the concentration of any gas in the unsaturated zone is needed. This is obtained by adding advection terms to Equation 12 of Thorstenson et al. (1983). The one dimensional equation is as follows:

$$-q_g \frac{\partial C_A}{\partial z} - q_L \frac{\partial C_A^*}{\partial z} + \tau \Theta_D D_A \frac{\partial^2 C_A}{\partial z^2} = \Theta_D \frac{\partial C_A}{\partial t} + (\Theta_T - \Theta_D) \frac{\partial C_A^*}{\partial t} + \frac{\partial \bar{C}_A}{\partial t} + \alpha_A \quad (8.3.5.13-28)$$

where

- q_g = Darcy velocity of mass flow of the pore gas (cm/s)
- q_L = Darcy velocity of liquid water flow (cm/s)
- C_A = concentration of gas A (mole/cm³)
- C_A^* = concentration of gas A and its reaction products in the soil water (mole/cm³ of water) (Thorstenson et al. define this variable as a concentration per unit mass)
- $\bar{C}_A$ = concentration of substance A and its reaction products in the solid phase (mole/[cm³ of medium], where [cm³ of medium] refers to the space occupied by solids + liquids + gases)
- z = dimension increasing with depth; 0 at land surface (cm)
- τ = a tortuosity factor accounting for the added resistance to diffusion imposed by the structure of the porous medium (dimensionless)
- Θ_D = drained or gas-filled porosity (dimensionless)
- D_A = molecular diffusion constant for diffusion of gas A into the pore gas (cm²/s)
- t = time (s)
- Θ_T = total porosity (dimensionless)
- α_A = a production term for substance A [mole/cm³ of medium/s].

In addition to the measurable parameters τ , Θ_D , D_A , and Θ_T , Equation 8.3.5.13-28 contains five quantities that must be calculated from other models: q_L , q_g , $\partial C_A^*/\partial t$, $\partial \bar{C}_A/\partial t$, and α_A . The production term α_A will, for carbon-14 originating from a repository, be obtained from waste-package models that will not be discussed here. The interphase transfer terms ($\partial C_A^*/\partial t$ and $\partial \bar{C}_A/\partial t$) depend on C_A , and if species A is total carbon dioxide the

relationship is nonlinear. The chemical models describing this relationship must therefore be incorporated into the transport model.

Since liquid-phase advection is almost certainly negligible for carbon species at Yucca Mountain, the second term on the left-hand side of the equation, involving q_L , can be dropped.

The gas advection velocity q_g at any point depends on the gas density throughout the mountain; the gas density depends on temperature and on the partial pressures of water vapor (which, in turn, depends on temperature because the relative humidity of pore gas is always close to 100 percent) and carbon dioxide. Both of these gases are more concentrated in unsaturated-zone gases than in the atmosphere; water vapor is lighter than air and carbon dioxide is heavier. Temperature differences between the mountain interior and the outside arise from the damping out of daily and annual temperature variations in the subsurface, the geothermal gradient, and the heat source in the repository. The first two of these factors, combined with the topographic relief of the mountain, induce a nonnegligible air flow under existing conditions (Weeks, 1986; Kipp, 1986). Another, steadier component of air flow will be induced by repository heating and continue until the rock temperature throughout the mountain has returned to its initial temperature. The relative magnitude of these flows is unknown.

Steady air flows, such as those due to repository heating or mean humidity differences between pore gas and atmosphere, are incorporated into Equation 8.3.5.13-28 through the q_g term. The best manner of treating oscillating flows due to daily and annual temperature variations is uncertain; rather than calculating a varying q_g , it may be easier to treat these flows as a mixing process and replace the effective molecular diffusion constant (τD_A) with a mixing constant (D^*), which varies from place to place.

Fortunately, it is possible at Yucca Mountain to decouple air-flow and carbon-dioxide-transport models and solve the air-flow problems without reference to CO_2 . The advection velocity q_g is essentially independent of carbon dioxide concentration because humidity and temperature effects are much greater than the density changes associated with variations in CO_2 partial pressures.

Equation 8.3.5.13-28 requires two boundary conditions, one at the water table and the other at or near the surface. Because the production of carbon dioxide by plant roots is large and difficult to quantify, it will probably be more convenient to locate the upper boundary at the base of the root zone rather than the surface. As for the lower boundary, Thorstenson et al. (1983) found that an assumption of chemical equilibrium between pore gas just above the water table and water just below it frequently is not borne out. Very likely, it will not be possible to develop mechanistic models of carbon dioxide fluxes at the boundaries, and concentrations there will simply have to be set to measured values.

The quantity that must be calculated to determine regulatory compliance is not the concentration C_A , but the integral of the net flux to the accessible environment over the area of the repository and over a 10,000 yr

period following closure. The mass flux of species A, which will be denoted q_A , can be computed from solutions to Equation 8.3.5.13-28 as

$$q_A = q_g C_A + q_L C_A^* - \tau \Theta_D \frac{\partial C_A}{\partial x} \quad (8.3.5.13-29)$$

Note that in the sign convention used here, the fluxes (q) are positive downward.

Solution of Equation 8.3.5.13-28 requires that formulae be derived for the time derivatives of the quantities C^* and C_A , representing the concentrations of species A in the liquid and solid phases. Because the species of interest are total carbon dioxide and carbon-14, these derivatives will be equal to the rates of carbon-dioxide dissolution and carbonate mineral precipitation. The rates of these reactions will be determined by the carbonate chemistry of the system. Unfortunately, existing data are not adequate to identify a unique chemical model. The model needed for resolving Issue 1.1 will be developed as part of an investigation in the NNWSI Project geochemistry program (Section 8.3.1.3.8).

A model for concentrations of total carbon dioxide is a prerequisite for predicting transport of carbon-14 for two reasons:

1. The equation for carbon-14 transport will contain parameters depending on concentrations of total carbon dioxide and bicarbonate.
2. The success of a model in explaining currently observed carbon-dioxide concentrations is a valuable test of its validity.

To apply the transport Equation 8.3.5.13-28 to total carbon dioxide, one needs formulae for the rates of change in the dissolved bicarbonate concentration C^* and the solid calcite concentration $\bar{C}$. These two quantities will be addressed in an investigation in the NNWSI Project geochemistry program (Section 8.3.1.3.8).

Two equations are needed to describe the aqueous and solid carbon-14 concentrations. Here, the concentrations and partial pressures of total carbon dioxide are denoted as C_T and P_T , respectively, and the concentration and partial pressures of carbon-14 dioxide are denoted as C_{14} and P_{14} .

The liquid and gas phases are intimately mixed, and both gas molecules and dissolved ions are very mobile. The chemical reactions are rapid, and isotopic fractionation factors between gas and aqueous-phase species and among aqueous-phase species in the carbonate system are all very close to unity. Consequently, isotopic equilibrium can be expected between gas-phase carbon dioxide and dissolved bicarbonate. This gives the equation

$$\frac{C_{14}^*}{C_T^*} = \frac{P_{14}}{P_T} \quad (8.3.5.13-30A)$$

Carbon atoms in solid calcite are much less mobile. At least as a first approximation, they may be thought of as a reservoir of "dead" carbon with no carbon-14 content. In this case, we can write equations not for the solid

concentration C , but for its time derivative. Different equations are obtained for the cases of net precipitation and net dissolution:

$$\frac{\partial \bar{C}_{14}}{\partial t} = \frac{P_{14}}{P_T}, \text{ for } \frac{\partial \bar{C}_T}{\partial t} > 0 \quad (8.3.5.13-30B)$$

$$\frac{\partial \bar{C}_{14}}{\partial t} = 0, \text{ for } \frac{\partial \bar{C}_T}{\partial t} < 0 \quad (8.3.5.13-30C)$$

Equation 8.3.5.13-30C for net dissolution rests on the assumption that there has been no precipitation in the relatively recent past (intervals of a few times the half-life of 5,730 yr). If a period of precipitation followed by dissolution within the next 10,000 yr is predicted, some carbon-14 would be released from the dissolving calcite and a different equation would have to be used instead of Equation 8.3.5.13-30C.

If Equation 8.3.5.13-28 for transport of total carbon can be solved without regard for carbon-14, substitution of that solution along with Equations 8.3.5.13-30 and 8.3.5.13-28 for carbon-14 will yield a linear equation for carbon-14 transport. This will indeed be the case. Natural carbon-14 abundances are on the order of one part in 10^{14} . The carbon-14 in the repository will be considerably more abundant, but still negligible compared with the carbon in impinging water and soil gas. Even a relatively high estimate of the repository carbon-14 inventory at 10^5 Ci (van Koynnenburg et al., 1985) only places about 22 kg of carbon-14 in the repository. It should be noted that less than 1% of the 22kg inventory of C-14 may become available for gaseous release. By comparison, if the disturbed zone around the repository has a thickness of 100 m, an area of 6 km, a drained porosity of 0.1, and a CO_2 partial pressure of 0.1 percent by volume, it will contain approximately $23,000$ kg of carbon in the gas phase, and even more carbon will be present as dissolved bicarbonate.

Disturbed case (A-1): direct release in basaltic volcanism

The consequences of basaltic volcanism on a waste-disposal site at Yucca Mountain were thoroughly studied some five years ago (Link et al., 1982) before reference repository host rock and inventories for the presently proposed site at Yucca Mountain were conceived. Many of the insights from this study are still relevant, however, and can be used as background for the discussion of this scenario class.

"The formation of the basic Basin and Range topography of the (Yucca Mountain site) has been punctuated throughout Tertiary and Quaternary time by volcanism. In fact, (the site) is an up-faulted block made up of at least 6,000 feet of tuff, a volcanic rock. Only basaltic volcanism (dike-fed cinder cones) is known to have occurred during Quaternary time in the region surrounding the (site)." (Link et al., 1982)

During eruption, cinder cones like the ones near the Yucca Mountain site are usually characterized by a pulsating columnar eruption of jets of gas and lava fragments. At repository depths, cones are fed by vertical, tabular magma bodies called dikes.

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"Geometric arguments suggest that if a tabular dike intersects the repository, it would most likely intercept about seven spent fuel canisters.... Other positions or lengths of penetration of the dike in the repository could result in the interception of as few as zero canisters or as many as 448 spent fuel canisters.... Because there is no information available on the possible interaction between a waste canister and a basaltic dike, all waste in each canister was assumed to be released into the magma.... If waste were entrained by magma, some of it would be released by the eruption column in the form of fine particles." (Link et al., 1982)

Using these insights about basaltic volcanism, one can make a rough estimate of the expected partial performance parameter (EPPM) for this scenario class. It is assumed that (1) the surface projection of the area bounded by the perimeter drift, and extensions, is 5.1 km^2 ; (2) a tabular feeder dike passes through the center of the area bounded by the perimeter drift, and extensions, and has dimensions 1 m by 3 km (i.e., $3 \times 10^{-3} \text{ km}^2$ area); (3) there are 18,000 waste packages uniformly distributed over the area bounded by the perimeter drift, and extensions, with radionuclide inventory given in columns 1 and 3 of Table 8.3.5.13-6; and (4) any waste packages intercepted by the feeder dike are immediately ejected through the cinder cone. The perimeter drift is the boundary of the primary repository area and extensions; the surface projection is the vertical projection of the primary repository area and extensions onto the ground surface.

Geometric argument shows that 11 waste packages are intercepted in this case. One can estimate a bound on the consequences for release to the accessible environment for this case using Equation 8.3.5.13-19, that is,

$$M \leq \frac{N}{N_T} \sum_i \frac{a_i}{L_i} = 104 \quad (8.3.5.13-31)$$

where $N = 11$, $N_T = 18,000$, and the sum over the index i of $\frac{a_i}{L_i}$ is computed at the bottom of column 5 of Table 8.3.5.13-6. If $4 \times 10^{-8}/\text{yr}$ (Crowe et al, 1982) is taken as the upper-bound estimate of the annual probability of occurrence of basaltic volcanism in the area bounded by the perimeter drift, and extensions, it is found that the probability of such an event occurring once in a 10,000-yr period is 4×10^{-4} , the probability of more than one occurrence is negligible, and that the expected consequence (the EPPM estimate) is

$$\text{EPPM} \sim 104 \times 4 \times 10^{-4} = 4.16 \times 10^{-2}$$

Note that this is not an upper bound because the size of the feeder dike was arbitrarily assumed. A more realistic calculation that takes into account the decay of the waste inventory, the distribution in sizes of feeder dikes, and the distribution of waiting times until occurrence of basaltic volcanism can easily be made once the values of performance parameters for the scenario are known.

Disturbed case (A-2): Direct release via human intrusion

Many scenarios involving human intrusion at Yucca Mountain can be imagined, but for this document consideration is restricted to the events cited in the list of potentially adverse conditions (PACs) (10 CFR 60.122(c)(2)). This list mentions some of the human activities that could adversely affect ground-water flow systems, namely (1) ground-water withdrawal, (2) extensive irrigation, (3) subsurface injection of fluids, (4) underground pumped storage, (5) military activity, and (6) construction of large-scale surface water impoundments. In considering the potential effects of future activities of these kinds, the DOE has assumed that none could credibly occur within the boundaries of the controlled area (the area to be delimited by long-lasting markers); however, the possibility of some circumspect exploratory drilling within the controlled area is allowed.

Scenarios involving activities (2) and (6) will be incorporated in the discussions of scenario classes C and D, which involve local or repository-wide flooding from sources above the repository (C) and effects on the saturated zone (D); neither of these activities could logically lead to direct releases of radionuclides to the accessible environment in the context of Yucca Mountain.

Activity 1, ground-water withdrawal, could lead to either direct or indirect releases. Direct releases would occur through the pumping to the surface of saturated-zone ground water that has become contaminated with radionuclides from the repository. This situation is of concern for the ground-water protection rule addressed by Issue 1.3 (Section 8.3.5.15). Indirect releases could be linked to changes in ground-water velocities in the saturated zone through changes in head gradients caused by water withdrawal. Given the long transport times through the unsaturated zone that are predicted for the nominal case (less than 1 percent of calculated ground-water travel times are less than 10,000 yr (Sinnock et al., 1986)), the consequences of direct release through ground-water withdrawal appear to be miniscule and can probably be ignored. The consequences of indirect release through alterations in the head gradients of the saturated zone can also probably be ignored, but in any case are amenable to quantification using models for failure of the saturated-zone barriers (scenario class D in Table 8.3.5.13-3).

This leaves the essentially underground activities (3, 4, and 5), which, along with other underground activities in the controlled area not mentioned in the potentially adverse condition (PAC) list (e.g., underground exploration for economic and scientific purposes), would logically be preceded by some kind of investigations from the surface. Consistent with the PAC list's context of late 20th-century socioeconomic needs and technology, the most likely method of exploration from the surface would be the drilling of boreholes. It is recognized that, in principle, other human activities could be important. However, the DOE's judgment is that the assumptions specified with regard to human activities in the definition of significant events and processes in the proposed amendments to 10 CFR 60.2 (and given in the regulatory background for this discussion) limit those that should, in fact, be considered. In the remainder of this discussion, an upper-bound estimate of

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the expected partial performance measures (EPPM) for such inadvertent exploratory drilling will be made. The scenario assumptions are given in the following paragraphs.

It is assumed that Yucca Mountain could become the site of many episodes of exploratory drilling during the 10,000-yr period following closure. Each episode is presumed to follow a period in which markers for the controlled area (as defined by the NRC in 10 CFR 60.2) have either disappeared or become unreadable, and records and knowledge of previous exploratory efforts are lost. During each episode, there is the possibility that deep drilling on the site will accidentally graze or penetrate a waste package, resulting in radioactive material being brought to the surface along with core. The activity of this material would thus contribute to the cumulative release to the accessible environment that is the focus of proposed amendments to 10 CFR 60.112. Depending on the time of an episode after closure and the depth of drilling in the unsaturated zone, some radioactivity could be brought to the surface in the pore water of cores from those boreholes that do not graze a waste package. This contribution is not considered in the present analysis, but it could be considered in future analyses, given the same kinds of data as will be required for a complete analysis of the present scenario class (A-1) and the nominal case (E).

It is assumed that 18,000 waste packages, each containing 3.89 MTHM of spent fuel, are uniformly distributed throughout the area bounded by the perimeter drift, and extensions, in the Topopah Spring (TS) unit, (Figure 8.3.5.13-2). The bounded area is 1,260 acres (510 ha, or 5.1 km²). The waste packages are cylindrical with an internal diameter of 68 cm and internal length of 4.3 m; the analysis below will treat both vertical and horizontal placement of waste packages. Waste composition of each package is given in Table 6-47 of DOE (1986b). To bound the EPPM estimate, it is assumed that a 100-yr-old waste inventory prevails during every exploratory episode and that the rate of penetration over the 10,000-yr period is constant and equal to 0.0003/km²yr (this rate of drilling is specified by the EPA in 40 CFR Part 191, Appendix B as a maximum rate of penetration at sites containing nonsedimentary rock). It is also assumed that each penetration passes through the TS unit and that the drill-bit diameter is constant and equal to 6 cm.

Given that the entire thickness of the TS unit under the surface projection of the perimeter drift and extensions is vertically penetrated by the drill-bit, the probability that a waste package is at least grazed by any one drill-bit is:

$$p = \begin{cases} .0125 & \text{(horizontal emplacement)} \\ .00152 & \text{(vertical emplacement)} \end{cases}$$

This probability is equal to the ratio of the total effective intercept area of the 18,000 packages to the area bounded by the perimeter drift and extensions. The effective intercept area/package is just the projected area/package plus the area of a 3-cm-thick border around the projected area. At the given upper limit on the rate of penetration of the site (3×10^{-4} /km²yr), one expects about 15 penetrations in 10,000 yr. Given $N_{th} = 15$ tries, the expected value of curies brought to the surface on the n^{th} try ($n = 1, 2, 3, \dots, N$) is $C_i(n)p$, where $C_i(n)$ is the expected curies, in the form of the

i^{th} nuclide species, intercepted by the drill bit on the n^{th} try. Note that this quantity would have to be estimated by simulation, taking into account the change in waste-package nuclide inventory with time. For purposes of this bounding calculation, we introduce $C_i(\text{max})$, the maximum curies that could be intercepted by a drill bit in any try; thus, the expected value of curies brought to the surface in N tries is

$$\bar{Q}_i = \sum_{n=1}^N C_i(n)p \leq NpC_i(\text{max}) \quad (8.3.5.13-32)$$

and the expectation of the performance measure for this scenario class is

$$\bar{M} = \sum_i \frac{\bar{Q}_i}{L_i} \leq Np \sum_i \frac{C_i(\text{max})}{L_i} \quad (8.3.5.13-33)$$

The quantity on the right side of the above inequality is an upper-bound estimate of the expected partial performance measure (EPPM) for this scenario class. The sum on the right side is calculated in Table 8.3.5.13-7. Using the values of N and p given above it is found that

$$\bar{M} < \begin{cases} 7.66 \times 10^{-4} & (\text{vertical}) \\ 9.92 \times 10^{-4} & (\text{horizontal}) \end{cases}$$

This upper-bound estimate should be compared with the estimate of the EPPM for nominal-case releases along water pathways, about 2×10^{-7} (Table 4 in Sinnock et al., 1986).

Disturbed case (C-1): Increased flux through unsaturated zone

Some of the initiating events or processes causing an increased percolation flux through the unsaturated zone (UZ) and a consequent decrease in radionuclide transport times through the UZ are the following:

1. Climatic change causes increase in infiltration over controlled area (C-area).
2. Offset on faults creates surface-water impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds.
3. Volcanic eruption causes flows or other changes in topography that result in surface-water impoundments or diversion of drainage.
4. Igneous intrusions, such as a sill, that could result in a change in flux.
5. Tectonic folding changes the dip of tuff beds in C-area, thereby changing flux.
6. Uplift or subsidence changes drainage, thereby changing flux.
7. Subsidence of the mined repository creates surface-water impoundments or diverts drainage.

Table 8.3.5.13-7. Maximum radioactivity (in curies) released in a single exploratory drilling at the Yucca Mountain site

Species ^a	Inventory ^b (Ci/MTHM)	Maximum radioactivity in 6-cm-dia core, C _i (max) (Ci)		Limit, L _i ^c (Ci) _i	C _i (max)/L _i	
		Horizontal	Vertical		Horizontal	Vertical
		emplacement	emplacement		emplacement	emplacement
Am-241	3.5 x 10 ³	16.7	106	7,000	2.39 x 10 ⁻³	1.51 x 10 ⁻²
Pu-241	1.0 x 10 ³	4.78	30.4	7,000	6.83 x 10 ⁻⁴	4.34 x 10 ⁻³
Pu-240	4.5 x 10 ²	2.15	13.7	7,000	3.07 x 10 ⁻⁴	1.96 x 10 ⁻³
Pu-239	2.9 x 10 ²	1.39	8.84	7,000	1.99 x 10 ⁻⁴	1.26 x 10 ⁻³
Pu-238	1.0 x 10 ³	4.78	30.4	7,000	6.83 x 10 ⁻⁴	4.34 x 10 ⁻³
Cs-137	9.4 x 10 ³	44.9	286	70,000	6.41 x 10 ⁻⁴	4.09 x 10 ⁻³
Sr-90	5.7 x 10 ³	27.2	173	70,000	3.89 x 10 ⁻⁴	2.47 x 10 ⁻³
	Subtotal	102	648			
	Contributions from other species	0.42	3			
	Totals	102	651		5.29 x 10 ⁻³	3.36 x 10 ⁻²

^aThe seven radionuclides listed contribute more than 99 percent of maximum radioactivity in core; refer to column 3.

^b100-yr-old spent fuel. Source: Tables 3.3.8, 3.3.9, and 3.3.10 in DOE (1979).

^cEPA limit on 10,000-yr releases for 70,000 MTHM of spent fuel (40 CFR Part 191).

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8. Natural surface-water impoundments are formed over access shafts connecting surface and repository.
9. Extensive irrigation is conducted near the C-area.
10. Large-scale surface-water impoundments are constructed near the C-area.

Of these events and processes, climatic change is probably the agent with the most potential for increasing local and repository-wide flux levels. The diversion of drainage from down-dip flow attending an episodic offset along a fault passing through the repository could also substantially increase local flux and, as a consequence, place a limited number of waste packages in pathways to the water table along which the UZ transport times are short relative to the mean transport times of the nominal case. The other initiating events or processes appearing in the above list will probably prove to have consequences that are indistinguishable from nominal-case consequences. In particular, those events or processes leading to floods over the C-area will probably have very long hydraulic-response times, and thus near-zero consequences. This belief stems from preliminary calculations of flooding that show response times of thousands of years. There is also a small number of waste packages that would be intercepted by the "plume" of a flooding event, and a negligible reduction in UZ transport time would be caused by the slight increase in flux that attends a flooding event.

Disturbed case (C-2): Foreshortening of the unsaturated zone

Initiating events and processes that could lead to a decrease in the effective thickness of the unsaturated zone (UZ) and a consequent decrease in radionuclide transport times through the UZ are the following:

1. Climatic change causes an increase in altitude of water table.
2. Igneous intrusion causes a flow barrier or thermal effects that alter water-table level.
3. Offset on fault juxtaposes transmissive and non-transmissive units, resulting in either the creation of a perched aquifer or a rise in water table.
4. Episodic changes in strain in the rock mass due to faulting cause changes in water-table level.
5. Folding, uplift, or subsidence lowers repository with respect to water table.
6. Extensive irrigation is conducted near the C-area.
7. Large-scale surface-water impoundments are constructed near the C-area.
8. Extensive surface or subsurface mining occurs near C-area.
9. Extensive ground-water withdrawal occurs near C-area.

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Of these events and processes, climatic change is again believed to be the agent with the most potential for increasing the elevation of the water table under the C-area; Czarnecki (1985) used a regional hydrologic model (Czarnecki and Waddell, 1984) and extremely conservative assumptions about the effects of climatic change on ground water systems to show that water-table elevations might rise by as much as 130 m in the future. The effect of changed offset along faults on saturated-zone transmissivity may also be important in determining water-table elevations. Barr and Miller (1987) have used the ISOQUAD code (Pinder, 1976) to explore the effects of abrupt alterations of saturated-zone (SZ) features presumed to control the distribution of hydraulic heads. For example, they assumed a fault-controlled model with sudden leakage across the Solitario Canyon fault and predicted rises in the water-table altitude under the C-area of 30 m with hydrodynamic response times of about 115 yr. A connection between fault motion and changes in leakage across that fault has not been firmly established. Hence, the calculations of Barr and Miller (1987) should be viewed as a worst-case calculation.

The other initiating events or processes appearing in the list will probably prove to have consequences indistinguishable from nominal-case consequences, or even have positive effects such as the lowering of the water-table level through ground-water withdrawals or mine dewatering. In any case, these beliefs need to be confirmed by quantitatively screening the consequences of realization of each of the initiating events or processes shown in the list.

Disturbed case (C-3): Altered UZ rock-properties and geochemistry

Initiating events and processes that could alter rock-hydrologic properties and geochemical conditions in the UZ in such a way as to decrease radionuclide transport times through the UZ are the following:

1. Igneous intrusions cause changes in rock hydrologic properties.
2. Igneous intrusions cause changes in rock geochemical properties.
3. Episodic offset on faults causes local changes in rock hydrologic properties, thereby destroying existing barriers to flow or creating new conduits for drainage.
4. Offset on a fault causes changes in movement of ground water, resulting in mineralogical changes along the fault zone.
5. Offset on a fault changes radionuclide travel pathway to one with different geochemical properties.
6. Changes in stress or strain in C-area resulting from episodic faulting, folding, or uplift cause changes in the hydrologic properties of the rock mass.
7. Tectonic processes cause changes in ground-water table or movement that results in mineralogical changes in C-area.
8. Extensive irrigation is conducted near C-area.

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9. Large-scale surface-water impoundments are constructed near the C-area.
10. Extensive surface or subsurface mining occurs near C-area.

Acting alone, none of these events or processes are currently believed to be capable of leading to consequences distinguishable from undisturbed-case consequences; nevertheless, this belief needs to be confirmed by a quantitative screening of consequences.

Disturbed case (D-1): Foreshortening of flow paths in the saturated zone

Initiating events and processes that could lead to the appearance of surficial discharge points within the C-area, thereby shortening radionuclide travel times through the SZ to the accessible environment, are the following:

1. Climatic change causes appearance of surficial discharge points within C-area.
2. Igneous intrusions cause flow barrier or thermal effects that alter water-table level.
3. Offset on fault juxtaposes transmissive and non-transmissive units, resulting in either the creation of a perched aquifer or a rise in the water table.
4. Episodic changes in strain in the rock mass due to faulting causes changes in water-table level.
5. Folding, uplift, or subsidence lowers repository with respect to water table.

Climatic change is believed to be the only credible cause of a water-table rise sufficient to create long-term surficial discharge points. Even so, a consideration of the minimum distances between the current water table and the surface levels apparent within recently proposed boundaries for the C-area (Rautman et al., 1987) shows that water-table rises greater than 160 m would be required to create new discharge points. The appearance of surficial discharge points within the C-area is not the only way by which the saturated zone (SZ) could be foreshortened. Changes in the horizontal component of the gradient of the SZ head contours could also lead to decreases in the means and increases in the variances of the radionuclide transport times (changes in the vertical components of the SZ head contours, i.e., changes in the magnitude of the linear water velocity through the SZ, are included in scenario class D-2). It is interesting that this latter effect depends upon the definition of the boundaries of the C-area that is ultimately adopted. The effect has not been considered in the choice of initiating events and processes in the preceding list.

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Disturbed case (D-2): Altered SZ head gradients, rock hydrologic properties, and geochemistry

Initiating events and processes that could lead to adverse alterations of the saturated zone (SZ) vertical head-gradients, or SZ rock hydrologic properties, or SZ geochemistry are the following:

1. Climatic change causes an increase in the hydraulic gradients of the water table within the C-area.
2. Igneous intrusion causes flow barriers or thermal effects that alter water table (or hydraulic gradients).
3. 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).
4. Extensive irrigation is conducted near C-area.
5. Large scale surface-water impoundments are constructed near the C-area.
6. Extensive surface or subsurface mining occurs near C-area.
7. Extensive ground-water withdrawal occurs near C-area.

"Adverse" alterations means changes that could decrease radionuclide transport times in the SZ. Again, the only potentially important cause of adverse alteration in the vertical head gradient is believed to be climatic change. In his most recent calculations, Czarnecki (1985) predicts that a four-fold increase in specific discharge in the SZ could accompany the 130 m water table rise associated with a model of future climatic conditions. Changes in SZ transmissivity associated with fault motion might also have some small effects on radionuclide transport times in the SZ, as shown by Barr and Miller (1987); however, the model effects on transport time of an uncoupled contaminant particle through the SZ observed by Barr and Miller (1987) are probably related more to changes in the horizontal components of the head gradients than in the vertical components. In any case, both climatic change and faulting need to be seriously considered as agents of change in the SZ transport times.

4. A preliminary performance allocation for Issue 1.1

A preliminary performance allocation for this issue is summarized in Table 8.3.5.13-8. Since we are concerned with the total system and performance measures for the total system, it is appropriate to allocate performance against those perceived events and processes to which the total system must respond. Column 1 of Table 8.3.5.13-8 lists the eight potentially significant scenario classes identified in Table 8.3.5.13-3. Column 2 indicates the mode(s) of the release (or release pathway) corresponding to each scenario class. For reasons mentioned in the background material on gas-phase releases, the gas pathway is considered important only for the nominal case (E). Column 3 shows a preliminary assessment of the barriers on which primary reliance may be placed in meeting the performance goal listed in

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

Release scenario class	Pathway	System elements		Primary processes or conditions	Performance measure ^c (EPPM)	Tentative goal	Needed confidence
		Primary barriers ^a	Primary barrier components ^b				
NOMINAL CASE							
E	Water	Unsaturated zone; saturated zone, EBS 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	Direct	(No allocation: see text for explanation)			EPPM	< 0.1	High
A-2					EPPM	< 0.1	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 (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 processes or conditions	Performance measure (EPPM) ^c	Tentative goal	Needed confidence
		Primary barriers ^a	Primary barrier components ^b				
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

^aEBS = engineered barrier system.

^bAE = accessible environment.

^cMaximum EPPM for each event/process associated with scenario/class (see subsection on discussion of issue-resolution strategy for Issue 1.1).

column 6; possible backup barriers are also indicated. Column 4 shows the component(s) of the primary barrier that are believed to contribute most to the achievement of the performance goal; column 5 gives the reason for the assignment of a primary barrier in the form of the processes or conditions that may ensure the achievement of the performance goal. Column 6 shows the performance measure for each scenario class, the expected partial performance measure (EPPM), and column 7 shows a goal for that measure; column 8 shows the needed confidence that this goal be met. It must be emphasized that these measures of confidence are subjective, since models to calculate the EPPMs for all scenario classes are not yet available, and considerable judgment has been used in making assignments in columns 7 and 8.

Except for the gas pathway in the first scenario class of Table 8.3.5.13-8, all entries in column 7 were made using the assumption that fractional release rates of radionuclides from the engineered barrier system (EBS) would not exceed the 10 CFR Part 60 limit of 0.00001 parts per year of the 1,000-yr inventory. This may be an unrealistic assumption for the highly soluble compounds associated with carbon, technetium, and iodine.

It is not possible to allocate performance of the total system for the direct-release scenario classes (A-1 and A-2 in Table 8.3.5.13-3). However, the estimates of the EPPMs for these scenarios that are in column 7 of Table 8.3.5.13-8 are conservative, particularly if the improbability of short delay times before the occurrence of the initiating events is taken into account. The delay-time probabilities have also been factored into the assignments in columns 7 and 8 for some of the water-pathway scenario classes (C-1, C-2, D-1, and D-2).

Tables 8.3.5.13-9 through 8.3.5.13-16 (performance parameter tables) list the parameters needed to evaluate the EPPM for the scenario classes and the goals associated with these parameters. Table 8.3.5.13-17 lists parameters that support the performance parameters in these tables and are needed to evaluate the overall CCDF. The eight performance parameter tables give, for each initiating event or process, the associated "performance measure," "performance parameters," "tentative goals," and confidence ("current" and "needed"). These phrases are explained in general terms in Section 8.1.1. In these tables, the "performance measure" is the EPPM specified in Table 8.3.5.13-8. The "performance parameters" are data and information that are required to calculate or assess values of the EPPM for each scenario class. The "tentative goals" state quantitative or qualitative conditions on the value of a performance parameter. These goals are not criteria that the site repository or other parts of the system must meet; they are merely values which, if met, are likely to lead to achieving the quantitative goal for the EPPM. In the "confidence" columns, "current confidence" is a measure of the confidence on a scale of high (h), medium (m), and low (l), that currently available data and information would suffice to show that the goal for the performance parameter could be met; the "needed confidence" column indicates, on the same scale, an assessment of the confidence needed to establish in a formal licensing action that the goal for the performance parameter has been met.

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 ^c	Needed confidence ^c
EPPM for liquid pathway, unsaturated zone (UZ) barrier only	$\bar{q}_u$ - average flux through R-area UZ	< 0.5 mm/yr	None	M	H
	$\bar{n}_e$ - average effective matrix porosity, R-area UZ	> 0.1	3.9.2.1	L	H
	$\bar{R}_i$ - average chemical retardation factor for i^{th} species	≥ 1	4.1.3.3, 8.3.1.3	H	H
	$\bar{d}_u$ - average thickness of R-area UZ between repository and water table	> 100 m	8.3.5.12, 3.9.1.2	M	H
	r_i - fractional mass release rate from engineered barrier system (EBS) for i^{th} species	< 10^{-4} /yr, all species	7.4.3.1.1, 7.4.3.2.1	L	M
EPPM for liquid pathway, saturated zone (SZ) barrier only ^d	$\bar{q}_s$ - average discharge in SZ under C-area	< 32 mm/yr	None	L	M
	$\bar{n}_f$ - average effective matrix porosity, C-area, SZ	> 0.1	3.9.2.1	L	M

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 pro- viding expected parameter values	Current confidence ^c	Needed confidence ^c
EPPM for liquid pathway, satura- ted zone (SZ) barrier only (continued)	$\bar{R}_i$ - average chemical retardation factor for i^{th} species, C-area, SZ	≥ 1	4.1.3.3, 8.3.1.3	H	M
	$\bar{d}_s$ - average length of flow paths through SZ from C-area to accessible environment boundary	$> 5,000$ m	3.6.4	L	M
	r_i - fractional mass release rate from EBS for i^{th} species	$< 10^{-4}$ /yr, all species	7.4.3.1.1, 7.4.3.2.1	L	M
EPPM for gas path- way	Fraction of total carbon-14 inventory that could be released as carbon-14 dioxide	Fraction $< 10\%$ of inventory at closure	7.4.3.1	L	H

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 pro- viding expected parameter values	Current confidence ^c	Needed confidence ^c
EPPM for gas path- way (continued)	Mean residence time of released carbon-14 dioxide in UZ units	Show resi- dence time > 30,000 yr	None	L	H

^aEPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution functions and significant processes and events.

^bR-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; UZ = unsaturated or partially saturated zone; SZ = saturated zone.

^cL = low, M = medium, and H = high.

^dPerformance 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 ^b	Needed confidence ^b	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	$< 10^{-6}/\text{yr}$	1.5.1	L	H	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	L	M	8.3.1.8.1

^aEPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution function and significant processes and events.

^bL = low, M = medium, and H = high.

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 ^b	Needed confidence ^b	SCP section
EPPM ^c	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	L	M	8.3.1.9.1
		Expected drilling rate (no. of boreholes/km ² yr) in R-area over the next 10,000 yr.	Expected drilling rate $\leq 3 \times 10^{-4}$ / km ² yr	None	L	L	None
		Distribution of depths of exploratory drillings.	No goal	None	L	L	None
		Distribution of diameters of exploratory drill holes.	No goal	None	L	L	None

^aR-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.

^bL = low and M = medium.

^cEPPM = 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 ^b	Needed confidence ^b	SCP section
EPPM ^c	Climatic change causes increase in infiltration over C-area	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 < 5 mm/yr with 67% confidence or more	3.7.1	L	H	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	L	M	8.3.1.8
			Probability of changing dip by >2° in 10,000 yr by faulting	< 10 ⁻⁴ per 10,000 yr	None	L	L	8.3.1.8
			Effect of faulting on flux	Faulting will not affect flux because of low slip rate	None	L	M	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 ⁻⁶ /yr	1.5.1	L	M	8.3.1.8
			Effects of a volcanic event on topography and flow rates	Topographic changes are not enough to affect flux	None	L	L	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 ⁻⁶ /yr	1.5.1	L	H	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	L	L	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	L	L	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 ^b	Needed confidence ^b	SCP section
EPPM	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	L	L	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	L	M	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 $< 25,000 \text{ m}^3/\text{yr}$ would pass through access shafts	3.7.1, 3.7.2	L	M	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	L	M	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	NA	NA	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	NA	NA	8.3.1.9.3

^aTSw = Topopah Spring welded unit; PTn = Paintbrush nonwelded unit.

^bL = low, M = medium, H = high, and NA = not applicable.

^cEPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution functions and significant processes and events.

^dC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

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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 ^a	Tentative parameter goal	SCP section providing expected parameter values	Current confidence ^b	Needed confidence ^b	SCP section
EPPM ^c	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	3.7.1	L	H	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 boundary	<10 ⁻⁵ /yr	1.5.1	L	M	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	L	L	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	L	L	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	L	M	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	L	L	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 ^b	Needed confidence ^b	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	L	L	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	L	L	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	NA	NA	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	NA	NA	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	NA	NA	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	NA	NA	8.3.1.9.3

^aC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

^bL = low, M = medium, H = high, and NA = not applicable.

^cEPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution function and significant processes and events.

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

Performance measure	Initiating event or process ^c	Intermediate performance measure	Performance parameter	Tentative parameter goal	SCP section providing expected parameter value	Current confidence ^a	Needed confidence ^a	SCP section
EPPM ^b	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 boundary	$<10^{-5}/\text{yr}$	1.5.1	L	M	8.3.1.8
			Effects of igneous intrusion on local permeabilities and effective porosities	No significant changes in rock hydrologic properties	None	L	L	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	$<10^{-5}/\text{yr}$	1.5.1	L	M	8.3.1.8
			Effects of igneous intrusions on local rock geochemical properties	Potential changes in mineralogy will not be extensive	None	L	L	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	$<10^{-4}/\text{yr}$	1.3.2.2	L	M	8.3.1.8
			Effects of fault motion on local permeabilities and effective porosities	Change in fracture permeability is less than a factor of 2 and fracture porosity decreases	None	L	M	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	$<10^{-4}/\text{yr}$ per fault	1.3.2.2	L	M	8.3.1.8
			Degree of mineralogic change in fault zone in 10,000 yr	Adverse changes in mineralogy will not occur	None	L	L	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	L	M	8.3.1.8
			Effects of fault offsets on travel pathway	Significant changes will not occur	None	L	L	8.3.1.8

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

Performance measure	Initiating event or process ^c	Intermediate performance measure	Performance parameter	Tentative parameter goal	SCP section providing expected parameter values	Current confidence ^a	Needed confidence ^a	SCP section
EPPM ^b	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	L	L	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	L	L	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	NA	NA	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 artificial lake near C-area in next 10,000 yr	No goal (human activity)	None	NA	NA	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	NA	NA	8.3.1.9.3, 8.3.1.3.7

^aL = low, M = medium, H = high, and NA = not applicable.

^bEPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution functions and significant processes and events.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

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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 ^b	Needed confidence ^b	SCP section
EPPM ^c	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	L	M	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 ⁻⁴ /yr	1.5.1	L	M	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	L	L	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	L	L	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	L	H	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	L	H	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 ⁻⁴ /yr	1.3.2.3	L	L	8.3.1.8

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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 ^b	Needed confidence ^b	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	L	L	8.3.1.8

^aC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

^bL = low, M = medium, H = high, and NA = not applicable.

^cEPPM = 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 ^a	Needed confidence ^a	SCP section
EPPM ^b	Climatic change causes an increase in the gradient of the water table within the C-area ^c	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	Change will be $<2 \times 10^{-3}$	3.7.1	L	M	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	L	M	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	L	L	8.3.1.8
			Thermal effects of igneous intrusions on hydraulic gradients	Gradients change less than a factor of 4	None	L	L	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	L	M	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	L	M	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	NA	NA	8.3.1.9.3
			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	NA	NA	8.3.1.9.3, 8.3.1.3.7

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 ^a	Needed confidence ^a	SCP section
EPPM (continued)	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	NA	NA	8.3.1.9.3
			Expected magnitude of changes in distribution coefficients of SZ units due to presence of an artificial lake near C-area in next 10,000 yr	No goal (human activity)	None	NA	NA	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	NA	NA	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	NA	NA	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 groundwater withdrawal near C-area in next 10,000 yr	No goal (human activity)	None	NA	NA	8.3.1.9.3

^aL = low, M = medium, H = high, and NA = not applicable.

^bEPPM = expected partial performance measure; see subsection on discussion of complementary cumulative distribution functions and significant processes and events.

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		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							
Specific-discharge field in UZ (Klavetter and Peters, 1985); 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

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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		Lateral spa- tial loca- tion where needed ^b	Unit where needed ^c	SCP section pro- viding expected parameter values	Characterization goal ^d	Current confidence ^e	Needed confidence ^e	SCP section
	Description	Modifier							
Coupling factors and radionuclide retarda- tion factors in UZ and SZ (Wilson and Dudley, 1987)	Bulk density	Rock matrix	C-area	All units	1.8.2.2 & 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 constrict- ivity/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 coef- ficients (K _d s)	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 conduc- tivity	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 net- works	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 net- works	C-area	SZ-units	3.6.4	m,v,a	L,L,L	M,M,L	8.3.1.3.3
	Fracture compressi- bility	Fracture net- works	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		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							
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		Lateral spatial location where needed ^b	Unit where needed ^c	SCP section pro- viding expected parameter values	Characterization goal ^d	Current confidence ^e	Needed confidence ^e	SCP section
	Description	Modifier							
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 kil- ograms (or cur- ies) per pack- age for radio- nuclides 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 pack- age 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		Lateral spa- tial loca- tion where needed ^b	Unit where needed ^c	SCP section pro- viding 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)	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 con- ditions; if necessary, as a function of: time since closure, posi- tion in reposi- tory, percola- tion 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 pack- age	Waste form to a gas phase; pre- and post- containment periods; if necessary, as a function of: time since closure, posi- tion 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

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 spa- tial loca- tion where needed ^b	Unit where needed ^c	SCP section pro- viding expected parameter values	Characterisation goal ^d	Current confidence ^e	Needed confidence ^e	SCP section
	Description	Modifier							
Source term - liquid and gas-phase releases from waste packages (continued)	Degradation rates of waste form in the k th kind of waste package	Ambient condi- tions (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
	Maximum concentration of chemical species associated with the i th radionuclide (i.e., solubility limits)	In general, for the radionu- clides listed in Table 8.3.5.13-4, ambient condi- tions	R-area	Host rock	None	m,v	L,L	M,M	8.3.5.10.3

^aUZ = unsaturated or partially saturated zone; SZ = saturated zone.

^bNotation 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 60 definition of controlled area.

^cOvb = 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.

^dNotation 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.

^eL = low, M = medium, H = high, and NA = not applicable.

^fEffective porosity, sometimes called the kinematic porosity (see pp. 24-25 of DeWarsi, 1986).

5. Summary of licensing and issue-resolution strategy for Issue 1.1

A nine-step program for providing the documented analyses and calculations for resolving Issue 1.1 is outlined in the following in-text list:

Step 1. Identify relevant phenomena leading to releases	Generic lists of phenomena potentially leading to releases from a geologic repository (IAEA, 1983a) are used together with site-specific information to single out those phenomena that are relevant to the waste-disposal system being considered.
Step 2. Identify potentially significant events and processes	Relevant phenomena are examined in the light of being possible initiators or promoters of release scenarios. The implications of the site-specific frequencies and magnitudes, insofar as these are known for the integrity of each of the system's barriers, are explored.
Step 3. Identify release scenarios	Events, processes, and conditions identified in step 2 are chained together to form scenarios. The construction of chains is constrained by physical causality and evidence concerning the likelihood of occurrence of events and processes that form the chain (in other words, screening against probability may occur in this step). The result of this step is usually a large number of potential release scenarios.
Step 4. Identify scenario classes	All release scenarios identified in step 3 are examined and, by judgment, assembled in classes, each class being amenable to formulation as a single mathematical model. The result of this step is usually a moderate number of scenario classes that, after being put in mathematical form in step 5, can be screened against consequences in step 6.
Step 5. Construct scenario class models	Mathematical models of the scenario classes identified in step 4 are constructed. The independent variables of each model are those state variables needed to determine initial conditions, boundary conditions, and any time-dependent forcing functions that appear in the scenario class; the dependent variable (the output) of each model is the partial performance measure for the scenario class associated with a particular choice of the class's independent variables.

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- Step 6. Eliminate incon-sequential scenarios Release scenarios or even whole scenario classes may be eliminated from set of exceptional scenarios by screening against relative or absolute consequences. If necessary, the models that survive screening against consequences may be simplified in this step by elimination of insensitive independent variables (sensitivity analyses).
- Step 7. Construct total system Simplified mathematical models resulting from step 6 are implemented by efficient computer codes which can be combined in a single calculational model under the control of a driver routine. The driver routine must provide independent variables for each submodel, direct a simultaneous calculation of the partial performance measure for each submodel, and sum the resulting partial performance measures to obtain a value of the total performance measure, M , for a system; the driver routine must also select independent variables for the submodels by Monte Carlo sampling from the joint probability distribution of state variables for all submodels. The form of the joint probability distribution of state variables, and the ranges of those state variables, will inevitably be determined by judgment. Wherever possible, judgment will be enhanced and supplemented with site specific actuarial data concerning magnitudes and frequencies of the phenomenon that determine the state variables.
- Step 8. Construct an empirical complementary cumulative distribution function (CCDF) The computer-implemented simulator assembled in step 7 is used to generate sample values of the total performance measure M . By repeated sampling, a large number of sample s can be generated and used to construct an empirical CCDF or as a data set to which standard statistical methods for estimating likelihoods with given confidence bounds may be applied.
- Step 9. Document results The logic and data bases supporting the analyses for steps 1 to 4, the rationales for the models developed in steps 5 to 7, and the results of the CCDF calculations in step 8 are all documented and presented as evidence that the proposed waste disposal system will meet the proposed 10 CFR 60.112 and 60.115 requirements, thereby resolving Issue 1.1 (8.3.5.13).

The logic of issue resolution is diagrammed in considerable detail in Figures 8.3.5.13-3A through 8.3.5.13-3G. The list and logic diagrams complement one another and both are shown in enough detail to be self-explanatory. Most of the elements, processes, and factors that appear in the list and logic diagrams are defined and explained in the previous background sections entitled "Construction of a CCDF" and "A preliminary selection of release-scenario classes for Yucca Mountain."

Interrelationships of information needs

Sections 8.3.5.13.2 through 8.3.5.13.5 address the information and tasks needed to complete the nine-step program. Section 8.3.5.13.2 (Information Need 1.1.2) covers the required information and activities for step 5, the construction of scenario-class models. Section 8.3.5.13.4 (Information Need 1.1.4) covers required information and activities for step 6, the screening of scenario classes on the basis of consequences, and for the process of constructing the simplified scenario-class models to be used in completing steps 7 and 8. Finally, Section 8.3.5.13.5 (Information Need 1.1.5) addresses construction of the total-system simulator (step 7) and the empirical CCDF (step 8). The activities and schedules necessary for the preparation of licensing material (step 9) are also addressed in Section 8.3.5.13.5. Section 8.3.5.13.1 (Information Need 1.1.1) is a summary of all data and information called for in Information Needs 1.1.2 (8.3.5.13.2) through 1.1.5 (8.3.5.13.5).

The schedule information provided for information needs in this section includes the sequencing, interrelationships, and relative durations of the activities in the information need. Specific durations and start/finish dates for the activities are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

8.3.5.13.1 Information Need 1.1.1: Site information needed to calculate releases to the accessible environment

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Section 8.3.5.13 (1) discusses the complementary cumulative distribution function (CCDF) and significant processes and events, (2) summarizes the issue resolution strategy, and (3) discusses the performance allocation for Issue 1.1. Applicable support documents include Ross (1986b) (scenario selection), Klavetter and Peters (1986), and Wilson and Dudley (1987) (flow and transport through porous, fractured rock).

Parameters

All information and data requested in this information need are specified in Tables 8.3.5.13-8 through 8.3.5.13-17 and discussed in the text of the preliminary performance allocation.

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Figure 8.3.5.13-3A. Logic diagram for Issue 1.1, Issue Resolution Strategy: Idealized scenario classification and screening.

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Figure 8.3.5.13-3B. Logic diagram for Issue 1.1, Issue Resolution Strategy: Subtree 1—idealized preliminary performance allocation.

CCDF - COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION

83513-3B

Figure 8.3.5.13-3C. Idealized probabilistic calculations and evaluations, logic diagram for Issue 1.1, Issue Resolution Strategy.

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Figure 8.3.5.13-3D. Logic diagram for Issue 1.1, Issue Resolution Strategy: Subtree 2-idealized scenario classification.

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83513-3E

Figure 8.3.5.13-3E. Subtree 3—idealized sequence for constructing a mathematical model of a scenario class logic diagram for Issue 1.1, Issue Resolution Strategy.

83513-3F

Figure 8.3.5.13-3F. Subtree 4—Idealized scenario screening logic diagram for Issue 1.1, Issue Resolution Strategy.

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Figure 8.3.5.13-3G. Subtree 5—Decision to include scenario in Complementary Cumulative Distribution Function calculation logic diagram for Issue 1.1, Issue Resolution Strategy.

Planned performance assessment activities

No performance assessment activities are planned.

8.3.5.13.1.1 Application of results

Site information needed to calculate releases to the accessible environment will be used in Information Needs 1.1.2 through 1.1.5.

8.3.5.13.1.2 Schedule and milestones

No studies, tests, or analyses are identified for Information Need 1.1.1.

8.3.5.13.2 Information Need 1.1.2: A set of potentially significant release scenario classes that address all events and processes that may affect the geologic repository

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Section 8.3.5.13 discusses the interpretation of significant processes and events and disruptive scenarios for the Yucca Mountain repository site. In the in-text list given in the discussion of the issue resolution strategy for Issue 1.1, Step 3 describes the identification of potentially disruptive scenarios and Step 4 describes the identification of scenario classes. Applicable supporting documents include DOE (1986b,a) and Ross (1986a) (preliminary identification of release scenarios).

Parameters

The parameters for this information need are

1. Information and data on, and interpretations of, site-specific phenomena from the NNWSI Project environmental assessment (EA) (DOE, 1986b) and its supporting references and documents.
2. Data and interpretive information to be supplied through the fulfillment of other performance and characterization issues. See Tables 8.3.5.13-9 through 8.3.5.13-17 for performance and supporting parameters.

Logic

All data and interpretive information arising from the resolution of the NNWSI Project site characterization program are potentially relevant to the identification of release-scenario classes at the Yucca Mountain repository

site. But in advance of obtaining these data, and for the purpose of guiding site characterization activities, one must proceed with scenario identification using the data and knowledge bases established during the preparation of the NNWSI Project EA (DOE, 1986b). On the other hand, once site characterization work is well advanced, the interpretations and decisions originally considered for the purpose of initially guiding site characterization activities must be reexamined in the light of new data and information. Accordingly, there are two phases of work toward fulfilling this information need: (1) a preliminary phase in which current data and interpretive information are used to construct potentially significant release scenario classes and (2) a final phase during which the preliminary scenario classes are modified, supplemented, dropped from consideration, or reconsidered if they had been previously dropped but warrant a second examination on the basis of new evidence. The logic of phase 1 is described in the following paragraph.

In the preliminary phase, the phenomena identified in the environmental assessment as being significant at the Yucca Mountain site are compared with generic lists of world-wide natural processes, events, or conditions that have been thought to influence the long-term performance of geologic waste disposal systems (for examples of such lists see Table 2.3.1 in Campbell et al. (1978); or IAEA (1983a)). Those natural processes or events in the generic lists that are either manifestly irrelevant to the context of the Yucca Mountain site (e.g., sea-level rise and glaciation) or have had demonstrably minor effects on site characteristics during the Quaternary (e.g., meteorites, hurricanes, and root penetration) are eliminated as potential ingredients of disruptive scenarios. In a similar fashion, features of the site and the repository design and available estimates of the effects of repository excavation and waste emplacement onsite characteristics are compared with anthropogenic processes and events in the generic lists and eliminated as being either irrelevant (e.g., brine-bubble migration) or insignificant. This elimination process leaves a set of natural and anthropogenic processes and events that, in the absence of further information, may be considered to play roles in changing the nominal performance of the total system (e.g., climatic change, seismic events, volcanic activity, erosion, dissolution of the host rock, undetected geologic features such as mineral resources near the site, subsidence, and permanent thermal changes in rock hydrologic and geochemical properties).

The processes and events that are determined to play potential roles in release scenarios are then subjectively arranged in series, and an attempt is made to discover the effects of realization of each series on the performance of one or more of the isolation barriers for the total system. This part of the analysis is necessarily subjective because the number of series formed in this way could be astronomical if the intuition and knowledge of the analyst is not applied to reduce the number of possibilities to a manageable size. Two nonsubjective principles may, however, be used at this point to guide the formation of the series: (1) the principle of causality (i.e., certain chains of events and processes are not possible because one or more event or process upstream in the chain is logically antecedent to others downstream in the chain) and (2) the fact that long series of events or processes are unlikely to be realized in the 10,000-yr period being considered (e.g., events with even a modest probability--chances of 0.1 or less in a 10,000-yr period--will compose an unlikely series if there are more than four of them in a serial chain). In addition, certain short series of events may be

eliminated on the basis of probability at this point if there is sufficient evidence that the initiating event or guiding process is improbable (in the sense of not exceeding the 0.0001 cutoff probability threshold in 10,000 yr). Using the kinds of reasoning and analyses indicated previously, Ross (1986a) has discovered 84 series of events and processes that could cause or influence releases of radioactivity to the accessible environment that have the potential of adding to nominal-case releases.

As seen from Ross (1986a), the results of the kinds of analyses previously indicated is a large but finite number of sequences of events and processes that must be further organized into scenario classes to efficiently begin construction of the mathematical models of those classes. In turn, the mathematical representations of the scenario classes are necessary to determine each class's consequences and also to enable screening of each class against relative consequences. A preliminary organization of Ross's 84 sequences in scenario classes is shown in Table 8.3.5.13-3.

8.3.5.13.2.1 Performance Assessment Activity 1.1.2.1: Preliminary identification of potentially significant release scenario classes

The objective of this performance assessment activity is to preliminarily identify significant release scenario classes for the purpose of determining data and informational needs that must be supplied by the NNWSI Project site characterization program. This activity includes two subactivities.

8.3.5.13.2.1.1 Subactivity 1.1.2.1.1: Preliminary identification of potentially significant sequences of events and processes at the Yucca Mountain repository site

Objectives

The objective of this subactivity is to identify a set of causally related, apparently probable sequences of events and processes, any member of which, if realized, could cause or influence releases of radioactivity to the accessible environment at the Yucca Mountain site in excess of nominal-case releases.

Parameters

See the general parameters listed previously for Information Need 1.1.2.

Description

See the general logic given previously for Information Need 1.1.2.

8.3.5.13.2.1.2 Subactivity 1.1.2.1.2: Preliminary identification of potentially significant release scenario classes

Objectives

The objective of this subactivity is to preliminarily identify a set of significant release scenario classes for the purpose of determining data and informational needs that must be supplied by the NNWSI Project site characterization program.

Parameters

The parameters for this subactivity are the sequences of events and processes identified in Subactivity 1.1.2.1.1 plus the information, data, interpretations, and calculational models related to site-specific phenomena from the NNWSI Project EA (DOE, 1986b) and its supporting documents.

Description

This subactivity has been completed, and the results are summarized in the section on approach to resolving this issue.

8.3.5.13.2.2 Performance Assessment Activity 1.1.2.2: Final selection of significant release scenario classes to be used in licensing assessments

Objectives

The objective of this performance assessment activity is to use data and information obtained in the NNWSI Project site characterization program to modify, if necessary, the set of significant release scenario classes developed in Activity 1.1.2.1 and in the preliminary phases of work fulfilling Information Needs 1.1.3 and 1.1.4 (Sections 8.3.5.13.3 and 8.3.5.13.4).

Parameters

All data and information that could arise during the site characterization program are potential parameters. The tables in the introductory material of this section give the requested data and information.

Description

Only examples of possible study topics can be given. Work in fulfillment of Information Need 1.5.4 (Section 8.3.5.10.4) may show that release rates of radionuclides from the engineered barrier system are orders of magnitude less than the regulatory rate under unanticipated conditions in the repository. In such a case, certain scenario classes in Table 8.3.5.13-3 would be screened again and possibly eliminated. Work in fulfillment of Information Need 1.1.3 (Section 8.3.5.13.3) and Investigation 8.3.1.5.2 may indirectly indicate that delay times for climatic infiltration pulses are long compared with 10,000 yr. In such a case, certain scenarios in class C-1

in Table 8.3.5.13-3 could be dropped from consideration. Similarly, two-dimensional calculations of transient flow in faulted zones, when combined with predictions of the effects of tectonic activity on hydrologic characteristics (from Investigation 8.3.1.8.3), may indicate that certain scenarios in class C-3 in Table 8.3.5.13-3 can be dropped. On the other hand, the development of evidence that colloids play a significant role in radionuclide transport (in fulfillment of Investigation 8.3.1.3.5) could force a modification of the transport equations used to screen scenario classes in Information Need 1.1.3 (Section 8.3.5.13.3), and a reassessment of all scenario classes involving releases along the water pathways. Finally, the development of evidence for future, inadvertent human activity on or near the site may lead to the reconsideration or augmentation of the direct-release scenario classes such as A-2 in Table 8.3.5.13-3.

8.3.5.13.2.3 Application of results

The preliminary phase of work addressing this information need will be used to guide the construction of the mathematical models of scenario classes during the partial fulfillment of Information Need 1.1.3 (Section 8.3.5.13.3). The tasks of showing that certain conditions mentioned in 10 CFR 60.122 and 10 CFR 960.4 (i.e., erosion and rock dissolution) are neither favorable or unfavorable at the Yucca Mountain site are also regarded as part of the preliminary phase of work in conjunction with the preliminary phase of work addressing Information Need 1.1.3.

The final phase of work addressing this information need will be used in conjunction with the final phase of Information Need 1.1.3 to modify the set of scenario-class models (if necessary) that must be simplified and made numerically efficient in work toward fulfillment of Information Need 1.1.4 (Section 8.3.5.13.4).

8.3.5.13.2.4 Schedule and milestones

The schedule and milestone information for this information need is given in Section 8.3.5.13.5.3, at the end of Information Need 1.1.5 (probabilistic estimates of the radionuclide releases to the accessible environment considering all significant release scenarios).

8.3.5.13.3 Information Need 1.1.3: Calculational models for predicting releases to the accessible environment attending realizations of the potentially significant release-scenario classes

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The introductory discussion of Section 8.3.5.13 develops disruptive scenarios for the Yucca Mountain repository site and addresses the topics of gas-phase releases and calculation of releases through the water pathways.

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In the in-text list under the issue resolution strategy for Issue 1.1, Step 5, discusses the construction of scenario-class models. The supporting documents are DOE (1986b), Sinnock et al. (1986) (calculational models used in Section 6.4.2 of the NNWSI Project EA), and Wilson and Dudley (1987).

Parameters

The parameters of this information need are

1. The release-scenario classes identified in the preliminary phase of work fulfilling Information Need 1.1.2 (Section 8.3.5.13.2).
2. The same rock hydrologic properties that are needed to resolve the ground-water travel time issue (Information Need 1.6.1, Section 8.3.5.12.1), but extended to include rock hydrologic properties for overburden units. See Tables 8.3.5.13-9 and 8.3.5.13-17 and parameters for Information Need 1.6.1 and Investigations 8.3.1.2.2 and 8.3.1.2.3.
3. Data and interpretive information concerning rock and ground-water geochemical properties, with emphasis on the properties of rock units and ground water below the repository horizon; also, the effective retardation of carbon dioxide by isotopic exchange with ground water in the overburden units of the unsaturated zone. See Tables 8.3.5.13-9 and 8.3.5.13-17 and parameters from Investigations 8.3.1.3.4, 8.3.1.3.5, 8.3.1.3.7, and 8.3.1.3.8.
4. Definition of the boundary of the engineered barrier system, and release rates of radionuclides from the engineered barrier system for nominal and disturbed conditions in the repository. See Tables 8.3.5.13-9 and 8.3.5.13-17 and parameters from Information Need 1.5.4 (Section 8.3.5.10).
5. Preliminary estimates of the kind and nature of human-intrusion and magmatic-intrusion events. See Tables 8.3.5.13-10 and 8.3.5.13-11 and parameters from Investigations 8.3.1.8.3 through 8.3.1.8.5 and 8.3.1.9.3.
6. Calculational models of transient flow in the unsaturated and saturated zones capable of predicting time-dependent specific discharge in at least two dimensions. See the introductory material to this section and parameters from Information Need 1.6.2 (Section 8.3.5.12.2).
7. Calculational models of transport of dissolved species in the unsaturated and saturated zones capable of predicting time-dependent mass-flux fields in at least two dimensions. See the introductory material to this section and parameters from Investigation 8.3.1.3.7.
8. Final conceptual models of the unsaturated and saturated zone hydrologic systems. See the introductory material to this section and parameters from Investigations 8.3.1.2.2 and 8.3.1.2.7.

9. Final conceptual models of the unsaturated and saturated zone geochemical systems, including geochemical effects on gas-phase transport. See the introductory material to this section and parameters from Investigations 8.3.1.3.7 and 8.3.1.3.8.

Logic

The release-scenario classes identified in the preliminary phase of work fulfilling Information Need 1.1.2 (item 1 in parameter list) are listed in Table 8.3.5.13-3. Mathematical models of these release-scenario classes are the product of this information need. The models are needed (1) to screen the scenario classes against consequences, and (2) provided that the scenario class survives screening against consequences, to serve as a basis for constructing the simplified mathematical models required for the construction of the complementary cumulative distribution function (CCDF) in fulfillment of Information Need 1.1.5 (Section 8.3.5.13.5). The screening of scenario-class models against relative consequences, and the construction of simplified scenario-class models based on the preliminary models developed in this information need, are studies to be conducted in Information Need 1.1.4 (Section 8.3.5.13.4). There are two phases of work toward the construction of scenario-class models: (1) a preliminary phase in which current data and interpretive information are used to build and test the models, and (2) a final phase in which data and interpretive information arising out of the site characterization program are used to justify modifications or replacements of existing models, or the construction of entirely new models. The logic of phase 1 is emphasized in the discussion that follows.

As shown by the grouping of release-scenario classes in Table 8.3.5.13-3, at least four distinct kinds of models are needed to calculate releases to the accessible environment: (1) those that predict radionuclide releases along water pathways, (2) those that predict gas-phase radionuclide releases, (3) those that predict releases associated with intrusive or extrusive magmatic events, and (4) those that predict direct releases associated with inadvertent human intrusion (here, inadvertent exploratory drilling on the site).

Water-pathway models. The Total System Performance Assessment Code (TOSPAC), which is under development (Klavetter and Peters, 1986), is currently the major "workbench" for the development of the phenomenology of water-pathway models that apply to Yucca Mountain conditions. As implied by its name, the TOSPAC is capable of simulating the static and dynamic response of a one-dimensional conceptual model of the total waste-disposal system at Yucca Mountain. This is done by the coupling of three submodels (or modules): (1) a flow module, that can predict time-dependent, specific-discharge fields in the unsaturated zone given surficial infiltration rates; (2) a source term module, that supplies mass flux or concentrations of liquid-phase radionuclides in the host rock near the repository given radionuclide release rates from the engineered barrier system (EBS); and (3) a transport module that solves the transport equations for coupled matrix-fracture flow (see Equations 8.3.5.13-10 to 8.3.5.13-15 in the introductory material to this section) in the unsaturated zone and computes cumulative releases to the water table, given the flow field from the flow module and the boundary concentrations from the source-term module. The

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TOSPAC currently has no modules for flow or transport through the saturated zone; these phenomena are being investigated with the ISOQUAD code (Pinder, 1976).

In spite of its limitation to one dimension, the TOSPAC can still be used to screen some of the water-pathway release scenarios in Table 8.3.5.13-3 against consequences. The code has already been used to show (1) that transient flooding from surficial sources may have little effect on repository performance and (2) that increases in fracture density will have no effect on repository performance in the absence of extreme climatic changes. Items 1 through 4 in the parameter list will be needed to provide a rock-property data set for these TOSPAC calculations. The screening of some other water-pathway release scenario classes in Table 8.3.5.13-3, namely in C-1, D-1, and D-2, will definitely require two-dimensional models of flow and transport of the kind mentioned in items 6 and 7 of the parameter list. These two-dimensional models will also be used to validate the phenomenology incorporated in TOSPAC's flow and transport modules (i.e., the neglect of horizontal flow paths and transport along those paths).

It is very likely that the TOSPAC and the phenomenology that it contains will require substantial modification after the "ground truth" of the site characterization program is established. Items 8 and 9 in the parameter list will be required to assess the changes that must be made in the systems-level models.

Models of gas-phase releases. The significance of gas-phase release of carbon-14 has only recently become apparent, and no models for transport of carbon-14 dioxide from the repository through Yucca Mountain overburden units have so far been developed within the NNWSI Project. It is believed that an adequate general theory of carbon-14 transport is presented in the introductory material to this section; however, application of that theory to the Yucca Mountain setting would seem to require considerable study of hydrologic, gas-phase hydraulic, and geochemical properties of the overburden units. For that reason, thought should be given to balancing complexity and cost factors associated with site-characterization studies with complexity and cost factors associated with engineered barrier system performance and design because these factors relate to models of gas-phase, carbon-14 releases. The parameters required by systems-level models for gas-phase transport would include both the effective diffusivity of carbon dioxide and the effective retardation factor for carbon-14 dioxide because of isotopic exchange, each as a function of depth within the overburden units. The latter quantity is requested in item 3 of the parameter list. The effective diffusivity of carbon dioxide might be inferred from final results of experiments being conducted in partial fulfillment of Investigation 8.3.1.2.2. As an alternative to a full transport calculation, a simpler systems-level model of gas-phase releases might be devised; use of this model would require estimates of the mean and standard deviation of residence time of carbon-14 nuclei in the repository overburden. Either modeling technique requires specification of the release rate of carbon-14 dioxide from the EBS, a quantity that is called for in item 4 of the parameter list. It should be noted, however, that release of C-14 is limited at the waste container and at the engineered barrier system boundary to satisfy the requirements in 10 CFR 60.113. Depending on the containment strategies, including alternatives adapted for the waste package, the C-14 source term for the total system may

be significantly changed. For example, if all of the fast fraction of C-14 was released before waste emplacement, no consideration of C-14 transport will be necessary for the total system performance assessment in Issue 1.1.

Models of releases through basaltic volcanism. It is believed that the mathematical model for predicting the consequences of basaltic volcanism developed by Link et al. (1982) can be modified and used to estimate cumulative releases to the accessible environment attending the realization of such events at Yucca Mountain. The work by Link et al. (1982) was specifically applied to the Yucca Mountain, but the conceptual and data bases may be outdated, and a request is made for the most current concepts and data in item 5 of the parameter list.

Models of releases through human intrusion. A calculation of an upper bound to the consequences of inadvertent exploratory drilling on the Yucca Mountain site during the next 10,000 yr is described in the introductory material to this section, along with a brief discussion of other types of human-intrusion scenarios that might be realized at that location. The model implicit in the calculation is easily put into mathematical terms. The state variables for the model include (1) the mean recurrence time between penetrations (current guidance in Appendix B of 40 CFR Part 191 sets a limit on the penetration rate of 0.0003 penetrations/km² per yr), (2) the depth of penetration (and the attending probability distribution), and (3) the diameter of the exploratory drill bit (and its probability distribution). Data required to implement the model, and models of other potential human-intrusion scenario classes, are requested through item 5 in the parameter list.

8.3.5.13.3.1 Performance Assessment Activity 1.1.3.1: Development of mathematical models of the scenario classes

The objective of this performance assessment activity is to construct mathematical models of the scenario classes developed in Information Need 1.1.3 (Section 8.3.5.13.3). Four subactivities are included in this activity. These subactivities describe the models to be developed for this activity.

8.3.5.13.3.1.1 Subactivity 1.1.3.1.1: Development of models for releases along the water pathways

Objectives

The objective of this subactivity is to produce mathematical models whose phenomenology is sufficient (1) to effect a screening of the release scenarios associated with the water pathways with respect to consequences and (2) to form an adequate basis for the simplified models needed to fulfill Information Need 1.1.5 (Section 8.3.5.13.5).

Parameters

The parameters for this subactivity are items 1 to 4 in the general parameter list for Information Need 1.1.3 and preliminary versions of conceptual models referred to in items 8 and 9 of the same general parameter list.

Description

Several systems-level models of releases along the water pathways have already been constructed: the TOSPAC (see Klavetter and Peters, 1986), RELEASE (Sinnock et al., 1986), and SPARTAN (Lin, 1985). The two- and three-dimensional models of flow and transport that could be used to screen scenario classes on the basis of long delays for certain effects are listed in Section 8.3.5.19. The TOSPAC will probably be sufficient to screen scenario classes E and C-2 through C-3 (Table 8.3.5.13-3) if calculations with the multi-dimensional models show that lateral flow paths can be ignored. The screening of scenario class C-1 will require at least a two-dimensional model of transient flow through a faulted zone. Scenario classes D-1 and D-2 can probably be screened with the simple RELEASE code (or modifications of it) if saturated-zone flow fields are provided by the two-dimensional ISOQUAD model. It should be emphasized that effective use of any of these models in the screening of water-pathway scenario classes will definitely require better, site-specific conceptual and data bases. Thus, items 2 and 3 are in the general parameter list.

8.3.5.13.3.1.2 Subactivity 1.1.3.1.2: Development of a model for gas-phase releases

Objectives

The objective of this subactivity is to produce a mathematical model whose phenomenology is sufficient (1) to effect a screening of the release scenario associated with the anticipated gas-phase releases and (2) to form a basis for the simplified model needed to fulfill Information Need 1.1.5.

Parameters

The parameters for this subactivity are items 3 and 4 in the general parameter list for Information Need 1.1.3.

Description

A systems-level model similar to the one described for water-pathway releases in the introductory material to this section may be sufficient to determine the expected partial performance measure (EPPM) for anticipated gas-phase releases, and at the same time be simple enough to use as a scenario-class model in the construction of the complementary cumulative distribution function (CCDF) (Information Need 1.1.5, Section 8.3.5.13.5). This subactivity will thus involve the calibration of one of the parameters of a system-level model (the reciprocal of the mean residence time) with estimates of the actual time for carbon-14 dioxide to diffuse from the

repository level to the surface (from item 4). Other parameters required by the model are supplied through item 3.

8.3.5.13.3.1.3 Subactivity 1.1.3.1.3: Development of a model of releases through basaltic volcanism

Objectives

The objective of this subactivity is to produce a mathematical model whose phenomenology is sufficient (1) to effect a screening of the release scenarios associated with basaltic volcanism and (2) to form an adequate basis for the simplified models needed to fulfill Information Need 1.1.5 (Section 8.3.5.13.5).

Parameters

The parameters for this subactivity are the model of basaltic volcanism proposed by Link et al. (1982) and the updated estimates of the kind and nature of magmatic-intrusion events at Yucca Mountain (item 5 in general parameter list).

Description

The model proposed by Link et al. (1982) will, if necessary, be modified to reflect most recent estimates of the kind and nature of basaltic volcanism to be expected at Yucca Mountain.

8.3.5.13.3.1.4 Subactivity 1.1.3.1.4: Development of a model of releases through human intrusion

Objectives

The objective of this subactivity is to produce mathematical models whose phenomenology is sufficient (1) to effect a screening of the release scenarios associated with inadvertent human intrusion and (2) to form an adequate bases for the simplified models needed to fulfill Information Need 1.1.5 (Section 8.3.5.13.5).

Parameters

The parameters of this subactivity are the model of releases through inadvertent exploratory drilling presented in Section 8.3.5.13 and the preliminary and final assessments of the nature of future human intrusion events at the Yucca Mountain repository site (item 5 in general parameter list).

Description

The model of releases through exploratory drilling presented in the introductory material to this section will be put into mathematical terms.

Depending upon the outcome of the preliminary assessments of potential human-intrusion events, new conceptual models may have to be developed and put into mathematical terms.

8.3.5.13.3.2 Application of results

The mathematical models developed in Activity 1.1.3.1 and their supporting data bases will be used in a study associated with Information Need 1.1.4 (Section 8.3.5.13.4) to screen the release-scenario classes in Table 8.3.5.13-3 against relative consequences. They must also form the basis for activities directed toward model simplification in Information Need 1.1.4, provided that the scenario class is to be included in calculations of the complementary cumulative distribution function (CCDF).

8.3.5.13.3.3 Schedule and milestones

The schedule and milestone information for this information need is given in Section 8.3.5.13.5.3, at the end of Information Need 1.1.5 (probabilistic estimates of the radionuclide releases to the accessible environment considering all significant release scenarios).

8.3.5.13.4 Information Need 1.1.4: Determination of the radionuclide releases to the accessible environment associated with realizations of potentially significant release scenario classes

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The introductory material to this section addresses the interpretation of "significant processes and events." In the in-text list given in the issue resolution strategy subsection of this section, Step 6 discusses the screening of scenario classes on the basis of relative consequences. The supporting documents are DOE (1986b), Sinnock et al. (1986), and Barr and Miller (1987).

Parameters

The parameters of this information need are the mathematical models of the release scenario classes that were developed in Activity 1.1.3.1 (Section 8.3.5.13.3.1) under Information Need 1.1.3 and their supporting data bases.

Logic

The goals of the work fulfilling this information need are twofold: (1) a screening of the release scenario classes in Table 8.3.5.13-3 (and other classes that may be proposed during the site characterization program) against the criterion of relative consequences, and (2) a set of simplified

mathematical models of those release scenario classes that survive the screening process. In simple terms, the release-scenario classes that survive the screening process will be those release-scenario classes that will provide the major contribution to the empirical complementary cumulative distribution function (CCDF) to be constructed during activities fulfilling Information Need 1.1.5 (Section 8.3.5.13.5). As is explained in the logic section of Information Need 1.1.3 (Section 8.3.5.13.3), there are necessarily two phases of work fulfilling the need: a preliminary and a final. There are also at least four distinct kinds of models that need to be considered in the preliminary phase of work.

To meet goal 1 in the preliminary phase, computer-implemented versions of the models developed in fulfillment of Information Need 1.1.3 (Section 8.3.5.13.3) will be used to simulate the general consequences of realizations of members of the scenario classes in Table 8.3.5.13-3, and the results of these simulations will be compared. The comparisons will show which (if any) of the scenario-class members may temporarily be dropped from consideration. The work toward meeting goal 2 in the preliminary phase will then focus upon the models of the scenario classes that survive these comparative studies. Work toward meeting goal 1 in the final phase will proceed in a similar fashion, except that the modified or entirely new models produced in the final phase of work fulfilling Information Need 1.1.3 (if any) and final data bases developed in site characterization work will be used in making the comparisons.

The procedures that may be used to turn a complex mathematical model into a simple one representing the same phenomenology (i.e., one that meets goal 2) are best described in a model-specific context. All such procedures could probably be lumped under the title of "sensitivity studies"; but the reader should recognize that there are at least two kinds of model sensitivity: (1) sensitivity of model output to the kinds and manner of representation of physical phenomena incorporated in the model and (2) the sensitivity of model output to variations in the model's input variables. Model simplification is primarily concerned with the first kind of sensitivity. A mathematical model may initially include kinds and representations of physical phenomenon that later prove inessential. These phenomena can be deleted from the model, thereby effecting a simplification and increasing computational efficiency. In the studies fulfilling this information need, sensitivity of the second kind will generally not be investigated; uncertainties in the model input variables will be taken into account by including them in the construction of the joint probability distribution of the model's state variables (i.e., input parameters) an activity conducted in fulfillment of Information Need 1.1.5 (Section 8.3.5.13.5).

8.3.5.13.4.1 Performance Assessment Activity 1.1.4.1: The screening of potentially significant scenario classes against the criterion of relative consequences

The objective of this performance assessment activity is to identify the set of scenario classes representing the significant events and processes mentioned in proposed 10 CFR 60.112 and 60.115. Two subactivities are included in this activity.

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8.3.5.13.4.1.1 Subactivity 1.1.4.1.1: The screening of the preliminary scenario classes

Objectives

The objective of this subactivity is to identify those scenario classes among the members of the preliminary set (Table 8.3.5.13-3) whose consequences of realization are not significantly different from nominal-case consequences, and therefore may be temporarily dropped from consideration.

Parameters

See the general parameter list for Information Need 1.1.4.

Description

See the general logic and descriptions of Subactivities 1.1.3.1.1 through 1.1.3.1.4 listed in Section 8.3.5.13.3.1.

8.3.5.13.4.1.2 Subactivity 1.1.4.1.2: A final screening of scenario classes

Objectives

The objective of this subactivity is to identify the final scenario classes to be used in constructing the empirical complementary cumulative distribution function (CCDF) during fulfillment of Information Need 1.1.5 (Section 8.3.5.13.5).

Parameters

The parameters for this subactivity are a modified and an amended set of mathematical models produced in the final phase of Subactivities 1.1.3.1.1 to 1.1.3.1.4, plus amended data bases from site characterization work.

Description

See the remarks on the final phase in the general logic section for this information need.

8.3.5.13.4.2 Performance Assessment Activity 1.1.4.2: The provision of simplified, computationally efficient models of the final scenario classes representing the significant processes and events mentioned in proposed 10 CFR 60.112 and 60.115

The objective of this performance assessment activity is to provide the simplified, computationally efficient models of the final scenario classes representing the significant processes and events mentioned in proposed 10 CFR 60.112 and 60.115. Two subactivities are included in this activity.

8.3.5.13.4.2.1 Subactivity 1.1.4.2.1: Preliminary development of simplified, computationally efficient scenario-class models

Objectives

The objective of this subactivity is to construct, as necessary, simple computationally efficient versions of the scenario-class models developed during the Subactivities 1.1.3.1.1 to 1.1.3.1.4 listed in Section 8.3.5.13.3.1.

Parameters

The parameters for this subactivity are the mathematical models developed in Activity 1.1.3.1 of Information Need 1.1.3.

Description

The activities to be conducted depend upon which of the scenario classes survive screening in Subactivity 1.1.4.1.1. If classes E, C-2, or C-3 in Table 8.3.5.13-3 survive, the phenomenology of the existing TOSPAC (in development, but see Klavetter and Peters, 1986) may be amenable to simplifications that preserve the code's ability to represent the essential events and processes of any one of these classes that survive. Simplified, exploratory versions of the TOSPAC have already been tried. See, for instance, the RELEASE model in Sinnock et al. (1986) or the systems-level model proposed in Section 8.3.5.13. These exploratory versions of TOSPAC may also be used to represent classes C-2 or C-3 in Table 8.3.5.13-3 if these classes survive a preliminary screening. The models currently proposed for the screening of the expected-case, gas-phase releases (part of scenario class E) and the direct releases (scenario classes A-1 and A-2), are being developed.

8.3.5.13.4.2.2 Subactivity 1.1.4.2.2: Development of the final, computationally efficient models of the scenario classes that will be used to represent all significant processes and events in the simulation of the total system

Objectives

The objective of this subactivity is to develop the final, computationally efficient models of the scenario classes that will be used to represent the simulation of the total system.

Parameters

The parameters for this subactivity are the scenario classes that survive the final screening of Subactivity 1.1.4.1.1 and the techniques and insight established in Subactivity 1.1.4.2.1.

Description

See the remarks on final phase of work in general logic section of this information need.

8.3.5.13.4.3 Application of results

The set of final, computationally efficient models developed in Activity 1.1.4.2 and their supporting data bases will be used in the construction of the total-system simulator, and calculations of an empirical complementary cumulative distribution function (CCDF) with that simulator, as described in activities of Information Need 1.1.5 (Section 8.3.5.13.5).

8.3.5.13.4.4 Schedule and milestones

The schedule and milestone information for this information need is given in Section 8.3.5.13.5.3, at the end of Information Need 1.1.5 (probabilistic estimates of the radionuclide releases to the accessible environment considering all significant release scenarios).

8.3.5.13.5 Information Need 1.1.5: Probabilistic estimates of the radionuclide releases to the accessible environment considering all significant release scenarios

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Section 8.3.5.13 discusses the regulatory basis for the issue and the construction of the complementary cumulative distribution functions (CCDFs). In the in-text list given in the issue resolution strategy subsection of this section, Step 7 discusses the construction of a total system simulator and Step 8 discusses the construction of an empirical CCDF.

Parameters

The parameters for this information need are

1. Simplified versions of the mathematical models of the significant scenario classes (from Information Need 1.1.4, Section 8.3.5.13.4).
2. Statistical data and interpretive information sufficient to construct the joint probability distribution for the set of state variables that describes all necessary state variables in the simplified mathematical models of the significant scenario classes. See the introductory material to this section and parameters from Tables 8.3.5.13-9 through 8.3.5.13-17.

Logic

The simplified mathematical models provided through fulfillment of Information Need 1.1.4 (Section 8.3.5.13.4) will be implemented by efficient computer codes that are then combined in a single calculational model under the control of a driver routine. The driver routine will (1) provide values for state variables for all submodels through Monte Carlo sampling from the joint distribution of the state variables, (2) direct a calculation of the partial performance measure for each submodel, and (3) sum the resulting partial performance measures for each submodel to obtain a sample value of the total system performance measure. By repeatedly sampling in this way, a large number of sample s can be generated and used to construct an empirical complementary cumulative distribution function or as a data set to which standard statistical methods for estimating likelihoods with given confidence bounds may be applied.

The joint distribution of state variables will be constructed using judgment guided by the site-specific statistical data and interpretive information mentioned in the foregoing parameter list.

8.3.5.13.5.1 Performance Assessment Activity 1.1.5.1: Calculation of an empirical complementary cumulative distribution function

Objectives

The objective of this performance assessment activity is to construct an efficient, total-system simulator that is capable of providing probabilistic estimates of radionuclide releases to the accessible environment, under both nominal and disturbed conditions, for 10,000 yr after closure. Three subactivities are included in this activity.

8.3.5.13.5.1.1 Subactivity 1.1.5.1.1: Construction of the total-system simulator

Objectives

The objective of this subactivity is to construct an efficient, total-system simulator.

Parameters

The parameters for this subactivity are efficient, computer-implemented mathematical models of significant scenario classes (see Information Need 1.1.4, Section 8.3.5.13.4) and a synthetic joint probability distribution for the state variables in all submodels sufficient for testing the operation of the total-system simulator.

Description

A driver routine will be constructed and tested, using submodels and synthetic joint probability distribution. Available variance-reduction techniques will be applied, and the technique most efficient for total-system simulation will be determined.

8.3.5.13.5.1.2 Subactivity 1.1.5.1.2: Construction of the joint probability distribution to be used in the licensing-assessment calculations

Objectives

The objective of this subactivity is to construct a joint probability distribution that incorporates data and interpretive information from the site characterization program.

Parameters

The parameters for this subactivity are given in the parameters list for this information need.

Description

The state variables will be grouped into statistically independent subsets. For each subset of state variables, a multivariate analytical distribution will be chosen, and its parameters fitted by techniques such as maximum-likelihood, using available, site-specific data for the mean annual probabilities and the intensities of the processes and events that determine the state variables.

8.3.5.13.5.1.3 Subactivity 1.1.5.1.3: Construction of an empirical complementary cumulative distribution function for the licensing action

Objectives

The objective of this subactivity is to construct an empirical complementary cumulative distribution function for the licensing application.

Parameters

The parameters for this subactivity are the total-system simulator from Subactivity 1.1.5.1.1 and the joint distribution function from Subactivity 1.1.5.1.2 (Sections 8.3.5.13.5.1.1 and 8.3.5.13.5.1.2).

Description

By repeated simulation, sample statistics on total system performance measure, , will be obtained with a sample size large enough to ensure that proposed 10 CFR 60.112 and 60.115 are (or are not) met with high confidence.

8.3.5.13.5.2 Application of results

The results of fulfilling this information need will be used by the DOE in a licensing application as evidence of compliance with proposed 10 CFR 60.112 and 60.115. Fulfillment of this information need resolves Performance Issue 1.1. There are no other issues or information needs that require the fulfillment of this information need.

8.3.5.13.5.3 Schedule and milestones

This issue consists of five information needs that will acquire data to evaluate if the mined geologic disposal system will meet the system performance objective for limiting radionuclide releases to the accessible environment. The information needs are 1.1.1 (site information needed to calculate releases to the accessible environment), 1.1.2 (potentially significant release scenario classes that address all events and processes that may affect the geologic repository), 1.1.3 (calculational models for predicting releases to the accessible environment attending realizations of the potentially significant release scenario classes), 1.1.4 (determination of radionuclide releases to the accessible environment associated with realizations of potentially significant scenario classes against the criterion of relative consequences), and 1.1.5 (probabilistic estimates of the radionuclide releases to the accessible environment considering all significant release scenarios).

In the figure that follows, the schedule information for this issue is presented in the form of timelines. The timelines extend to the issuance of the final products associated with the information needs. Summary schedule and milestone information for this issue can be found in Section 8.5.2.2.

The analysis and modeling work for this entire issue will proceed in parallel with site activities and will interact with them in an iterative fashion. The conceptual models developed for site investigations are needed to finalize the performance assessment of the total system for the license application.

Completion of the activities in these information needs are constrained by other program elements. Development of conceptual models as part of the site program investigations discussed in Section 8.3.1 and the iterative interaction required with the site programs will constrain the resolution of this issue.

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The information need numbers and titles corresponding to the timelines are shown on the left in the following figure. No studies, tests, or analyses are identified for Information Need 1.1.1; so it is not included in the figure. The points shown on the timelines represent major events or important milestones associated with the information need. Solid lines represent activity durations, and dashed lines show interfaces.

The points on the timeline are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone M126. Report on the data needs for postclosure performance assessment.
2	Milestone P654. Report on the description of preliminary scenario classes to be screened against consequences.
3	Input refined scenario classes to Information Need 1.1.4.
4	Milestone M125. Report on preliminary models of releases through volcanism and human intrusion.
5	Milestone P655. Report on preliminary models of gas-phase releases.

<u>Point number</u>	<u>Description</u>
6	Milestone P086. Report on preliminary systems models of releases through water pathways.
7	Milestone M193. Report on a refined source term model using exploratory shaft and waste package advanced conceptual design information.
8	Complete validation of models and verification of codes in support of the draft environmental impact statement (DEIS).
9	Milestones Z043 and Z075. Reports on the results of screening scenario class models.
10	Milestone Z077. Report on final computationally efficient models to be used in the total system simulator.
11	Milestone Z078. Report on structure of the total system simulator.
12	Milestone Z079. Report on joint probability distributions used in the total system simulator.
13	Milestone N121. Complete interim probability analysis of performance of the total system for input into the DEIS.
14	Output of performance assessment calculations in support of the DEIS.
15	Update of DEIS performance assessment calculations in support of the final environmental impact statement (FEIS) and license application.

Nuclear Waste Policy Act
(Section 113)

Section 83.5.14

Consultation Draft

INDIVIDUAL PROTECTION

Site Characterization Plan

***Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

Volume VII

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U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

8.3.5.14 Issue resolution strategy for Issue 1.2: Will the mined geologic disposal system meet the requirements for limiting individual doses in the accessible environment as required by 40 CFR 191.15?

Regulatory basis for the issue

The relevant parts of 40 CFR 191.15 are quoted in the following:

191.15 Individual protection requirements.

Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 yr after disposal, undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 millirems to the whole body or 75 millirems to any critical organ. All potential pathways (associated with undisturbed performance) from the disposal system to people shall be considered, including the assumption that individuals consume 2 L per day of drinking water from any significant source of ground water outside of the controlled area.

In the regulation just given, undisturbed performance means the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events. The term accessible environment means (1) the atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, and (5) all the lithosphere that is beyond the controlled area, a surface location that encompasses no more than 100 km² and extends horizontally no more than 5 km in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system.

In addition, the regulation (40 CFR 191.12) defines the significant source of ground water to mean:

(1) An aquifer that: (i) Is saturated with water having less than 10,000 milligrams per liter of total dissolved solids; (ii) is within 2,500 feet of the land surface; (iii) has a transmissivity greater than 200 gallons per day per foot, provided that any formation or part of a formation included within the source of ground water has a hydraulic conductivity greater than 2 gallons per day per square foot; and (iv) is capable of continuously yielding at least 10,000 gallons per day to a pumped or flowing well for a period of at least a year; or (2) an aquifer that provides the primary source of water for a community water system as of the effective date of this Subpart.

The expected condition of the repository environment is such that no significant amounts of liquid water will be present in and adjacent to the borehole for at least 300 yr after repository closure. For 300 to 1,000 yr after closure, a limited amount of water (i.e., less than 5 liters per package per year for 90 percent of the packages and less than 20 liters per package per year for 10 percent of the packages) may be available to contact some waste containers, although most of the containers are expected to remain

in a dry environment for well over 1,000 yr (Section 8.3.4). A limited amount of radionuclides, therefore, may be released from breached containers and transported by ground water to the accessible environment.

Three radionuclides might be able to escape from the breached container as gaseous species under the conditions at Yucca Mountain: carbon-14, tritium, and krypton-85. Of these, only carbon-14 is readily available for rapid release from a breached waste container. The other radionuclides, both of which have short half-lives, are contained within the waste form (Sections 8.3.5.9 and 8.3.5.10). Carbon-14 release is expected to be in the form of carbon-14 dioxide that will percolate up through the pore space in the unsaturated overburden to the accessible environment.

Approach to resolving the issue

There are only two significant pathways for the radionuclides from the waste package to reach humans in the accessible environment (i.e., ground-water transport and gas phase transport). These probable flow paths for each transport mechanism lead to quite different and separate exposure sources for any released radionuclides. Therefore, they will be treated separately.

The approach to resolving Issue 1.2 for the ground-water pathway is to determine whether any exposure to the public will result during the 1,000-yr period. No significant source of ground water may exist at the boundary of the controlled area. However, the dose calculation will assume that individuals consume 2 liters per day of drinking water at the outside boundary of the controlled area, where the concentration of radionuclides in ground water could be expected to be the highest. For the gaseous pathway, the reference case will examine whether the upper bounding value of the exposure to the public will be less than 25- and 75-mrem/yr dose limits based on the amount of the carbon-14 inventory that can be released in gaseous form. Alternatively, it may be possible to show that the gaseous carbon-14 dioxide may never reach the accessible environment during the 1,000-yr period. The total dose to the individuals will be the sum of the doses through both pathways and it will be compared against the required dose limits. Figure 8.3.5.14-1 illustrates the objective and logic to resolve Issue 1.2.

Under the undisturbed conditions of the repository, it is expected that most of the waste packages will remain dry and that the radionuclides will be substantially completely contained in the waste package. Under very conservative assumptions, however (described in Section 8.3.5.9), up to 20 percent of the waste containers may be breached and radionuclides may be released and transported in the ground water through the unsaturated and saturated zones before they reach the accessible environment (Section 8.3.5.13). Sorbing species of the radionuclides would travel slower than the ground-water movement because of retardation, and even the nonsorbing species cannot travel faster than the ground-water movement itself along the path of likely radionuclide travel. For the ground-water pathways, this issue will be resolved if reasonable expectations are established that contaminant transport to the water table exceeds 1,000 yr with high confidence. Current estimates of the ground-water travel time show a mean value of 43,265 yr with a standard deviation of 12,765 yr (Sinnock et al., 1986), thus providing an initial level of confidence that the radionuclide travel time will be longer than 1,000 yr (Section 8.3.5.12).

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Figure 8.3.5.14-1. Logic diagram for Issue 1.2 (individual protection).

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If the radionuclide transport time is less than 1,000 yr, then the concentration of radionuclides in ground water and its change with time will be calculated using the total system performance model (see Section 8.3.5.13) at the boundary of the controlled area. There may be no significant source of ground water at the outside boundary of the controlled area. However, using the concentration of radionuclides at the boundary of the controlled area and the assumption that individuals consume 2 liters per day of drinking water, the dose to a maximally exposed individual can be calculated. Alternatively, it could be determined that there is no significant source of ground water outside the controlled area but that a source exists within the 1,000-yr radionuclide travel time boundary. If, however, any such source is identified, the same calculation as above can be made for that location. It should be noted that there is another requirement for the site (10 CFR 60.113(a)(2) that the pre-waste-emplacement ground-water travel time must be greater than 1,000 yr. The pre-waste-emplacement ground-water travel time and the radionuclide travel time (post-emplacement) are related but not the same; therefore, a radionuclide travel time that is less than 1,000 yr, although very unlikely, would not necessarily violate the 10 CFR 60.113 requirement (see Section 8.3.5.12).

Both spent fuel and glass waste forms contain carbon-14. The total amount of carbon-14 in the spent fuel is conservatively estimated to be 1.5 Ci/MTHM (metric tons of heavy metal) by actual measurements and analyses (Van Konynenburg et al., 1986). A smaller inventory of carbon-14 is expected for glass waste forms because of the potential for release and transfer to other waste streams during reprocessing. Most of the carbon-14 in the spent fuel is locked inside UO_2 fuel, Zircaloy cladding, and fuel assemblies and will be released slowly after the containment is breached. Only a small fraction of the total carbon-14 inventory in the spent fuel could be rapidly released from the oxidized skin of the Zircaloy cladding by reaction of the oxygen in the atmosphere with the carbon in the cladding oxidation layer (Oversby and McCright, 1984). Oversby and McCright believe that as much as 1 percent of the carbon-14 inventory in spent fuel could be rapidly released in this way during the first 100 to 1,000 yr following closure when high temperature and gamma radiation are expected (Section 8.3.5.9). No rapid release of carbon-14 is known from glass waste forms.

A bounding-case calculation for carbon-14 release can be made as follows: when the repository is completely filled with 70,000 MTHM, the total inventory of carbon-14 will be less than 105,000 Ci; considering that some of the wastes are in glass waste forms, the rapid release fraction of carbon-14 from the entire repository is not likely to exceed 1,000 Ci even if every waste container were breached within 1,000 yr. The goal of the waste-container design limits the container failure to less than 5 percent for the first 300 yr and to less than 20 percent for 1,000 yr after closure. Under a conservative assumption of 20 percent container failure, the total inventory of available carbon-14 for rapid release in gaseous form, therefore, would be less than 200 Ci. The 200 Ci would most likely be released gradually as the containers fail in a time-distributed manner. Even with a total failure of the entire 20 percent of the containers in 1 yr, the maximum release will not exceed 200 Ci in 1 yr, with no further release during the subsequent years, because there will be no more carbon-14 available for rapid release. Evaluation of the inventory and release of carbon-14 from Zircaloy cladding is being investigated in Section 8.3.5.10.

The carbon-14 released from the spent fuel during the initial breach of the container is expected to be in the form of carbon dioxide. Gas-phase carbon-14 dioxide moves upward through air-filled pores in the unsaturated tuffs by molecular diffusion and by advection in a thermally driven air-convection cell. In the course of the upward movement of carbon-14 dioxide, isotopic exchange of carbon-14 with the normal carbon of the carbon dioxide gas in the pore space will occur, thus retarding the movement of the carbon-14 to the atmosphere above the repository. The carbon dioxide gas in the pore space is probably in equilibrium with dissolved bicarbonate in the pore water. Therefore, a large reservoir of normal carbon exists in the unsaturated tuffs and is available for carbon-14 isotopic exchange. In addition, precipitation of calcite, if it occurs, will irreversibly remove carbon-14 from the system. Actual residence times of carbon-14 in the pore spaces of the repository overburden could, in principle, be estimated by solving a transport equation that takes the isotope exchange and chemical models into account. However, site-specific data that would permit realistic estimates of the carbon-14 residence time are lacking.

If the residence time of the carbon-14 in the overburden (the time needed for carbon-14 to travel through the overburden) is established with high confidence to exceed 1,000 yr, this part of Issue 1.2 will be resolved. The mean and standard deviation of the residence time in the overburden of a carbon-14 nucleus that is released at the repository level will be estimated in Section 8.3.1.3.8, and a model for gas-phase releases will be developed in Information Need 1.1.3 (Section 8.3.5.13.3).

A realistic estimate of doses from the gaseous pathway to the public in the accessible environment will have to be based on the gas-phase release estimated from Information Need 1.1.3 (Section 8.3.5.13.3). For the resolution of Issue 1.2, however, a bounding-value calculation will be used. The inventory of carbon-14 available for rapid release, a total of 200 Ci for 1,000 yr, is small compared with (1) an average release of 5 to 10 Ci from each operating nuclear power plant (boiling water and pressurized water reactors) into the atmosphere every year and (2) the design-basis release of approximately 800 Ci/yr from a 1,500-MTHM/yr fuel-reprocessing plant. Because of the very small dose consequences expected from the assumed release of carbon-14 through the repository overburden, bounding calculations will be done for a hypothetical maximally exposed individual on the ground surface above the repository assuming a ground-level release of the total 200 Ci in one year. Internal dose from ingestion has not been calculated because of the lack of site-specific data. This dose is, however, expected to be significantly smaller than the inhalation dose because of the lack of vegetation at the Yucca Mountain site.

Unless this issue has been resolved by having both the radionuclide travel time (liquid pathway) and residence time of carbon-14 in the overburden greater than 1,000 yr, doses from the individual pathways will be summed to see if the goal is met. At present, there is a high confidence that the goal can be met with the current design of the waste package and the site geohydrologic conditions. If, however, the goal has not been met, the source term for the radionuclide release can be reduced by a more realistic (less conservative) assessment of the dose pathways to the individuals or by alternative designs of the waste package (Section 8.3.5.9).

A preliminary performance allocation for this issue is summarized in Table 8.3.5.14-1. Because Issue 1.2 concerns only the undisturbed performance of the disposal system with respect to individual protection from radiation, it is appropriate to allocate performance against the expected pathways. A goal is set for the liquid pathways for near-zero release; it calls for the radionuclide travel time to exceed 1,000 yr. More detailed performance measures and their goals are set for the gaseous pathway. No significant external dose is expected from the weak beta radiation from carbon-14 through the skin. The only significant pathways for internal dose are through inhalation of carbon-14 dioxide in breathing air and ingestion of carbon-14-containing food items grown in the area. Specific goals based on the preliminary analysis are established with a high confidence for the internal doses by inhalation and ingestion. A goal is also set for the residence time of gaseous carbon-14 in the overburden.

Table 8.3.5.14-1 also illustrates the relationship between the performance measures and the parameters. Table 8.3.5.14-2 identifies the characterization parameters needed to determine the transport of carbon-14 dioxide on the surface above the repository.

Interrelationships of information needs

Two information needs have been identified for Issue 1.2: Information Need 1.2.1 determines the doses through the ground-water pathway, using the same methodology as that used for Issue 1.1, total system releases. The second information need (1.2.2) determines the internal and external doses to the public in the accessible environment through the gaseous pathway of carbon-14.

The schedule information provided for the information needs in this section includes the sequencing, interrelationships, and relative durations of the activities in the information need. Specific durations and start/finish dates for the activities are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

8.3.5.14.1 Information Need 1.2.1: Determination of doses to the public in the accessible environment through ground-water transport

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The information needed to satisfy this information need and the methodology to be used is basically the same as that used for Section 8.3.5.13, total system performance.

Parameters

The parameters needed to satisfy this information need are the same as those required for Information Need 1.1.4, Section 8.3.5.13.4. Specifically, these parameters include:

Table 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)	Ground water	Unsaturated zone and saturated zone	Individual dose (whole body)	Near zero (dose much less than standards)	High
	Gas phase	Waste container and overburden	Individual dose (whole body)		High
			External	Near zero	High
			Internal Inhalation Ingestion	<5 mrem/yr <5 mrem/yr	High High

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Table 8.3.5.14-2. Performance parameters for Issue 1.2 (individual protection)

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
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
				Retardation	>1	High	4.1.3.3	Medium
Overburden (gas phase transport)	Retardation of movement of gaseous nuclides	Isotope exchange, chemical equilibrium and pre- cipitation	Individual dose	Residence time of carbon-14 in over- burden	>1,000 yr	High	None	Low
Waste form (gas phase transport)	Containment and controlled release of gaseous nuclides	Distribution of radio- nuclides and con- tainment	Individual dose	Inventory of rapid release fraction of carbon-14	<1,000 Ci	High	7.4.3.1	Low

^aGround-water travel time is used as a measure of the radionuclide transport time to the boundary of the accessible environment.

1. Flux through the unsaturated zone (also from Section 8.3.5.12.4).
2. Retardation through the unsaturated zone (also from Section 8.3.1.3.4).
3. Dose conversion factors (standard values).

Logic

This information need addresses the movement of radionuclides through the ground water to the accessible environment. The parameters needed and the methodology to be used to satisfy this information need are similar to those used to determine the total releases to the accessible environment under expected conditions. The difference between this issue and Issue 1.1 is that the parameters and scenarios to be considered for this issue will cover only the first 1,000 yr after closure under expected conditions, whereas Issue 1.1 (Section 8.3.5.13) releases over 10,000 yr under expected and unexpected conditions. Radionuclide releases will be determined from the engineered barrier system, and contaminant transport will be considered through the unsaturated zone to the water table. Because the ground-water travel time through the unsaturated zone is expected to be much greater than 1,000 yr, this issue will examine the transport to the water table first. If the ground-water travel time to the water table through the unsaturated zone is less than 1,000 yr, then the ground-water travel time to the boundary of the controlled area and the change in radionuclide concentration at the boundary will be calculated for the dose evaluation.

8.3.5.14.1.1 Activity 1.2.1.1: Calculation of doses through the ground-water pathway

Objectives

The objective of this activity is to use the methodology applied in Section 8.3.5.13 to calculate the radionuclide transport to the boundary of the controlled area.

Parameters

See the general parameters list for this information need.

Description

This activity will obtain from Information Need 1.1.4 the distribution of radionuclides transported to the boundary of the controlled area during the first 1,000 yr after closure. Only expected conditions will be considered for this analysis. The radionuclide transport model used to make this evaluation will be verified and validated under Issue 1.1. The concentration of radionuclides in the ground water at the boundary of the controlled area and the assumption that individuals consume 2 liters per day of drinking

water from a significant source of ground water at the controlled area boundary will be used to calculate the individual dose. The results of this evaluation will be presented in a report.

8.3.5.14.1.2 Application of results

This information will be used to resolve the doses through the ground-water pathway section of this Issue (1.2).

8.3.5.14.1.3 Schedule and milestones

The schedule and milestone information for this information need is given in Section 8.3.5.14.2.4 following the discussion of Information Need 1.2.2 (determination of doses to the public in the accessible environment through gaseous pathway).

8.3.5.14.2 Information Need 1.2.2: Determination of doses to the public in the accessible environment through the gaseous pathway

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The following sections of Chapter 8 summarize the information relevant to this information need.

<u>Chapter 8 section</u>	<u>Short title</u>
8.3.1.12	Meteorology
8.3.5.3	Public radiological exposures-- normal conditions
8.3.5.13	Total system performance

Sections 8.3.5.9 and 8.3.5.10 will establish that carbon-14 is the only important gaseous radionuclide that can be transported to the accessible environment through the gaseous pathway and also will establish the maximum inventory of carbon-14 for rapid release. Since a bounding-value calculation is believed to be sufficient to resolve this issue, time distribution of container failure from Information Need 1.4.4 (Section 8.3.5.9.4) will not be used here.

Parameters

Most of the parameters needed to satisfy this information need are obtained from other information needs as noted in the following list:

1. Important gaseous radionuclides (Section 8.3.5.10.1).
2. Inventory and release of gaseous radionuclides (Section 8.3.5.10.2).
3. Retardation of gaseous flow through the overburden (Section 8.3.5.13.3).
4. Site meteorological data (Section 8.3.1.12.2).
5. Offsite activities for ingestion and inhalation scenarios (Section 8.3.1.13).
6. Dose conversion factors (standard published values).

Logic

Releases of gaseous radionuclides will be determined by using a two-step process. The first step involves examining the retardation of gaseous flow of carbon-14 dioxide through the overburden. This step will use the same parameters and methodology as used to address Issue 1.1, total system performance, with the exception that this issue considers only expected conditions over the first 1,000 yr following disposal. The second step involves examining inhalation and ingestion rates when the carbon-14 dioxide reaches the surface. This step will be performed only if it is determined that the goal for gaseous retardation through the overburden cannot be achieved with a high level of confidence.

For a given radionuclide, when the release rate, wind speed, and dispersion coefficients are known, it is a straightforward calculation to obtain the external and internal inhalation doses with standard dose-conversion factors. Inhalation dose is expected to be the overwhelming component of the potential dose from carbon-14 releases. Uptake by ingestion, however, greatly depends upon local vegetation and agricultural activities and can vary significantly from area to area even for the same amount of release. No significant agricultural activities are currently present at the Yucca Mountain area, and the expected conditions for 1,000 yr in the area can be assumed in order to estimate the ingestion dose. Since the dose rate will be highest at the land surface, only one calculation for a hypothetical maximally exposed person will be required to resolve this information need.

Two activities are planned to calculate doses to the public in the accessible environment through the gaseous pathway. The second activity will be performed only if it is determined that the goal for gaseous retardation through the overburden cannot be achieved with a high level of confidence.

8.3.5.14.2.1 Activity 1.2.2.1: Calculation of transport of gaseous carbon-14 dioxide through the overburden

Objectives

The objective of this activity is to estimate the transport time for gaseous carbon-14 dioxide from the repository to the land surface during the first 1,000 yr after disposal.

Parameters

Parameters 1, 2, and 3 identified under Information Need 1.2.2 are required for this activity.

Description

This activity will obtain from Information Need 1.1.4 the distribution of gaseous radionuclides transported through the overburden to the land surface during the first 1,000 yr after disposal. Only expected conditions will be considered for this analysis. The results of this evaluation will be presented in a final report on doses to the public in the accessible environment through gas phase transport.

8.3.5.14.2.2 Activity 1.2.2.2: Calculation of land-surface dose and dose to the public in the accessible environment through the gaseous pathway of carbon-14

Objectives

The objectives of this activity are to collect the necessary data on carbon-14 inventory and meteorology, and to calculate upper bound values for external and internal doses. The latter objective includes doses from both inhalation and ingestion.

Parameters

See the general parameter list for this information need.

Description

This activity will extract the carbon-14 inventory data from Information Need 1.5.2 (Section 8.3.5.10.2) and calculate the dispersion coefficients and wind speed from meteorological data from Section 8.3.1.12.1. This activity will also calculate the expected and upper bound internal and external doses to a hypothetical maximally exposed person on the land surface above the repository. The AIRDOS-EPA program or other appropriate programs will be used for the dose calculation. Model verification and validation are discussed in the NNWSI Project Radiological Monitoring Plan (Section 8.3.5.3). The results will be presented in a report.

8.3.5.14.2.3 Application of results

This information will be used to resolve the doses through the gaseous pathway section of this issue.

8.3.5.14.2.4 Schedule and milestones

Performance Issue 1.2 consists of two information needs to evaluate if the mined geologic disposal system will meet the system performance objective for limiting individual doses in the accessible environment. These information needs are 1.2.1 (determination of doses to the public in the accessible environment through ground-water transport) and 1.2.2 (determination of doses to the public in the accessible environment through gaseous pathways). In the figure that follows, the schedule information for this issue is presented in the form of timelines. The timelines extend from implementation of the activities to the issuance of the final products associated with the activities. Summary schedules and milestone information for this issue can be found in Section 8.5.1.1.

The analysis and modeling work for this entire issue will proceed in parallel with characterization and design activities and will interact with them in an iterative fashion.

The activities in this issue are constrained by other program elements. Information is needed from Sections 8.3.5.13 (total system performance), 8.3.5.10 (engineered barrier system release rates), and 8.3.1.12 (meteorology).

The titles corresponding to the timelines are shown on the left in the following figure. The points shown on the timelines represent major events or important milestones associated with the issue. Solid lines represent activity durations and dashed lines show interfaces.

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The points on the timelines are described in the following table.

<u>Point number</u>	<u>Description</u>
1	Information received from the ground-water travel time performance issue (Section 8.3.5.12) and the geochemistry program (Section 8.3.1.3).
2	Milestone Z456. Issue report on the determination of doses to the public in the accessible environment through the ground-water pathway.
3	Information received from the engineered barrier system release rates performance issue (Section 8.3.5.10), the total system performance issue (Section 8.3.5.13), and the meteorology program (Section 8.3.5.12).
4	Initial calculation of gaseous transport time of carbon-14 dioxide through overburden complete. If the confidence levels are adequate, prepare report on gaseous transport time (Z457). If the confidence levels are not adequate, initiate next activity to evaluate upper bound internal and external doses.
5	Milestone Z457. Issue report on the determination of doses to the public in the accessible environment through gas-phase transport.

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Section 8.3.5.15

Consultation Draft

**GROUND-WATER
PROTECTION**

Site Characterization Plan

***Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

Volume VII

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U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

8.3.5.15 Issue resolution strategy for Issue 1.3: Will the mined geologic disposal system meet the requirements for the protection of special sources of ground water as required by 40 CFR 191.16?

Regulatory basis for the issue

The parts of 40 CFR 191.16 relevant to Issue 1.3 are quoted in the following:

191.16 Ground water protection requirements

- (a) Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation that, for 1,000 yr after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of ground water to exceed:
 - (1) 5 picocuries per liter of radium-226 and radium-228;
 - (2) 15 picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon); or
 - (3) The combined concentrations of radionuclides that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body or any internal organ greater than 4 millirems per year if an individual consumed 2 liters per day of drinking water from such a source of ground water.
- (b) If any of the average annual radionuclide concentrations existing in a special source of ground water before construction of the disposal system already exceed the limits in 191.16(a), the disposal system shall be designed to provide a reasonable expectation that, for 1,000 years after disposal, undisturbed performance of the disposal system shall not increase the existing average annual radionuclide concentrations in water withdrawn from that special source of ground water by more than the limits established in 191.16(a).

In the previous regulations, undisturbed performance means the predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events.

An aquifer must meet several criteria to be designated as a special source. The first step in the evaluation is to establish whether the aquifer is a Class I source as defined by the EPA Ground Water Protection Strategy of 1984 (EPA, 1984). The conditions that must be met for designation as a Class I source are (1) that the source is highly vulnerable to contamination

because of the hydrologic characteristics and (2) that the source is irreplaceable in that no reasonable alternative is available to substantial populations or that the source is ecologically vital in that it provides baseflow to a sensitive ecological system.

If an aquifer meets the criteria for a Class I source, the next step is to determine whether it qualifies as a special source of ground water. 40 CFR 191.12 defines a special source of groundwater as "those Class I ground waters identified in accordance with the agency's Ground-Water Protection Strategy . . . that: (1) are within the controlled area encompassing a disposal system or less than 5 km beyond the controlled area [the controlled area is the actual area chosen according to the 40 CFR 191.12 definition of the controlled area]; (2) are supplying drinking water for thousands of persons as of the date that the [DOE] chooses a location within that area for detailed characterization as a potential site for a disposal system (e.g., in accordance with Section 112(b)(1)(B) of the Nuclear Waste Policy Act); and (3) are irreplaceable in that no reasonable alternative source of drinking water is available to that population."

Approach to resolving the issue

The approach to resolving this issue consists of a series of determinations and decision points, any one of which could result in an affirmative resolution. As shown in the logic diagram for this issue (Figure 8.3.5.15-1), the first decision is whether Class I or special sources of ground water exist in the vicinity of Yucca Mountain as determined by comparing the criteria with the hydrogeologic, demographic, and ecologic characteristics of the site and its contiguous vicinity. If Class I or special sources are found not to exist, the issue is resolved affirmatively.

If a Class I source exists, the NNWSI Project will proceed to evaluate whether the Class I ground water is also a special source of ground water. If so, the concentration of waste in special-source ground water must remain below the limits specified in 40 CFR 191.16. The approach is first to determine whether slow ground-water movement or containment of waste within the waste package alone can ensure meeting the limits. If neither path can provide this assurance, the NNWSI Project will conduct transport modeling to test whether concentrations in special-source ground water will remain below the established limits.

These two fundamental questions (i.e., whether special sources exist, and whether contamination of a special source will be below the 40 CFR 191.16 limits) are the basis for defining two information needs:

- 1.3.1 Determine whether any Class I or special sources of ground water exist at Yucca Mountain, within the controlled area, or within 5 km of the controlled area boundary.
- 1.3.2 Determine for all special sources whether concentrations of waste products in the ground water during the first 1,000 yr after disposal will not exceed the limits established in 40 CFR 191.16.

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Figure 8.3.5.15-1. Logic diagram for Issue 1.3 (ground-water protection).

Performance allocation for Issue 1.3

A preliminary performance allocation for this issue (1.3) is summarized in Table 8.3.5.15-1. Because this issue is concerned with the protection of special ground-water sources from contamination, it is appropriate to first establish whether a Class I or special ground-water source exists. If no special sources exist, then the issue is resolved. If a special source is identified at or near the site, this issue could be resolved by establishing that the concentrations of waste products in the special source are likely to be much less than allowed by EPA limits. The relationship between the performance measures and the required parameters is illustrated in Table 8.3.5.15-1.

Interrelationships of information needs

Two information needs have been identified for this issue; the first is the determination whether a Class I or special source of ground water exists at or in the vicinity of the Yucca Mountain site. If a special source aquifer is identified during site characterization, a second information need will be addressed to determine whether concentrations of waste in the ground water could exceed the limits established by 40 CFR 191.16.

The schedule information provided for information needs in this section includes the sequencing, interrelationships, and relative durations of the analyses in the information need. Specific durations and start/finish dates for the analyses are being developed as part of ongoing planning efforts and will be provided in the SCP at the time of issuance and revised as appropriate in subsequent semiannual progress reports.

8.3.5.15.1 Information Need 1.3.1: Determination whether any Class I or special sources of ground water exist at Yucca Mountain, within the controlled area, or within 5 km of the controlled area boundary

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

The following sections of Chapter 3 (hydrology) summarize the data relevant to this information need:

<u>SCP section</u>	<u>Subject</u>
3.6	Regional hydrogeologic reconnaissance of candidate area and site
3.7	Regional ground-water flow system
3.8	Ground-water uses
3.9	Site hydrogeologic system

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	<substantial	VF T LC	>3,000, < 5,000 <1,000 ≈500	High Medium Medium	High High High
			or					
			b. Baseflow to sensitive ecological system	None	VF T LC	None None Exists	Medium Medium Medium	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

^aNA = not applicable.^bControlled area is the actual area chosen according to the 40 CFR 191.12 definition of controlled area.

The information contained in these sections supports a preliminary determination that no potential special sources of ground water are present at the site, below the site, within the boundaries of the controlled area, or within 5 km of the controlled area boundary. The following discussion is a brief compilation of this information from Chapter 3.

All the aquifers meet the criterion for location. The tuff aquifer and the lower carbonate aquifer both underlie the proposed repository location. The valley-fill aquifer is located within 5 km of the controlled area (Chapter 3) and was the only aquifer in the Yucca Mountain area serving a population of thousands of persons at the time that the site was chosen for characterization (Section 3.8). Within the Amargosa Desert where the valley-fill aquifer is used, it is underlain by the Paleozoic rocks of the lower carbonate aquifer.

The lower carbonate aquifer is considered an irreplaceable source because it supplies baseflow to the Ash Meadows region in southern Nye County (Dudley and Larson, 1976), which has been designated a critical habitat for several species of endangered fishes. The Ash Meadows area, however, is part of a different ground-water subbasin (Ash Meadows) from the Alkali Flat-Furnace Creek Ranch ground-water subbasin, which contains Yucca Mountain (Section 3.6). Evaluations of the hydrologic feasibility of developing the lower carbonate aquifer must consider the possibility of interbasin diversion of this baseflow (refer to Section 8.3.1.9.2).

It is presently considered, with a medium level of confidence, that none of the three aquifers is vulnerable to contamination within 1,000 yr after emplacing waste at Yucca Mountain, based on the hydraulic and geochemical characteristics of the thick unsaturated zone that would contain the repository. In addition to its protection by the thick unsaturated zone, the lower carbonate aquifer has a higher potentiometric head than does the tuff aquifer in the vicinity of the site, according to data obtained from drillhole UE-25p#1 (Craig and Robison, 1984). Therefore, the potential or tendency for flow is upward from the lower carbonate aquifer rather than downward into it. Both the lower carbonate and tuff aquifers crop out in limited areas of rugged terrain, indicating the potential for contamination directly into these aquifers from future human activities is slight. However, a low level of confidence is assigned (Table 8.3.5.15-1) to this determination for the valley-fill aquifer because (1) the valley-fill materials occur at the surface over broad areas and (2) the designation of a Class I source is not restricted to its vulnerability to contamination from the proposed repository (EPA, 1984).

Parameters

Most of the cultural parameters (i.e., demographic and water-use data) needed to complete this information need relative to potential special sources have already been obtained from preliminary investigations. Further investigations being carried out as part of the geohydrology test program will provide confirmatory hydrologic data needed to raise the confidence level of the preliminary finding. The main parameters to be confirmed are

1. The degree and location(s) of hydraulic communication between the aquifers of the flow system (Investigation 8.3.1.2.3).

2. The potential for contamination of the aquifers from the mined geologic disposal system (Investigation 8.3.1.2.1).
3. Refined demographic information on local ground-water users (Investigation 8.3.1.9.2).

Logic

There are four criteria that must be met in order to classify an aquifer as a special source. One of the criteria (that the aquifers are located within the controlled area or within 5 km of the controlled area boundary) has been established with a high level of confidence. The three remaining parameters will need to be known with greater certainty to resolve this issue.

One analysis, which consists of two activities, is planned to evaluate the data that will be obtained from the geohydrology and human interference programs. This analysis will be a synthesis of the required information and will present the final evaluation of the three subject aquifers against the regulatory criteria.

8.3.5.15.1.1 Analysis 1.3.1.1: Determine whether any aquifers near the site meet the Class I or special source criteria

This analysis consists of two synthesis activities that will obtain required parameter values from Investigations 8.3.1.2.1 and 8.3.1.2.3, which are part of the postclosure geohydrologic programs. Additional information will be taken from Investigation 8.3.1.9.2, which is a part of the human activities program.

8.3.5.15.1.1.1 Activity 1.3.1.1.1: Synthesis and evaluation of hydrologic and environmental information needed to determine whether aquifers at the site meet the special source criteria

Objectives

The objectives of this activity are (1) to raise the confidence levels of the previously obtained hydrologic and environmental data and (2) to analyze these data in order to evaluate whether any aquifers at or near Yucca Mountain meet the criteria for designation as a Class I or special source of ground water.

Parameters

The parameters that will be obtained and evaluated are the location(s) and degree of hydraulic communication between the aquifers and the expected susceptibility of the aquifers to contamination from the mined geologic disposal system.

Description

This activity will extract its parameters from Investigations 8.3.1.2.1, 8.3.1.2.3, and 8.3.1.9.2, which are needed to raise the confidence on the determination whether any special source of ground water exists at or near the Yucca Mountain site. The results of the synthesis will be evaluated in conjunction with data obtained from Activity 1.3.1.1.2 (Section 8.3.5.15.1.1.2) and will be presented in a report.

8.3.5.15.1.1.2 Activity 1.3.1.1.2: Synthesis and evaluation of demographic and economic data needed to determine whether Class I or special sources of ground water exist

Objectives

The objectives of this activity are (1) to obtain refined demographic data on water use needed to establish the number of users from each aquifer at the time Yucca Mountain was selected for site characterization and (2) to examine the economic feasibility of development of the lower carbonate aquifer for alternative water supply to local populations.

Parameters

The parameters that will be obtained and evaluated are population data and locations, depths, and completion dates for all wells within the boundaries of the hydrogeologic study area (Chapter 3 introduction). Information on short-term water demand, water supply, and projected socioeconomic conditions will be obtained (Section 8.3.1.9.2.2.1) and evaluated to determine the economic feasibility of developing the lower carbonate aquifer.

Description

This synthesis activity will obtain data from Section 8.3.1.9.2.2.1 (human interference program) in order to evaluate the site aquifers against the criteria for special source status. These criteria are (1) population served at the time Yucca Mountain was selected for site characterization and (2) presence of alternative water supplies.

8.3.5.15.1.2 Application of results

The information obtained from this analysis will be used to satisfy the regulatory requirements of 40 CFR 191.16. To confirm that there have been no designations of the subject aquifers as special sources, the NNWSI Project will request on a regular basis, information from the EPA on the status of each of the three aquifers.

8.3.5.15.1.3 Schedule and milestones

The schedule and milestone information for this analysis is given in Section 8.3.5.15.2.4, at the end of Analysis 1.3.2.1 (determine the concentration of waste products in any special source of ground water during the first 1,000 yr after disposal).

8.3.5.15.2 Information Need 1.3.2: Determine for all special sources whether concentrations of waste products in the ground water during the first 1,000 yr after disposal could exceed the limits established in 40 CFR 191.16

Technical basis for addressing the information need

Link to the technical data chapters and applicable support documents

Section 8.3.5.13 (Issue 1.1, total system performance) presents the data and methods relevant to this information need. The information contained in this section supports the preliminary determination that concentrations of contaminants in the ground water during the first 1,000 yr after disposal will not exceed the limits established in 40 CFR 191.16.

Parameters

The parameters needed to satisfy this information need will be obtained from other studies, in particular from the geohydrology program (Section 8.3.1.2) and the total system performance issue (Section 8.3.5.13). The main parameters are (1) concentration of existing contaminants in all potential special source aquifers identified by Analysis 1.3.1.1 and (2) total system performance over the next 1,000 yr.

Logic

This information need will be investigated only if it is determined that a special source of ground water exists within 5 km of the controlled area at Yucca Mountain (Figure 8.3.5.15-1).

8.3.5.15.2.1 Analysis 1.3.2.1: Determine the concentrations of waste products in any special source of ground water during the first 1,000 yr after disposal

This analysis consists of one activity that will calculate the concentration of waste products in any special-source aquifers during the first 1,000 yr after disposal.

8.3.5.15.2.2 Activity 1.3.2.1.1: Synthesis and evaluation of releases of waste products to special sources of ground water during the first 1,000 yr after disposal

Objectives

The objective of this activity is to determine the quantity of waste products that could be released and transported to a special source of ground water during the first 1,000 yr after disposal.

Parameters

The parameters that will be obtained are the releases to the accessible environment under expected conditions over the first 1,000 yr after disposal.

Description

This study will obtain information directly from studies associated with Issue 1.1 (total system performance, Section 8.3.5.13). The difference between this issue and Issue 1.1 is that the parameters and scenarios to be considered in this issue will only cover the first 1,000 yr after disposal under expected conditions, whereas Issue 1.1 examines releases over 10,000 yr under expected and unexpected conditions. No additional information is requested under this activity.

8.3.5.15.2.3 Application of results

The information obtained from this analysis will be used to satisfy the regulatory requirements of 40 CFR 191.16.

8.3.5.15.2.4 Schedule and milestones

Performance Issue 1.3 consists of two analyses to evaluate if the mined geologic disposal system will meet the requirements for the protection of special sources of ground water. These analyses are 1.3.1.1 (determine whether any aquifers near the site meet the Class I or special source criteria) and 1.3.2.1 (determine the concentration of waste products in any special source of ground water during the first 1,000 yr after disposal). In the figure that follows, the schedule information for this issue is presented in the form of timelines. The timelines extend from implementation of the activities to the issuance of the final products associated with the activities. Summary schedules and milestone information for this issue can be found in Section 8.5.1.1.

The analysis and modeling work for this entire issue will proceed in parallel with characterization and performance activities and will interact with them in an iterative fashion.

The activities in this issue are constrained by other program elements. Information is needed from Sections 8.3.5.13 (total system performance), 8.3.1.2 (geohydrology), and 8.3.1.9 (human interference).

The titles corresponding to the timelines are shown on the left in the following figure. The points shown on the timelines represent major events or important milestones associated with the issue. Solid lines represent activity durations, and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.

The points on the timelines are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Analysis begins with information passed from Investigations 8.3.1.2.1 (regional hydrology system), 8.3.1.2.3 (site saturated-zone hydrologic system), and 8.3.1.9.2 (value of resources).
2	Milestone Z454. Issue report on evaluation of the potential for special sources of ground water at Yucca Mountain.
3	Milestone Z360. Complete evaluation of the potential for special sources of ground water at Yucca Mountain.

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<u>Point number</u>	<u>Description</u>
4	Analysis begins with decision that analysis is needed based on results from 8.3.5.15.1.1 (special sources of ground water); information is also passed from Investigation 8.3.1.2.3 (site saturated hydrologic system) and Section 8.3.5.13 (total system performance).
5	Milestone Z455. Issue report on the calculations to determine concentration of waste products in special source aquifers over the first 1,000 yr after disposal.

Nuclear Waste Policy Act
(Section 113)

Section 8.3.5.16

Consultation Draft

**PERFORMANCE
CONFIRMATION**

Site Characterization Plan

***Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

Volume VII

January 1988

***U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585***

8.3.5.16 Issue resolution strategy for Issue 1.7: Will the performance-confirmation program meet the requirements of 10 CFR 60.137?

As discussed in Section 8.2.2.1.1.7, the performance confirmation process begins during site characterization with baseline activities. The testing activities described in the SCP that support the resolution of the Performance Issues 1.1 to 1.6 supply the baseline data upon which the confirmation phase testing and monitoring is developed. Some of the site characterization testing done to support the performance issue resolutions may be continued into the confirmation phase (post-license application time frame) if useful confirmation data can be gathered.

As mentioned in Section 8.2.2.1.1.7, until the detailed performance assessments supporting the performance issue resolution are developed for the license application, it is not possible to detail all the testing and monitoring included in the confirmation phase. Table 8.3.5.16-1 identifies the tests presently considered as confirmation phase testing, but which will be initiated during site characterization. The primary purpose of these tests is to generate confirmatory data but, because of the long time scales required, they must be initiated during site characterization. This list is not intended to be complete but rather to indicate the tests that have been identified at this time. As issue resolution proceeds during site characterization, additional confirmation phase testing and monitoring activities will be identified.

Table 8.3.5.16-1. Confirmation phase testing initiated during site characterization

Test title	Location	Purpose	Performance assessment analysis	Approximate dates	SCP section providing information
Heated rooms	Repository level of the exploratory shaft facility	Evaluate large-scale thermo-mechanical behavior	Behavior of underground openings when heated	1991 to start of repository construction	8.3.2.4, 8.3.2.5, 8.3.5.2, 8.3.1.15.1.6.5
Engineered barrier system field tests (1 of 4)	Repository level of the exploratory shaft facility	Measure simulated near-field waste-package environment	Near-field thermal, mechanical, and hydrologic environment	1990 to two yr after license application	8.3.4.2.4.4

Chapter 8

Nuclear Waste Policy Act
(Section 113)

Section 8.3.5.17

Consultation Draft

NRC SITING CRITERIA

***Site Characterization
Plan******Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

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Washington, DC 20585

8.3.5.17 Issue resolution strategy for Issue 1.8: Can the demonstrations for favorable and potentially adverse conditions be made as required by 10 CFR 60.122?

Regulatory basis for the issue

Postclosure Performance Issue 1.8 addresses the NRC siting criteria. These criteria, set forth in 10 CFR 60.122, consist of two sets of conditions that describe human activities and natural conditions, processes, and events. The first set (10 CFR 60.122(b)) encompasses 8 favorable conditions (FCs) that could enhance the ability of a site to meet the performance objectives relating to the isolation of waste if they were present at the site. These favorable conditions are shown in Table 8.3.5.17-1. The second set (10 CFR 60.122(c)) encompasses 24 conditions (potentially adverse conditions, or PACs) that could adversely affect the ability of a site to meet the performance objectives relating to the isolation of waste if they were present at the site. These potentially adverse conditions are shown in Table 8.3.5.17-2.

The siting criteria also include requirements for the demonstrations that must be made regarding these conditions. For each potentially adverse condition determined to be present, the NRC requires that the following be demonstrated:

- (i) The potentially adverse human activity or natural condition has been adequately investigated, including the extent to which the condition may be present and still be undetected, taking into account the degree of resolution achieved by the investigations; and
- (ii) The effect of the potentially adverse human activity or natural condition on the site has been adequately evaluated using analyses which are sensitive to the potentially adverse human activity or natural condition and assumptions which are not likely to underestimate its effect; and
- (iii)
 - (A) The potentially adverse human activity or natural condition is shown by analysis pursuant to paragraph (a)(2)(ii) of this section not to affect significantly the ability of the geologic repository to meet the performance objectives relating to isolation of the waste, or
 - (B) The effect of the potentially adverse human activity or natural condition is compensated by the presence of a combination of the favorable characteristics so that the performance objectives relating to isolation of the waste are met, or
 - (C) The potentially adverse human activity or natural condition can be remedied.

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Table 8.3.5.17-1. Favorable conditions, Performance Issue 1.8 (Nuclear Regulatory Commission siting criteria)^a
(Page 1 of 2)

Favorable condition	Text of the Condition
1	The nature and rates of tectonic, hydrogeologic, geochemical, and geomorphic processes (or any of such processes) operating within the geologic setting during the Quaternary Period, when projected, would not affect or would favorably affect the ability of the geologic repository to isolate the waste.
2	For disposal in the saturated zone, hydrogeologic conditions that provide - (i) A host rock with low horizontal and vertical permeability; (ii) Downward or dominantly horizontal hydraulic gradient in the host rock and immediately surrounding hydrogeologic units; and (iii) Low vertical permeability and low hydraulic gradient between the host rock and the surrounding hydrogeologic units.
3	Geochemical conditions that - (i) Promote precipitation or sorption of radionuclides; (ii) Inhibit the formation of particulates, colloids, and inorganic and organic complexes that increase the mobility of radionuclides; or (iii) Inhibit the transport of radionuclides by particulates, colloids, and complexes.
4	Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having equal or increased capacity to inhibit radionuclide migration.
5	Conditions that permit the emplacement of waste at a minimum depth of 300 meters from the ground surface. (The ground surface shall be deemed to be the elevation of the lowest point on the surface above the disturbed zone.)
6	A low population density within the geologic setting and a controlled area that is remote from population centers.

Table 8.3.5.17-1. Favorable conditions, Performance Issue 1.8 (Nuclear Regulatory Commission siting criteria)^a
(Page 2 of 2)

Favorable condition	Text of the Condition
7	Pre-waste-emplacement travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 years.
8	<p>For disposal in the unsaturated zone, hydrogeologic conditions that provide-</p> <ul style="list-style-type: none"> (i) Low moisture flux in the host rock and in the overlying and underlying hydrogeologic units; (ii) A water table sufficiently below the underground facility such that fully saturated voids contiguous with the water table do not encounter the underground facility; (iii) A laterally extensive low-permeability hydrogeologic unit above the host rock that would inhibit the downward movement of water or divert downward moving water to a location beyond the limits of the underground facility; (iv) A host rock that provides for free drainage; or (v) A climatic regime in which the average annual historic precipitation is a small percentage of the average annual potential evapotranspiration.

^aQuoted from 10 CFR 60.122 (b).

Table 8.3.5.17-2. Potentially adverse conditions, Performance Issue 1.8
(Nuclear Regulatory Commission siting criteria)^a
(Page 1 of 4)

Potentially adverse condition	Text of the condition
1	Potential for flooding of the underground facility, whether resulting from the occupancy and modification of floodplains or from the failure of existing or planned man-made surface water impoundments.
2	Potential for foreseeable human activity to adversely affect the ground-water flow system, such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activity or construction of large scale surface water impoundments.
3	Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitude that large-scale surface water impoundments could be created that could change the regional ground-water flow system and thereby adversely affect the performance of the geologic repository.
4	Structural deformation, such as uplift, subsidence, folding or faulting, that may adversely affect the regional ground-water flow system.
5	Potential for changes in hydrologic conditions that would affect the migration of radionuclides to the accessible environment, such as changes in hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.
6	Potential for changes in hydrologic conditions resulting from reasonably foreseeable climatic changes.

Table 8.3.5.17-2. Potentially adverse conditions, Performance Issue 1.8
(Nuclear Regulatory Commission siting criteria)²
(Page 2 of 4)

Potentially adverse condition	Text of the condition
7	Ground-water conditions in the host rock, including chemical composition, high ionic strength, or ranges of Eh-pH, that could increase the solubility or chemical reactivity of the engineered barrier system.
8	Geochemical processes that would reduce sorption of radionuclides, result in degradation of the rock strength, or adversely affect the performance of the engineered barrier system.
9	Ground-water conditions in the host rock that are not reducing.
10	Evidence of dissolution such as breccia pipes, dissolution cavities or brine pockets.
11	Structural deformation, such as uplift, subsidence, folding, and faulting, during the Quaternary Period.
12	Earthquakes that have occurred historically that if they were to be repeated could affect the site significantly.
13	Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase.
14	More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located.
15	Evidence of igneous activity since the start of the Quaternary Period.
16	Evidence of extreme erosion during the Quaternary Period.

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Table 8.3.5.17-2. Potentially adverse conditions, Performance Issue 1.8
(Nuclear Regulatory Commission siting criteria)^a
(Page 3 of 4)

Potentially adverse condition	Text of the condition
17	The presence of naturally occurring materials, whether identified or undiscovered, within the site, in such a form that: (i) Economic extraction is currently feasible or potentially feasible during the foreseeable future; or (ii) Such materials have a greater gross value or net value than the average for areas of similar size that are representative of and located within the geologic setting.
18	Evidence of subsurface mining for resources within the site.
19	Evidence of drilling for any purpose within the site.
20	Rock or ground-water conditions that would require complex engineering measures in the design and construction of the underground facility or in the sealing of boreholes and shafts.
21	Geomechanical properties that do not permit design of underground openings that will remain stable through permanent closure.
22	Potential for the water table to rise sufficiently so as to cause saturation of an underground facility located in the unsaturated zone.
23	Potential for existing or future perched water bodies that may saturate portions of the underground facility or provide a faster flow path from an underground facility located in the unsaturated zone to the accessible environment.

Table 8.3.5.17-2. Potentially adverse conditions, Performance Issue 1.8
(Nuclear Regulatory Commission siting criteria)^a
(Page 4 of 4)

Potentially adverse condition	Text of the condition
24	Potential for the movement of radionuclides in a gaseous state through air-filled pore spaces of an unsaturated geologic medium to the accessible environment.

^aQuoted from 10 CFR 60.122(c).

The demonstration requirements for the favorable conditions are not as explicit as the requirements for the potentially adverse conditions. The NRC, in 10 CFR 60.122(a)(1), requires that

A geologic setting shall exhibit an appropriate combination of the... [favorable conditions]...so that, together with the engineered barrier system, the favorable conditions present are sufficient to provide reasonable assurance that the performance objectives relating to isolation of the waste will be met.

This requirement from 10 CFR Part 60 indicates that a site judged suitable for a repository does not necessarily have all favorable conditions. To demonstrate that the combination of conditions is appropriate, the safety analysis report in the license application to the NRC is required to contain "analyses to determine the degree to which each of the favorable and potentially adverse conditions, if present, has been characterized, and the extent to which it contributes to or detracts from isolation" (60.21(c)(1)(ii)(B)). For those potentially adverse conditions that could detract from isolation, the NRC allows a site to rely on the favorable conditions present at the site to compensate for the potentially adverse conditions (60.122(a)(2)(iii)(B)). Thus, the presence of favorable conditions is expected to contribute substantially to the demonstration of reasonable assurance, and their functions in enhancing isolation will be included explicitly, whenever it is feasible to do so, in calculations demonstrating compliance with the performance objectives.

Approach to resolving the issue

Because 10 CFR 60.122 addresses two kinds of conditions, two strategies for resolving this issue have been developed and are described in the following section. The first addresses the demonstrations required for the potentially adverse conditions, and the second addresses the demonstrations required for the favorable conditions. There is a strong tie between these strategies and the strategy for resolving Issue 1.1 (Section 8.3.5.13). Issue 1.1 addresses the NRC's overall system performance objective (10 CFR 60.112). The strategies for Issue 1.8 (Section 8.3.5.17) ensure that the

overall system performance assessment conducted through Issue 1.1 considers the site characteristics with which the NRC is concerned, specifically the favorable and potentially adverse conditions of 10 CFR 60.122. To conduct a realistic performance assessment, Issue 1.1 will rely upon input from Issue 1.5 (engineered barrier system release rates), which must in turn consider the site conditions specified in 10 CFR 60.122. The strategy for resolving Issue 1.1 is discussed in detail in Section 8.3.5.13.

Issue 1.8 has many similarities to Issue 1.1; the two issues take many of the same site conditions into account, and both deal with the effects of site conditions on the isolation of the waste. They do not, however, have to be structured identically. Although each of the two issues will require both quantitative and qualitative arguments for resolution, the DOE expects that the resolution of Issue 1.8 will rely more heavily on expert geotechnical judgment. The resolution of Issue 1.1 will result in a definitive quantitative demonstration of compliance by the construction of the cumulative complementary distribution function. This resolution will rely on qualitative reasoning primarily for the justification of the conceptual models it uses and for showing the reasonable assurance required by 10 CFR 60.101. Because 10 CFR 60.122 makes explicit reference to meeting the waste-isolation performance objectives, the resolution of Issue 1.8 cannot be wholly qualitative. It can, however, be a forum for full expression of sound qualitative technical judgment on the site's ability to isolate waste. The DOE expects that such judgments can frequently be made without recourse to complex calculations of releases to the accessible environment; for example, modeling of ground-water flow may be used to address increases in water-table elevations and in infiltration. Such simpler calculations and the use of expert geotechnical judgment will play important roles in the resolution of Issue 1.8.

Strategy for addressing the potentially adverse conditions

In 10 CFR 60.122 the NRC states that these conditions are potentially adverse if they are characteristic of the controlled area or may affect isolation within the controlled area. If present, these conditions could significantly affect the ability of a site to meet the performance objectives relating to isolation of waste. Therefore, each PAC must be investigated to determine whether the condition is present at the Yucca Mountain site, what effects the PAC could have on the site's ability to isolate waste, and whether the effects, if any, are significant.

Figure 8.3.5.17-1 shows the major steps that the DOE intends to take in resolving Issue 1.8 for each potentially adverse condition (PAC) listed in 10 CFR 60.122. The figure, which is an expansion of the general issue-resolution strategy shown in Section 8.1, outlines the licensing strategy and the subsequent steps that will lead to the final resolution of Issue 1.8 for each PAC. As explained in detail below, certain steps in the licensing strategy--i.e., the steps up to the collection of site characterization data--were carried out in preparing this section and have been used in the development of the site characterization program presented in other parts of Section 8.3.

The following detailed explanation of Figure 8.3.5.17-1 describes the steps and the reasoning behind them. The explanation is intended to guide

Figure 8.3.5.17-1. Logic diagram for resolving Issue 1.8 for potentially adverse conditions (PACs). The text discussion is keyed to the numbers in this logic diagram.

the reader's understanding of the detailed discussions presented later in Section 8.3.5.17 that explain how the licensing-strategy decisions were made for each PAC. To keep the section as concise as possible, those detailed discussions omit many of the general principles that underlie the strategy. The following explanation supplies those principles. The steps in the figure are numbered to aid the reader in following the explanation.

The first step in the licensing strategy for dealing with each PAC is to adopt a tentative strategy on whether the license application will show that the PAC is present at the Yucca Mountain site (step 1). This decision has been based on the evidence currently available to the DOE. As Section 8.1 explains in detail, the tentative decisions adopted in the development of licensing strategies will be changed if evidence acquired in the future shows them to be technically unsound. For now they are simply a basis for planning site characterization.

Strategy for addressing PACs with preliminary findings not present at the site--The major branch on the right side of Figure 8.3.5.17-1 shows the steps to be followed to test the hypothesis that a PAC is not present at the site. If the available data show conclusively that the condition is not present (step 2), the issue will be resolved simply by reporting those data (step 3). If the available data are not conclusive, the strategy will follow the remainder of the major branch.

Step 4 shown in Figure 8.3.5.17-1 is an examination of the performance allocation in Issue 1.1. The reason for this step and for two other steps near it in the diagram (5, 6) is the following: a major premise of the licensing strategy for Issue 1.8 is that most of the data needed for resolution are already called for by other issues. Issue 1.1 (total-system performance) is the principal issue that calls for data needed in resolving Issue 1.8 because it is the issue that must consider all the credible scenarios for future events and processes at the site. The list of PACs in 10 CFR 60.122 includes many conditions that might serve as initiating events for credible disruptive scenarios, and for that reason Issue 1.1 has used the list in allocating performance for the assessment of such scenarios. Furthermore, the allocation of performance for the scenarios has relied on the technical judgment of both performance-assessment and geoscience personnel; this effort has been intended to make the allocations in Issue 1.1 responsive to the data needs of Issue 1.8, as well as to the need to address the overall system performance objective adequately.

Thus, Step 4 in Figure 8.3.5.17-1 is a decision on whether the performance allocation for the nominal and disruptive scenarios in Issue 1.1 calls for the data needed for testing the hypothesis that the PAC is not present. If such data are not called for in Issue 1.1, other issues are examined to see whether they address the PAC by calling for the needed data (step 5). If no issue that addresses the PAC is found, the strategy calls for a separate development of data needs for testing the hypothesis that the PAC is not present (step 6).

If Issue 1.1 or some other issue addresses the PAC, the licensing strategy for Issue 1.8 proceeds by examining the allocation made in that issue (step 7). If the site characterization information called for there is judged to be adequate for testing the hypothesis that the PAC is not present,

the allocation is adopted as the licensing strategy for collecting the data needed for resolving the PAC (step 8). As the detailed descriptions of the licensing strategy for each PAC show, Issue 1.1 usually contains an adequate allocation because the PACs were specifically used in constructing the strategy for its resolution. If the allocation is judged inadequate, the strategy requires a separate development of the data needed for resolution (step 6). (The DOE has carried out the work described in the steps leading to this point, and the results are described in the detailed discussion of the strategy for each PAC.) Data called for by the licensing strategy will be collected through the site characterization program (described in other sections of the SCP); the diagram shows this collection in a single box (step 8).

The remaining steps in Figure 8.3.5.17-1 describe the DOE plans for work after site characterization has provided the requested information. The DOE will decide whether the data are adequate for testing the hypothesis that the PAC is not present (step 9). In other words, the DOE will decide whether the investigation that provided the data is likely to be judged adequate in the licensing proceedings. If the investigation is found adequate, the DOE will consider the issue resolved (step 10). If the investigation is not found adequate, the DOE must decide (step 11) whether the information suggests a change in the overall strategy for the PAC: should the strategy be to test the hypothesis that the PAC is present? If the answer is yes, the steps to be followed appear in the left branch of Figure 8.3.5.17-1. If the answer is no, the DOE will develop new data needs that will provide an adequate investigation (step 6), and the collection of data (step 8) will begin again.

Demonstration strategy for PACs present at the site--For PACs present at the site, 10 CFR 60.122 offers three options for demonstrating that they do not compromise the ability of the site to isolate the waste. Currently, however, the DOE feels that all the PACs that are present can be shown to meet the particular option allowing for the PACs to be shown "not to affect significantly the ability of the geologic repository to meet the performance objectives relating to isolation of the waste." The strategy shown as the major branch on the left side of Figure 8.3.5.17-1 assumes that those PACs will be treated in the license application according to that option. Figure 8.3.5.17-1 uses the word "significant" as a short form to refer to the option. The possible use of the other two choices appears in the strategy much later--to be used if evidence suggests that the site characterization data will not demonstrate insignificance.

The first steps in the left branch of Figure 8.3.5.17-1 are similar to the first steps in the right branch. The strategy calls first for an examination of Issue 1.1 to see whether the PAC is addressed in the nominal and disruptive scenarios there (step 12); for the reasons explained above, Issue 1.1 is a likely issue in which to find considerations of PACs because it uses the PACs in identifying the scenarios that are credible at the site. If the PAC is not addressed there, other issues are examined to see whether they address the PAC (step 13). If no issue addresses it, the DOE will develop a new performance allocation--i.e., a scenario and the set of data needed for showing the presence and significance of the PAC (step 14).

If an issue is found to address the PAC, the performance allocation in the issue is examined to see whether the data it calls for appear adequate for determining the presence and significance of the PAC (step 15). If the data appear adequate, they are adopted for resolving Issue 1.8. If they do not, the DOE constructs a new performance allocation based on the strategy for showing the presence of the PAC and determining its significance (step 14). (The work described in the steps leading to this point has been done, and the results are described in the explanation of the strategy for each PAC). The data called for by the licensing strategy will be collected as part of the site characterization program described in other sections of the SCP (step 16).

The remainder of the left branch of Figure 8.3.5.17-1 describes the issue-resolution steps that the DOE expects to take after site characterization has provided the needed information. The collected data may show that, contrary to the expectation embodied in the licensing strategy, the PAC is not present at the site (step 17). If it is not present, the DOE will change the strategy for dealing with the PAC, and the figure therefore shows a decision that leads to the major right branch of the diagram (step 2).

The statements of some PACs in 10 CFR 60.122 do not refer simply to the presence of a condition; for such a PAC to be shown present, the condition must be shown to adversely affect the performance of a repository. For example, PAC 5 refers not simply to the presence of a potential for changes in hydrologic conditions but to the presence of a potential for changes "that would affect the migration of radionuclides to the accessible environment." Such PACs cannot be shown to be present in step 17 alone. Their presence can be shown only after subsequent steps in the strategy have examined their effect on performance, which, as explained above, Figure 8.3.5.17-1 refers to as their "significance."

If step 17 has failed to show that the PAC is not present at the site, the DOE will use the site characterization information in analyses intended to determine whether the PAC is significant in the sense of 10 CFR 60.122 (step 18). These analyses will not necessarily trace the contribution of the PAC to the full cumulative complementary distribution function (CCDF) required for resolving Issue 1.1 (Section 8.3.5.13). An elaborate model of the total system will be used in deriving the CCDF, but it will often be possible to use simpler models of the system or its subsystems to see whether the presence of a PAC changes the characteristics (e.g., the performance parameters) of the site enough to affect waste isolation. The analyses of significance will include sensitivity and uncertainty studies in order to provide confidence that the conclusions derived from the system or subsystem analyses are justified by the data they use and the assumptions they make. Step 18 in Figure 8.3.5.17-1 represents the performance of these analyses.

All these analyses--(calculations using total-system models or simpler subsystem models, sensitivity studies, uncertainty studies)--will contribute to the decision on whether the PAC is significant. That decision, shown as step 19 in the figure, will rely on both the results of the analyses and expert professional judgment in the technical fields appropriate to studies of the PAC. Whether the decision is that the PAC is or is not significant, several steps remain in the strategy before the issue can be resolved, and Figure 8.3.5.17-1 shows a separate branch for each of the two outcomes.

If the analyses fail to show that the PAC is not significant, the analyses themselves must be examined to make sure that the methods they use are realistic representations of the effects of the PAC (step 20). The reason such an examination is necessary is that many analyses of repository performance will make conservative assumptions intended to overestimate adverse effects. Such assumptions are usually appropriate for licensing decisions because they contribute to the required reasonable assurance that the performance objectives will be met. Moreover, they generally make the analyses easier to perform and easier to understand than the complex analyses that are less conservative but more realistic. If these assumptions are overly conservative, however, predictions based on them could overestimate the effects of a PAC so severely that the actual effects of the PAC would be obscured. Before concluding that a PAC has significant effects on performance, therefore, the DOE would examine the methods used in the analyses of significance to be sure that they are realistic enough to give reliable predictions. Figure 8.3.5.17-1 shows this step (20) as a decision in the issue-resolution strategy. Step 20 also shows an examination of whether the site characterization investigations have been adequate for the determination of significance. If the analyses are found realistic and the investigations adequate, the DOE will abandon the strategy of showing that the PAC is present and not significant.

The next step, shown in Figure 8.3.5.17-1, is to decide whether the strategy should adopt either of the other two options--remediation or compensation by a combination of favorable conditions--for showing that the PAC does not compromise waste isolation (step 21). If neither option appears feasible for the PAC, the DOE expects to interpret the analyses as showing that the PAC is present and does indeed compromise performance (step 22). If one of the options appears feasible, the DOE expects, as shown in the diagram, to develop a new strategy showing that remediation or compensation can be demonstrated and that the PAC will not compromise performance (step 23).

If, on the other hand, either the analyses or the investigation is found unacceptable, the strategy calls for the DOE to reformulate the analysis methods or the scope of the investigations in an attempt to make the decision on significance better reflect the conditions at the site (step 24). As Figure 8.3.5.17-1 shows, such a step would be followed by a decision on whether the new methods or the new scope requires that additional data be collected (step 25). If more data are needed, new data needs are developed (step 26); and the strategy calls for a reiteration through the collection of data. If more data are not needed, the strategy calls for the question of significance to be revisited through new calculations (step 18).

If the analyses of significance show the PAC to be not significant, the strategy calls for answers to two further questions that express requirements of 10 CFR 60.122. The question shown first in Figure 8.3.5.17-1 asks whether the investigations have been adequate (step 27). The DOE expects that this question will be answered primarily through expert review of the data-collection program; the regulations give no guidance on how the adequacy is to be assessed. If the answer to this question is no, new data needs will be developed to ensure that the program is adequate (step 28). If the answer is yes, the strategy proceeds to the second question.

The second question addresses the requirement in 10 CFR 60.122(a)(2)(ii) that the evaluation of the PAC be done with analyses that are sensitive to "the potentially adverse human activity or natural condition" and that use assumptions that "are not likely to underestimate its effect" (step 29). The DOE expects to perform sensitivity analyses as adjuncts to the analyses of significance. This work will demonstrate that the methods are sensitive in the sense required, and it will contribute to a demonstration that the effects have not been underestimated. Further examination of the answer to this question will come from expert review of the analyses themselves.

If the answer to the second question is no, the strategy calls for the cycle of reformulating the analysis methods and investigations (step 24), possibly collecting more data (steps 25, 26, and 16), and again evaluating the significance of the PAC (step 18). If the answer is yes, the PAC will have been shown to be present but not to significantly affect the ability of the site to isolate waste (step 30).

It should be emphasized that the DOE does not expect to perform steps 20, 27, and 29 only in the strict order shown in Figure 8.3.5.17-1. The questions of adequacy and realism will not, for example, be left unexamined until the analyses have been finished. These questions will be considered throughout site characterization as the DOE constructs and manages a program that will produce the information needed for the license application. The actual order of these steps is somewhat arbitrary; the important point to be drawn from the figure is that they must all be completed before Issue 1.8 can be resolved.

Strategy for favorable conditions

Figure 8.3.5.17-2 shows the major steps that the DOE intends to take in resolving Issue 1.8 for each favorable condition (FC) listed in 10 CFR 60.122. The figure, which is an expansion of the general issue-resolution strategy shown in Section 8.1, outlines the licensing strategy and the subsequent steps that will lead to the final resolution of Issue 1.8 for each FC. The steps in the licensing strategy--i.e., the steps up to the collection of site characterization data--were carried out in preparing this section, and have been used in the development of the site characterization program presented in other parts of Section 8.3.

The following detailed explanation of the figure describes all the steps and the reasoning behind them. The explanation is intended to guide the reader's understanding of the detailed discussions that, later in Section 8.3.5.17, explain how the licensing-strategy decisions were made for each FC. To keep the section as concise as possible, those detailed discussions omit many of the general principles that underlie the strategy they follow. The following explanation supplies those principles. The steps in the figure are numbered to aid the reader in following the explanation.

The first step in the licensing strategy for dealing with each FC is to adopt a tentative strategy on whether the license application will show that the FC is present at the Yucca Mountain site (step 1). This decision has been based on the evidence currently available to the DOE. As Section 8.1 explains in detail, the tentative decisions adopted for licensing strategies

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Figure 8.3.5.17-2. Logic diagram for resolving Issue 1.8 for favorable conditions (FCs). The text discussion is keyed to the numbers in this diagram.

will be changed if evidence acquired in the future shows them to be technically unsound. For now they are simply a basis for planning site characterization.

If the DOE adopts a strategy for showing that the FC is not present at the site, no further action is planned (step 2). As far as the FC is concerned, Issue 1.8 will have been resolved, and the FC will be assumed in the license application to be not present at the site.

If the DOE adopts a strategy for testing the hypothesis that the FC is present at the site, several steps remain to be carried out before the issue can be resolved. The strategy calls first for an examination of Issue 1.1 to see whether the performance allocation there calls for site characterization data that can be used in determining whether the FC is present. As discussed in the explanation of the strategy diagram for potentially adverse conditions (Figure 8.3.5.17-1), the reason for this step and for two other steps near it in the diagram is the following: a major premise of the licensing strategy for Issue 1.8 is that most of the data needed for resolution are already called for by other issues. Issue 1.1 (total system performance) is the principal issue that calls for data needed in resolving Issue 1.8. It is particularly important to the strategy for dealing with FCs. The list of FCs in 10 CFR 60.122 includes many conditions that are expected to contribute to the performance of the Yucca Mountain site; these conditions are included in the scenarios that Issue 1.1 has developed for allocating performance to the elements of the site that will contribute to isolating the emplaced waste. This allocation of performance has relied on the technical judgment of both performance assessment and geoscience personnel; this reliance has been important in making sure that the allocations in Issue 1.1 are responsive to the qualitative as well as the quantitative data needs of Issue 1.8.

The next step in Figure 8.3.5.17-2, therefore, is a decision on whether the site characterization data called for in the performance allocation for Issue 1.1 appear adequate for testing the hypothesis that the FC is present (step 3). If these data appear adequate, they are adopted as the licensing strategy for collecting the data that will determine the presence or absence of the FC. If the data in Issue 1.1 do not appear adequate, other issues are examined to see whether they call for the needed data (step 4). If no issue that addresses the FC is found, the strategy calls for a separate development of data needs for testing if the FC is present (step 5). Site characterization can then proceed to collect the needed data (step 6). The steps shown in Figure 8.3.5.17-2 up to the collection of data have been carried out and are reported later in this section. In actual practice, as the detailed descriptions of the individual FCs point out, the data called for by Issue 1.1 have proved sufficient for defining the strategy for dealing with each FC.

After the site characterization program has collected the data called for in the licensing strategy, the DOE examines the investigation that provided the data to decide whether the investigation is adequate for a conclusive decision on the presence or absence of the FC. This decision will be based on expert judgment after a careful review of the site studies (step 7). If the investigation is found to have been inadequate, the DOE will develop a new set of data needs for deciding on the presence or absence of the FC, as the figure shows in a return to an earlier step (5). It should be

emphasized that the DOE will not actually wait until after site characterization to examine the adequacy of the investigation. Such examination is a part of planning the investigations, and it will continue through the site characterization period. As shown in Figure 8.3.5.17-2, however, an examination for adequacy must precede the determination of the presence or absence of the FC.

If the investigation is found to have been adequate, the DOE will proceed to decide whether the FC is present or absent at the site (step 8). This decision will be made primarily through expert judgment and peer review, which will, of course, be aided by the quantitative data collected in response to the calls made by the licensing strategy. If the FC is determined in this way not to be present, Issue 1.8 will have been resolved for the FC: the DOE, as shown in the diagram, will conclude that, contrary to the tentative position adopted for the licensing strategy, the FC is not present at the site (step 2). If the determination is that the FC is present, Issue 1.8 will also have been resolved and the license application will present the analyses to show that the FC is present at the site (step 9). These analyses will explicitly take into account the functions of the FCs in enhancing isolation; they are also expected to use the presence of FCs in contributing to the demonstration of reasonable assurance.

Discussion of the potentially adverse conditions

This section presents individual discussions of the PACs listed in 10 CFR 60.122. For each PAC the discussion identifies the tentative strategy (present or not present) called for in step 1 of Figure 8.3.5.17-1. The potential effects of the PAC and their expected significance on performance are discussed, and the site characterization data needed for addressing the PAC are specified. The general method for identifying the needed data is similar for each PAC; it is explained here to avoid repeating it in each discussion.

As mentioned in the text accompanying the logic diagram for dealing with PACs (Figure 8.3.5.17-1), a preliminary set of scenarios has been developed for Issue 1.1, which covers the overall performance objective on cumulative radionuclide release to the accessible environment. Because the number of different scenarios could be unmanageably large, they have been grouped into classes; the scenarios within a class can be dealt with similarly and require similar data for this evaluation. These classes help to focus the site characterization program on potentially significant processes and events that may affect the ability of the geologic repository to meet the system performance objective. A scenario class (the nominal case) has been developed for undisturbed conditions due to likely natural events. Other scenario classes have been developed for disturbed conditions, i.e., those due to unlikely natural events and human intrusion. These scenario classes are discussed in detail in Section 8.3.5.13.

The preliminary scenario classes focus on the particular events and processes that are considered potentially significant for the Yucca Mountain site. Their development has taken into account the PACs specified in the siting criteria of 10 CFR 60.122; each PAC can be associated with one or more of the scenario classes. Performance measures and goals consistent with meeting the overall system performance objective have been selected for these

scenario classes. Parameters and tentative parameter goals needed to evaluate these performance measures have also been identified. (Section 8.1 explains the special meanings used in performance allocation for such terms as "performance measure," "goal," and "parameter.") The values chosen for the parameter goals are consistent with the performance-measure goals in the following sense: if the parameter goals are achieved, the performance-measure goals will probably also be achieved. In other words, the calculation of cumulative release to the accessible environment is likely to show compliance with the overall performance objective if the site characterization data provide confidence that the parameter goals have been met.

Because they were set for consistency with the overall performance objective, the goals for the parameters in a particular scenario class are suitable for addressing the testing needed for the PACs associated with that scenario class. The data needs for each scenario class have been derived from the performance parameters, which address effects on waste isolation; for this reason, they are considered appropriate for guiding the testing needed to determine the significance of the PACs associated with those scenario classes. The application of this method for deriving data needs is discussed for each PAC individually in this section.

This discussion reports a comparison of each PAC with the relevant scenario classes, i.e., the comparison called for in steps 4, 7, 12, and 15 of Figure 8.3.5.17-1. This comparison uses available information and the tentative strategy in examining the nominal and disruptive scenarios to identify the relevant data needs.

Information to determine the performance parameters for these scenario classes will be obtained in the characterization programs. The complete specification of the data needs for each potentially adverse condition, therefore, includes (in addition to the relevant scenario classes, performance parameters, and goals) the SCP sections that describe the characterization programs to obtain the information needed to determine the parameters. The following discussions of the PACs contain tables that summarize this specification.

The postclosure characterization programs are discussed in detail in Section 8.3.1 according to the following topical breakdown: geohydrology, geochemistry, rock characteristics, climate, erosion, dissolution, tectonics, and human interference. These topical areas may be addressed in more than one potentially adverse condition depending on the actual wording found in 10 CFR 60.122. Some readers may be interested in determining which potentially adverse conditions are of interest to particular technical disciplines. To assist such readers, the following is a general guide stating the topical breakdown in terms of the potentially adverse conditions they treat. Geohydrology data are requested by PACs 1 to 8, 11 to 15, and 22 to 24; geochemistry data by PACs 7 to 9 and 24; rock-characteristics data by PACs 4, 5, 7, 8, 11 to 14, 20, and 21; climate data by PACs 5, 6, 22, and 23; erosion data by PAC 16; dissolution data by PAC 10; tectonics data by PACs 3 to 5, 7, 8, 11 to 15, 22, and 23; and human interference data by PACs 2, 5, 9, 17 to 19, and 22.

Potentially adverse condition 1: Potential for flooding of the underground facility, whether resulting from the occupancy and modification of floodplains or from the failure of existing or planned man-made surface water impoundments.

This PAC addresses a condition occurring before closure that could affect postclosure performance (statements of consideration, 10 CFR Part 60). Flooding of the underground facility during the preclosure period could result in conditions, such as standing pools of water, that could adversely affect the performance of the waste package.

Because of the rugged terrain and meteorological conditions at the Yucca Mountain site, local intense flooding occurs periodically in the normally dry washes draining down from the Yucca Mountain ridge (Section 3.2.1). Preliminary investigations of the 100- and 500-yr floods have determined that the 100-yr flood would not exceed the banks of incised channels of Fortymile Wash or its major tributaries (Yucca, Drill Hole, and Busted Butte washes). The 500-yr flood, however, could exceed the banks of Busted Butte and Drill Hole washes. The available evidence, therefore, suggests that this PAC may be present. The strategy for resolution of this PAC is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

This PAC is expected to be fully addressed by design of the systems that will take into account the probable maximum flood (PMF) (Section 6.1.2.6). This method has been successfully used by the U.S. Army Corps of Engineers for dam design and by the nuclear power industry for protection of safety-related facilities. The underground entries at the repository site will be protected against the PMF by diverting the upland runoff. Also, finish grade elevations will be set above the PMF levels.

Site characterization data will be collected in support of the design activities that will provide for this protection from preclosure flooding. Those data are also, therefore, the data to be used in the resolution of PAC 1. They are developed and presented in Section 8.3.2.5, which also lists the site characterization activities for collecting the data. The needed information consists of the surface-hydrology data that will permit descriptions of the 5-, 25-, 50-, 100-, and 500-yr floods, the PMF, and the corresponding areas of inundation. As explained in Section 8.3.2.5, these data are stream flow rates, quantities, durations for surface water systems at the site, and descriptions of channel morphology.

Because PAC 1 will be addressed by the design of the repository system, its resolution, unlike that of most other PACs, does not depend on data called for by Issue 1.1. The strategy for resolving Issue 1.1 does not call for explicit modeling of preclosure flooding of the underground repository. Neither the nominal-case scenario nor the disturbed-performance scenario classes include such flooding. If it is determined later that such a scenario class should be developed, the information needed to evaluate it could be found in the data needs of the scenario classes that address increased

moisture flux through the repository (scenario class C-1) and water-table rise (scenario class C-2). These two scenario classes are discussed in Section 8.3.5.13.

Potentially adverse condition 2: Potential for foreseeable human activity to adversely affect the ground-water flow system, such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activity or construction of large scale surface water impoundments.

This PAC is concerned with future human activities that could alter the ground-water flow system to adversely affect the waste-isolation capabilities of a site. Isolation could be adversely affected, for example, by decreasing the ground-water travel time to the accessible environment, thereby increasing the rate of transport to the accessible environment of radionuclides dissolved in the ground water. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Assessing the potential for human activity at a site presents special problems because of the dependence upon future, unpredictable activities of humans (Section 8.3.1.9). Quantitative estimates of the absolute probability of human activities (e.g., ground-water withdrawal) in the distant future may not be feasible. For this reason, the DOE may not incorporate the effects of such activities into the cumulative probability distribution that will demonstrate compliance with the overall performance objective in 10 CFR 60.112. Instead, the DOE may consider such effects in separate evaluations. The treatment of such events and processes will, however, follow an approach similar to that for the natural processes and events: the effects of potentially adverse human activities will be evaluated, appropriate scenario classes will be developed, and relative probabilities and consequence for these scenarios will be estimated. The data needed for resolving PAC 2 and other conditions produced by human activity can be found among the scenario classes of Section 8.3.5.13.

In the evaluation of future human activities that could affect post-closure performance (in the overall system performance assessment), the following were identified as potential future activities at the Yucca Mountain site: exploratory drilling, extensive irrigation near the controlled area, the construction of large-scale surface water impoundments near the controlled area, extensive surface or subsurface mining near the controlled area, and extensive ground-water withdrawal near the controlled area. Preliminary disturbed-performance scenario classes have been developed for these activities.

In the development of the scenario class for exploratory drilling, it was concluded that significant adverse effects in the ground-water flow system are not sufficiently credible to warrant consideration. For the other scenario classes, it was concluded that potentially significant effects on the ground-water flow system include an increase in percolation flux through

the unsaturated zone, an increase in the ground-water-table altitude, changes in rock-hydrologic properties of the unsaturated zone, an increase in head gradients, and changes in rock-hydrologic properties of the saturated zone.

No scenario classes are developed explicitly for subsurface injection of fluids, underground pumped storage, and military activity. Subsurface injection of fluids and underground pumped storage are considered unlikely at the Yucca Mountain site. The presence of ground-water resources at the site preclude subsurface injection of fluids, and the geohydrologic conditions at Yucca Mountain are not conducive to underground pumped storage. The DOE has judged that additional site data are not needed to demonstrate that these human activities are not likely to occur and that they are, therefore, not likely to adversely affect repository performance. The strain generated from large-scale weapons testing may have an effect on the hydrologic conditions at the site; however, these effects are expected to be less significant than those from natural seismic activity (Section 1.4). The seismic effects of weapons testing are considered to be bounded by the scenario classes for tectonic disturbances (see, for example, the discussions of PACs 3, 4, and 11).

Table 8.3.5.17-3 lists the scenario classes associated with this PAC that are being investigated in the system performance assessments. The performance parameters associated with these scenario classes are also shown. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-3. Table 8.3.5.17-3 also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 3: Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitude that large-scale surface water impoundments could be created that could change the regional ground-water flow system and thereby adversely affect the performance of the geologic repository.

This PAC is concerned with naturally formed surface-water impoundments that could adversely affect postclosure performance at a site. For example, if surface-water impoundments were to form, an increase in percolation through the unsaturated zone, and subsequently an increase in radionuclide transport rate, could result.

There is no substantial evidence of large-scale, rapid episodes of mass wasting, such as rock slides, debris avalanches, and earth flows, at the site (Section 1.1.3); thus, no disruptive scenario class was developed to explicitly address this process. Volcanic and tectonic processes, on the other hand, are believed to have the potential to alter the topography in such a way that surface-water impoundments could form over the next 10,000 yr. The available information, however, indicates that these events are not likely to adversely affect the performance of the geologic repository. Therefore, the strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Table 8.3.5.17-3. Scenario classes and parameters associated with potentially adverse condition 2^a
(page 1 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Extensive irrigation is conducted near the C-area ^c (judged not a credible scenario; see Section 8.3.1.9.3.2)	Expected magnitude of flux change due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	8.3.1.9.3 Area irrigated, net water consumption, and crop and evapotranspiration rates Infiltration rates Unsaturated-zone flow model	8.3.1.9.3.2.2(D), 8.3.1.9.3.2 8.3.1.2.2.1.2 8.3.1.2.2.9 or 10
	Expected magnitude of change in head gradients of the saturated zone in C-area due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	8.3.1.9.3 Area irrigated, net water consumption, and crop and evapotranspiration rates Infiltration rates Unsaturated-zone flow model Saturated-zone flow models	8.3.1.9.3.2.2(D), 8.3.2.9.3.2 8.3.1.2.2.1.2 8.3.1.2.2.9 or 10 8.3.1.2.1.4.4, 8.3.1.2.3.3.3

Table 8.3.5.17-3. Scenario classes and parameters associated with potentially adverse condition 2^a
(page 2 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Extensive ground-water withdrawal occurs near C-area	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)	8.3.1.9.3 Area irrigated, net water consumption, and crop and evapo-transpiration rates	8.3.1.9.3.2.2(D), 8.3.2.9.3.2
			Infiltration rates	8.3.1.2.2.1.2,
			Unsaturated-zone flow model	8.3.1.2.2.9 or 10
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Extensive ground-water withdrawal occurs near C-area	Expected magnitude of change in water-table level due to extensive ground-water withdrawal near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 Locations, hydro-stratigraphic sources, and rates of withdrawal	8.3.1.9.2.2, 8.3.1.16.2.1
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Expected magnitude of changes in gradient of water table under C-area due to ground-water withdrawal near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 Locations, hydro-stratigraphic sources, and rates of withdrawal	8.3.1.9.2.2, 8.3.1.16.2.1

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Table 8.3.5.17-3. Scenario classes and parameters associated with potentially adverse condition 2^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Extensive surface or subsurface mining occurs near C-area	Expected magnitude of change in water-table level due to mine water use or mine dewatering near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 (No change expected)	
			Rates and locations of dewatering	8.3.1.9.3.2.2
	Expected magnitude of change in gradient 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)	Saturated-zone flow model	8.3.1.2.3.3.3
			8.3.1.9.3 (No change expected)	8.3.1.9.3.2.2
			Rates and locations of dewatering	8.3.1.9.3.2.2
			Saturated-zone flow model	8.3.1.2.3.3.3
Large scale surface-water impoundments are constructed near the C-area	Expected magnitude of flux change due to presence of an artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 (No change expected)	
			Area, depth, flow input, rate of impoundment	8.3.1.9.3.2.2(D), 8.3.1.9.3.2

Table 8.3.5.17-3. Scenario classes and parameters associated with potentially adverse condition 2^a
(page 4 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
	Expected magnitude of change in water-table level due to placement of artificial lake near C-area in next 10,000 yr	No goal (human activity)	Infiltration/ percolation rates	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.9
			8.3.1.9.3 (No change expected)	8.3.1.9.3.2.2(D), 8.3.1.9.3.2.2
			Area, depth, flow input, rate of impoundment	8.3.1.9.3.2
			Infiltration/ percolation rates	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.9 or 10
	Expected magnitude of changes in head gradients of the saturated zone in C-area due to presence of an artificial lake near C-area in next 10,000 yr	No goal (human activity)	Saturated-zone flow models	8.3.1.2.3.3.3
			8.3.1.9.3 (No change expected)	8.3.1.9.3.2.2(D), 8.3.1.9.3.2.2
			Area, depth, flow input, rate of impoundment	8.3.1.9.3.2
			Infiltration/ percolation rates	8.3.1.2.2.1.2

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Table 8.3.5.17-3. Scenario classes and parameters associated with potentially adverse condition 2^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
			Unsaturated-zone flow model	8.3.1.2.2.9 or 10
			Saturated-zone flow models	8.3.1.2.3.3.3
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	Show there is >50% chance that markers are readable over next 10,000 yr	8.3.1.9 Rates of processes decreasing survival period, visibility, or readability of markers	8.3.1.9.3.1.1(D), 8.3.1.9.1.1

^aInformation on scenario classes, performance parameters, and tentative parameter goals is from Section 8.3.5.13.

^bStudy or activity directly addresses scenario.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

Additional information is required for testing the presence or absence of this PAC. Information to be obtained in the site characterization program with regard to the effect of natural surface-water impoundments is defined by disturbed-performance scenario classes. The relevant scenario classes defined in Section 8.3.5.13 are identified in Table 8.3.5.17-4, which also gives the associated parameters and goals. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-4. Table 8.3.5.17-4 also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 4: Structural deformation, such as uplift, subsidence, folding or faulting, that may adversely affect the regional ground-water flow system.

This PAC is concerned with future structural deformation and tectonic activity that could affect the regional ground-water flow system in such a way that a site's ability to isolate waste would be impaired. The flow system could, for example, be disrupted if tectonic processes could increase the percolation flux through the repository horizon, increase the altitude of the ground-water table, change the head gradients in the saturated zone, or create surficial discharge points within the boundaries of the accessible environment.

Quaternary rupture on 32 faults within an $1,100\text{-km}^2$ area surrounding the site has been documented, with evidence of movement on five of the faults within the past 270,000 yr (Section 1.3.2). Also, the region is currently undergoing active lateral crustal extension. Local patterns of uplift, tilting, and subsidence near Yucca Mountain are typical of shallow crustal response to regional extension and attendant volcanic activity in the Great Basin (Section 1.3.2.4).

According to the available information, these conditions are not likely to affect significantly the ability of the geologic repository to meet the performance objectives relating to isolation of the waste. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Additional information is required for evaluating the presence or absence of this PAC. Faulting, folding, uplift, or subsidence that could affect the ground-water flow system in such a way as to significantly increase the probability of cumulative releases to the accessible environment was found unlikely or not credible during the development of the scenario classes for disturbed performance of the geologic repository (see Section 8.3.5.13). The nominal-case scenario includes these tectonic processes only at their expected rates, which would not produce significant effects. Therefore, the information needed to investigate such effects is to be obtained in terms of scenario classes for unlikely natural events. Table 8.3.5.17-5 lists the scenario classes similar to those that will be considered in the overall system performance assessment, and the performance parameters that will be addressed. To address this PAC explicitly, the tectonic scenario classes listed in Table 8.3.5.17-5 will be considered on a broader, regional scale, rather than the controlled-area scale that is addressed in the total system performance assessment. Table 8.3.5.17-5 also

Table 8.3.5.17-4. Scenario classes and parameters associated with potentially adverse condition 3^a
(page 1 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Offset on fault creates surface impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds	Probability of offset >2 m on faults in the C-area ^c in 10,000 yr	<10 ⁻¹	8.3.1.8 Vertical slip rate and recurrence intervals	8.3.1.8.3.1.5(D), 8.3.1.8.3.1.3,, 8.3.1.17.4.6.2, 8.3.1.17.4.4.3
	Probability of changing dip by >2° in 10,000 yr by faulting	<10 ⁻⁴	8.3.1.8 Rates of vertical slip and tilting	8.3.1.17.4.6.2
	Effect of faulting on flux	Faulting will not affect flux because of low slip rates	8.3.1.8 Locations of faults Runoff estimates Unsaturated-zone flow model	8.3.1.8.3.1.4, 8.3.1.17.4.6, 8.3.1.17.4.7, 8.3.1.17.4.12 8.3.1.5.2.2.1 8.3.1.2.2.6

Table 8.3.5.17-4. Scenario classes and parameters associated with potentially adverse condition 3^a
(page 2 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Volcanic eruption causes flows or other changes in topography that result in impoundment or diversion of drainage	Annual probability of volcanic events within C-area	$<10^{-5}$ /yr	8.3.1.8 Probability of volcanic event	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of volcanic event on topography and flow rates	Topographic changes are not great enough to affect flux	8.3.1.8 Topographic effects of eruptions	8.3.1.8.1.2.1, 8.3.1.8.1.2.2

^aInformation on scenario classes, performance parameters, and tentative parameter goals is from Section 8.3.5.13.

^bStudy or activity directly addresses scenario.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

Table 8.3.5.17-5. Scenario classes and parameters associated with potentially adverse condition 4^a
(page 1 of 4)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Episodic offset on faults causes local changes in rock hydrologic properties thereby destroying existing barriers to flow or creating new conduits for drainage	Annual probability of 1-m displacement on Quaternary faults within 0.5 km of C-area ^c boundary	<10 ⁻⁴ per year	8.3.1.8 Locations, slip rates and recurrence intervals for Quaternary faults at the site and in the region	8.3.1.8.3.3.2(D), 8.3.1.17.4.3, 8.3.1.17.4.4, 8.3.1.17.4.5, 8.3.1.17.4.6.2, 8.3.1.17.4.7, 8.3.1.17.4.2
	Effects of fault motion on local permeabilities and effective porosities	Change in fracture permeability is less than a factor of 2; fracture porosity decreases	8.3.1.8 Evidence of episodic rock-property changes along faults	8.3.1.4.2.2.3, 8.3.1.4.2.2.4, 8.3.1.4.2.2.5, 8.3.1.2.1.4, 8.3.1.2.3.1, 8.3.1.2.3.3
Offset on fault creates impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds	Probability of offset >2 m on a fault in the C-area in 10,000 yr	<10 ⁻¹	8.3.1.8 Offsets, slip rates, and recurrence intervals for Quaternary faults at the site and in the region	8.3.1.8.3.1.5(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.12

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Table 8.3.5.17-5. Scenario classes and parameters associated with potentially adverse condition 4^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
	Probability of changing dip by $>2^\circ$ in 10,000 yr by faulting	$<10^{-4}$ per 10,000 yr	8.3.1.8 Rates of vertical slip and tilting at the site and in the region	8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.12
	Effect of faulting on flux in the C-area	Faulting will not affect flux because of low slip rate	8.3.1.8 Locations of faults in the C-area and in the region Saturated-zone flow models	8.3.1.8.3.1.4, 8.3.1.17.4.6, 8.3.1.17.4.7, 8.3.1.17.4.12 8.3.1.5.2.2.1, 8.3.1.2.2.9 8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Offset on faults juxtaposes transmissive and nontransmissive units, resulting in the creation of a perched aquifer, a rise in the water table, or a change in hydraulic gradients	Probability of total offsets >2.0 m in 10,000 yr on faults within C-area boundary	$<10^{-1}$	8.3.1.8 Offsets, slip rates, and recurrence intervals for Quaternary faults at the site and in the region	8.3.1.8.3.1.5(D), 8.3.1.8.3.2.6(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.12

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Table 8.3.5.17-5. Scenario classes and parameters associated with potentially adverse condition 4^a
(page 3 of 4)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
	Effects of fault offsets on water-table levels and hydraulic gradients	Expected magnitude of change in water-table altitude will not bring water table to within 100 m of repository horizon in 10,000 yr	8.3.1.8 Locations of faults in C-area and in region Unsaturated-zone flow model Saturated-zone flow models	8.3.1.5.3.1.5, 8.3.1.17.4.6, 8.3.1.17.4.7, 8.3.1.17.4.12 8.3.1.2.2.9 8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Episodic changes in strain in the rock mass due to faulting cause changes in water-table level	Probability that strain-induced changes increase potentiometric level to >850 m mean sea level	<10 ⁻⁵ /yr	8.3.1.8 Magnitudes and rates of strain changes in region, relation of hydraulic properties to strain Saturated-zone flow model	8.3.1.8.3.2.3(D), 8.3.1.17.4.8.1, 8.3.1.17.4.8.4, 8.3.1.17.4.12.1 8.3.1.8.3.3.3, 8.3.1.8.1.4.4 8.3.1.8.3.3.3

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Table 8.3.5.17-5. Scenario classes and parameters associated with potentially adverse condition 4^a
(page 4 of 4)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Tectonic folding changes dip of tuff beds in C-area, thereby changing flux	Probability of changing dip by >2° in 10,000 yr by folding	<10 ⁻⁴ per 10,000 yr	8.3.1.8 Rates of folding in region	8.3.1.8.3.1.7(D), 8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6
Uplift or subsidence changes drainage, thereby changing flux	Probability of exceeding 30-m elevation change in 10,000 yr	<10 ⁻⁴ per 10,000 yr	8.3.1.8 Rates of uplift and subsidence in region	8.3.1.8.3.1.7(D), 8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3
Folding, uplift, or subsidence lowers repository with respect to water table	Probability that repository will be lowered 100 m through action of folding, uplift, or subsidence in 10,000 yr	<10 ⁻⁴ per 10,000 yr	8.3.1.8 Rates of subsidence in region Rates of folding in region	8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3, 8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6

^aInformation on scenario classes, performance parameters, and tentative parameters is from Section 8.3.5.13.

^bStudy or activity directly addresses scenario.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

lists the site characterization data to be collected to address this PAC and the associated studies or activities in the SCP. These data will be used to evaluate the effects of tectonic processes on the regional flow regime (such as water-table rises and flow-path changes). If these processes appear to produce significant changes in the larger-scale flow system, the effects on local flow-system behavior will be evaluated along with their effects on meeting the site-related parameter goals listed in the table. As explained in the introduction to the PAC discussions, these goals are those associated with the scenario classes developed for the total-system performance assessments (Section 8.3.5.13).

Potentially adverse condition 5: Potential for changes in hydrologic conditions that would affect the migration of radionuclides to the accessible environment, such as changes in hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.

This PAC is concerned with future changes in hydrologic conditions that could adversely affect the isolation capabilities of the site. Changes in hydrologic conditions could, for example, reduce the ground-water travel time, thereby increasing the rate of radionuclide transport to the accessible environment.

As discussed in Sections 8.3.5.12 and 8.3.5.13, hydrologic properties at the Yucca Mountain site could be altered by a number of mechanisms, including tectonic processes and events, climatic changes, and human activities. Hydrologic changes that could affect the migration of radionuclides to the accessible environment include increases in percolation flux through the repository horizon, increases in the altitude of the ground-water table, alteration of rock-mass hydrologic properties, the creation of surficial discharge points within the boundaries of the accessible environment, and changes in head gradients in the saturated zone. According to current information, changes of sufficient magnitude to significantly affect the migration of radionuclides are not likely. Therefore, the strategy for resolution of this PAC is to demonstrate that this condition is not present at the Yucca Mountain site.

The effects of tectonic processes, climate changes, and human activities on the ground-water flow system were evaluated with regard to each of the mechanisms previously specified in the development of the scenario classes. The potential for the changes in hydrologic conditions that are likely to occur are considered in the nominal-case scenario in Section 8.3.5.13. The unlikely, disruptive changes are considered in the disturbed-performance scenario classes, from which the information needs to address this PAC follow. Table 8.3.5.17-6 lists the scenario classes from which a potentially significant effect on the ground-water flow system may result and gives the performance parameters associated with these scenario classes. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-6. Table 8.3.5.17-6 also references

Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5^a
(page 1 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Climatic change causes increase in infiltration over C-area ^c	Expected magnitude of flux change due to climatic changes over next 10,000 yr	Expected flux change will be <5 mm/yr	8.3.1.5.2 Future-climate model Infiltration characteristics Unsaturated-zone flow model	8.3.1.5.2.2.2(D), 8.3.1.5.1.6 8.3.1.2.2.1 8.3.1.2.3.2.9
Climatic change causes an increase in altitude of water table	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 be < + 100 m	8.3.1.5.2 Future-climate model Saturated-zone recharge/flow models Paleoclimate synthesis Quaternary discharge areas Analog recharge data Distribution, origin, and age of vein deposits	8.3.1.5.2.2.3(D), 8.3.1.5.1.6 8.3.1.2.3.3 8.3.1.5.1.5 8.3.1.5.2.1.3 8.3.1.5.2.1.4 8.3.1.5.2.1.5

Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5^a
(page 2 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Climatic change causes appearance of surficial discharge points within C-area	Expected locations of surficial discharge points within C-area over the next 10,000 yr; magnitudes of discharges at each location	No surficial discharge points could appear within C-area, given a water-table rise < + 160 m	8.3.1.5.2	
			Future climate model	8.3.1.5.2.2.3(D), 8.3.1.5.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5
			Quaternary discharge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
			Distribution, origin, and age of vein deposits	8.3.1.5.2.1.5
Climatic change causes an increase in the gradient of the water table within the C-area	Expected magnitude of change in water-table gradient due to climatic change over the next 10,000 yr	Change will be < 4 times current value	8.3.1.5.2	
			Future-climate model	8.3.1.5.2.2.3(D), 8.3.1.5.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5
			Quaternary discharge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4

Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5^a
(page 3 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Extensive irrigation is conducted near the C-area	Expected magnitude of flux change due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	Distribution, origin, and age of vein deposits	8.3.1.5.2.1.5
			8.3.1.9.3 Net water-consumption rates	8.3.1.9.3.2.2
			Cropland evapo-transpiration rates	
	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)	Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.9
			8.3.1.9.3 Net water consumption rates, cropland evapo-transpiration	8.3.1.9.3.2.2
			Infiltration characteristics	8.3.1.2.2.1.2

Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5^a
(page 4 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
	Expected magnitude of change in head gradients of saturated zone in C-area due to extensive irrigation near C-area over next 10,000 yr	No goal (human activity)	Unsaturated-zone flow model	8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
			8.3.1.9.3	
			Net water consumption rates, crop-land evapo-transpiration	8.3.1.9.3.2.2
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Large scale surface-water impoundments are constructed near the C-area	Expected magnitude of flux change due to presence of an artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3	
			Impoundment characteristics	8.3.1.9.3.2.2
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.9

Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5^a
(page 5 of 12)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
	Expected magnitude of change in water-table level due to placement of artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 Impoundment characteristics	8.3.1.9.3.2.2
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Expected magnitude of changes in head gradients of saturated zone in C-area due to presence of an artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 Impoundment characteristics	8.3.1.9.3.2.2
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.9
			Saturated-zone flow models	8.3.1.2.1.4.4, 8.3.1.2.3.3.3

Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Extensive surface or subsurface mining occurs near C-area	Expected magnitude of change in water-table level due to mine water use or mine dewatering near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 Locations of mining and dewatering rates Saturated-zone flow model	8.3.1.9.3.2.2 8.3.1.2.3.3.3
	Expected magnitude of changes in gradient 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)	8.3.1.9.3 Locations of mining and dewatering rates Saturated-zone flow model	8.3.1.9.3.2.2 8.3.1.2.3.3.3
Extensive ground-water withdrawal occurs near C-area	Expected magnitude of change in water-table level due to extensive ground-water withdrawal near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 Locations and rates of expected withdrawals Saturated-zone flow model	8.3.1.9.3.2.1(D) 8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Expected magnitude of changes in gradient of water-table under C area due to ground-water withdrawal near C area in next 10,000 yr	No goal (human activity)	8.3.1.9.3 Locations and rates of expected withdrawals Saturated zone flow model	8.3.1.9.3.2.1(D) 8.3.1.2.1.4.4, 8.3.1.2.3.3.3

Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Volcanic eruption causes flows or other changes in topography that result in impoundment or diversion of drainage	Annual probability of volcanic events within C-area	$<10^{-5}$ /yr	8.3.1.8 Probability of volcanic event	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of a volcanic event on topography and flow rates	Topographic changes are not great enough to affect flux	8.3.1.8 Topographic effects of eruption	8.3.1.8.1.2.1, 8.3.1.8.1.2.2
Igneous intrusion causes barrier to flow or thermal effects that alter water table level	Annual probability of igneous intrusion within 0.5 km of C-area boundary	$<10^{-5}$ /yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Barrier-to-flow effects of igneous intrusion on water-table levels	Water-table rise <100 m	8.3.1.8 Locations and geometry of possible intrusions at site Saturated-zone flow model	8.3.1.8.1.2.1 8.3.1.17.4.12.1 8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Thermal effects of igneous intrusions on water-table levels	Water table rise <100 m	8.3.1.8 Locations and geometry of possible intrusions at site	8.3.1.8.1.2.1 8.3.1.17.4.12.1

Table 8.3.5.17 6. Scenario classes and parameters associated with potentially adverse condition 5^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Igneous intrusions, such as a sill, result in a change in flux			Saturated-zone flow model	8.3.1.2.1.4.4,
			Thermal effects near intrusion	8.3.1.2.3.3.3
	Thermal effects of igneous intrusions on hydraulic gradients	Gradient change < factor of 4	8.3.1.8 Thermal effects near intrusion	8.3.1.2.3.3.3
	Annual probability of igneous intrusion in the C-area	<10 ⁻⁵ /yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of an igneous intrusion on flux	Igneous intru- sion will not affect flux because of depth, location, and extent of intrusion	8.3.1.8 Locations and geometry of possible intru- sions at site Unsaturated-zone flow model Saturated-zone flow model	8.3.1.8.1.2.1, 8.3.1.17.4.12.1 8.3.1.2.2.9 8.3.1.2.3.3
Igneous intrusion causes changes in rock hydrologic properties	Annual probability of igneous intrusions within 0.5 km of C-area boundary	<10 ⁻⁵ /yr	8.3.1.8 Probability of igneous intru- sion	8.3.1.8.3.3.1(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1

Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Offset on fault creates impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds	Effects of igneous intrusions on local permeabilities and effective porosities	No significant changes in rock hydrologic properties	8.3.1.8 Locations and geometry of possible intrusions	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Effects of intrusions on hydraulic properties	8.3.1.8.3.3.1
	Probability of offset >2 m on faults in the C-area in 10,000 yr	<10 ⁻¹	8.3.1.8 Vertical slip recurrence intervals	8.3.1.8.3.1.5(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Probability of changing dip by >2° in 10,000 yr by faulting	<10 ⁻⁴	8.3.1.8 Rates of vertical slip and tilting	8.3.1.17.4.6.2
	Effects of faulting on flux	Faulting will not affect flux because of low slip rate	8.3.1.8 Unsaturated-zone flow model	8.3.1.8.3.1.4, 8.3.1.2.2.9

Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
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)	Probability of total offsets >1.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-1}$	8.3.1.8 Slip rates and recurrence intervals	8.3.1.8.3.2.6(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Effects of fault offset on water-table levels and hydraulic gradients	Water-table rise <100 m	8.3.1.8 Fault location and geometry	8.3.1.8.3.2.5, 8.3.1.17.3.1
		Gradients change < factor of 4	Unsaturated-zone flow model Saturated-zone flow model Quaternary water levels	8.3.1.2.2.6, 9, or 10 8.3.1.2.1.4.4, 8.3.1.2.3.3.3 8.3.1.5.2.1.5
Episodic offset on faults causes local changes in rock hydrologic properties, thereby destroying existing barriers to flow, or creating barriers to flow, or creating new conduits for drainage	Annual probability of 1 m displacement on Quaternary faults within 0.5 km of C-area boundary	$<10^{-4}$ per year	8.3.1.8 Slip rates and recurrence intervals	8.3.1.8.3.3.2(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Effects of fault motion on local permeabilities and effective porosities	Change in fracture permeability is < factor of 2; fracture porosity increases	8.3.1.8 Evidence of episodic rock-property changes along faults	8.3.1.4.2.2.3, 8.3.1.4.2.2.4, 8.3.1.4.2.2.5

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Folding, uplift, or subsidence lowers repository with respect to water table	Probability that repository will be lowered relative to water table by 100 m through action of folding, uplift, or subsidence in 10,000 yr	$<10^{-4}$	8.3.1.8 Rates of subsidence Rates of folding	8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3 8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6
Uplift or subsidence changes drainage, thereby changing flux	Probability of exceeding 30-m elevation change in 10,000 yr	$<10^{-4}$	8.3.1.8 Rates of uplift and subsidence	8.3.1.8.3.1.7(D), 8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3
Tectonic folding changes dip of tuff beds in C-area, thereby changing flux	Probability of changing dip by $>2^\circ$ in 10,000 yr by folding	$<10^{-4}$	8.3.1.8 Rates of folding	8.3.1.8.3.1.7(D), 8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6
Changes in stress or strain in C-area resulting from episodic faulting, folding, or uplift cause changes in the hydrologic properties of the rock mass	Effects of changes of stress or strain on hydrologic properties of the rock mass	Changes in conductivity and porosity of rock mass are greater than a factor of 2	8.3.1.8 In situ stress field Magnitude of stress change Stress-strain relationships	8.3.1.8.3.3.3(D), 8.3.1.17.4.8.1 8.3.1.17.4.8.4 8.3.1.4.2.1.3

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Table 8.3.5.17-6. Scenario classes and parameters associated with potentially adverse condition 5^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Episodic changes in strain in the rock mass due to faulting causes changes in water-table level	Probability that strain-induced changes increase potentiometric level to > 850 m mean sea level	<10 ⁻⁸ /yr	Relation of hydraulic properties to strain	8.3.1.8.3.3.3
			8.3.1.8	
			In situ stress field	8.3.1.8.3.3.3(D), 8.3.1.17.4.8.1
			Magnitude of stress change	8.3.1.17.4.8.4
			Stress-strain relationships	8.3.1.4.2.1.3
			Relation of hydraulic properties to strain	8.3.1.8.3.3.3 8.3.1.17.4.12.1
			Rate of stress change	8.3.1.8.3.2.3(D)
			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3

^aInformation on scenario classes, performance parameters, and tentative goals is from Section 8.3.5.13

^bStudy or activity directly addresses scenario.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 6: Potential for changes in hydrologic conditions resulting from reasonably foreseeable climatic changes.

This PAC is concerned with future climatic conditions that could adversely affect the isolation capabilities of a site by disrupting the hydrologic conditions at the site. Changes in hydrologic conditions could result in a decrease in the ground-water travel time from the repository horizon to the boundary of the accessible environment, thereby possibly increasing radionuclide transport to the accessible environment.

On the basis of current information, climatic changes are likely at the Yucca Mountain site during the next 10,000 yr. However, changes sufficient to affect significantly the ability of the geologic repository to meet the performance objectives relating to waste isolation are not likely. That is, changes in the percolation flux, the water-table level in the vicinity of the controlled area, the head gradient in the saturated zone, or the discharge conditions due to reasonably foreseeable climatic changes are not likely to significantly affect the performance of the repository. If the wording of this PAC included an evaluation of the significance of the effect on isolation, the strategy for PAC resolution would be to test the hypothesis that this condition is not present; however, since the PAC, as stated, refers only to the potential for climate-induced hydrologic changes, the strategy for resolution is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

The scenario classes for climatic changes leading to these effects are summarized in Table 8.3.5.17-7. The parameters needed to evaluate this condition and the goals for these parameters are also shown in this table. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-7. This table also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 7: Ground-water conditions in the host rock, including chemical composition, high ionic strength, or ranges of Eh-pH, that could increase the solubility or chemical reactivity of the engineered barrier system.

This PAC is concerned with ground-water conditions that could adversely affect the performance of the engineered barrier system (EBS). The EBS consists of the waste form, the waste container, and an air gap separating the waste container from the borehole wall. Ground-water conditions in a host rock could have an effect on the degradation rate of the waste packages and thus on radionuclide release rates from the EBS. This release rate is directly related to the source term to be used in determining releases to the accessible environment.

Table 8.3.5.17-7. Scenario classes and parameters associated with potentially adverse condition 6^a
(page 1 of 3)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Climatic change causes increase in infiltration over C-area ^c	Expected magnitude of flux change due to climatic changes over next 10,000 yr	Expected flux change will be <5 mm/yr	8.3.1.5.2 Future climate model	8.3.1.5.2.2.2(D) 8.3.1.2.1.6
			Infiltration characteristics	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.9
Climatic change causes an increase in altitude of water table	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 be < + 100 m	8.3.1.5.2 Future-climate model	8.3.1.5.2.2.3(D) 8.3.1.2.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5
			Quaternary discharge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
			Distribution, origin, and age of vein deposits	8.3.1.5.2.1.5

Table 8.3.5.17-7. Scenario classes and parameters associated with potentially adverse condition 6^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Climatic change causes appearance of surficial discharge points within C-area	Expected locations of surficial discharge points within C-area over the next 10,000 yr; magnitude of discharge at each location	No surficial discharge points could appear within C-area, given a water-table rise < + 160 m	8.3.1.5.2 Future-climate model	8.3.1.5.2.2.3(D) 8.3.1.2.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5
			Quaternary discharge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
Climatic change causes an increase in the gradient of the water-table within the C-area	Expected magnitude of change in water-table gradient due to climatic change over the next 10,000 yr	Change will be <4 times current value	Distribution, origin, and age of vein deposits	8.3.1.5.2.1.5
			8.3.1.5.2 Future-climate model	8.3.1.5.2.2.3(D) 8.3.1.2.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5

Table 8.3.5.17-7. Scenario classes and parameters associated with potentially adverse condition 6^a
(page 3 of 3)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
(continued)			Quaternary dis- charge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
			Distribution, origin, and age of vein deposits	8.3.1.5.2.1.5

^aThe information on scenario classes, performance parameters, and tentative parameter goals is from Section 8.3.5.13.

^bStudy or activity directly addresses scenario.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

The corrosion rate of the metallic barriers and the release rates from the waste form are affected by the pH and oxidation-reduction conditions as well as composition of the fluids contacting the waste package. Site data to be collected to address this PAC include the major ion composition of the unsaturated-zone ground waters and the thermal stability of the minerals in the host rock. These data will be used to develop a ground-water model that will be used to show that near-field geochemical processes will not adversely affect EBS performance. During characterization, the ground-water chemistry of the unsaturated zone will be analyzed to ensure that the chemistry falls within the range considered in the testing programs supporting EBS design. The geochemical modeling to reliably predict the emplacement environment will consider the interactions of the host rock and ground waters under expected conditions. The EBS design or material selection may have to be modified if adverse effects are indicated. In addition, ground water is not expected to come into contact with, and thus will not affect, the waste container during the 300-yr containment period. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

The nominal (undisturbed-performance) scenario class in Section 8.3.5.13 takes into account the expected range of geochemical conditions, i.e., variations in ground-water composition, and the EBS design is also based on this range. Disturbed-performance scenario classes have been developed to address changes in ground-water conditions that could adversely affect the EBS performance. Those disturbed-performance scenarios that address this PAC are listed in Table 8.3.5.17-8. These scenarios are applicable because they deal with the ground-water conditions that affect performance of the EBS. Scenarios concerning effects of surface-water impoundments, irrigation, and mining (from Issue 1.1) are not considered to have credible effects on geochemical processes and conditions at the site. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-8. Table 8.3.5.17-8 also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 8: Geochemical processes that would reduce sorption of radionuclides, result in degradation of the rock strength, or adversely affect the performance of the engineered barrier system.

This PAC is concerned with conditions that could significantly affect the site geochemical characteristics related to the transport of radionuclides and performance of the engineered-barrier system (EBS). These conditions could result from the thermal effects of the emplaced waste or from tectonic or human activities that could significantly change the ground-water composition by introducing ground water or other fluids into the isolation system. In principle, tectonic activity could also alter the mineralogic characteristics along the likely radionuclide transport pathways or create new pathways with different mineralogic characteristics; such effects are expected to be minor.

The expected thermal effects of waste emplacement may affect minerals in the tuffs, producing phase changes that may, in turn, affect sorptive

Table 8.3.5.17-8. Scenario classes and parameters associated with potentially adverse condition 7^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Nominal case	Distribution coefficients (K_d s) for Sr, Cs, Pu, Am, C, U, Np, Tc, Zr, I, and Cm in unsaturated-zone units below repository and above water table	$K_d \geq 0$ for I and C. $K_d \geq 0.1$ for other elements under expected temperature range	8.3.1.3 Saturated and unsaturated-zone sorptive properties	8.3.1.3.4(D)
			Solubility of radionuclides	8.3.1.3.5(D)
			Rock-unit mineralogy, petrology, and chemistry	8.3.1.3.2(D)
			Fracture filling mineralogy	8.3.1.3.2(D)
			Unsaturated- and saturated-zone ground-water chemistry	8.3.1.3.1(D)
	Liquid constrictivity/tortuosity factor		Unsaturated- and saturated-zone dispersive and diffusive properties	8.3.1.3.6(D)

Table 8.3.5.17-8. Scenario classes and parameters associated with potentially adverse condition 7^a
(page 2 of 3)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
			Retardation potential changes over 10,000 yr	8.3.1.3.7(D)
Igneous intrusions cause changes in rock geochemical properties	Annual probability of igneous intrusions within 0.5 km of C-area ^c boundary	$<10^{-5}$ /yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.4.1.1(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of igneous intrusions on local rock geochemical properties	Potential changes in mineralogy will not be extensive	8.3.1.8 Locations and geometry of intrusions Mineralogic changes	8.3.1.5.3, 8.3.1.8.1.2.1, 8.3.1.17.9- 4.12.1 8.3.1.3.2.2.2, 8.3.1.8.5.2.2
Tectonic processes cause changes in ground-water table or movement that results in mineralogic changes in C-area	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 will not occur	8.3.1.8 Probability and magnitude of mineralogic changes Rate of mineral alteration	8.3.1.8.4.1.4(D), 8.3.1.8.3.2.2, 8.3.1.8.3.2.3, 8.3.1.8.3.2.4, 8.3.1.8.3.2.6 8.3.1.3.2.2.1, 8.3.1.3.3.2, 8.3.1.3.3.3
Offset on a fault changes travel path way to one with	Probability of total offsets >1.0 m in 10,000 yr on faults within 0.5 km	$<10^{-1}$ /yr	8.3.1.8 Offsets, slip rates, and	8.3.1.8.4.1.3(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2

Table 8.3.5.17-8. Scenario classes and parameters associated with potentially adverse condition 7^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
different geochemical properties	of C-area boundary		recurrence intervals	
	Effects of fault offset on travel pathway	Significant changes will not occur	8.3.1.8 Unsaturated-zone flow model Saturated-zone flow model	8.3.1.2.2.9 8.3.1.2.3.3.3
	Offset on a fault causes changes in movement of ground water that result in mineralogical changes along the fault zone	Probability of movement and location of Quaternary faults in C-area $<10^{-4}$ /yr per fault	8.3.1.8 Locations of faults, slip rates, and recurrence intervals	8.3.1.8.4.1.2(D), 8.3.1.17.4.6.1, 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Degree of mineralogic change in fault zone in 10,000 yr	Adverse changes in mineralogy will not occur	8.3.1.8 Nature and age of mineralogic changes along faults	8.3.1.4.2.2.3, 8.3.1.4.2.2.5, 8.3.1.3.2

^aInformation on scenario classes, performance parameters, and tentative parameter goals is from Section 8.3.5.13

^bStudy or activity directly addresses scenario.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

properties. Sorption could also be affected by disturbance to ground-water chemistry. These geochemical processes that affect the sorptive mineralogy are expected to occur at rates too slow to significantly affect the sorptive capacity of the tuffs in the time frame of concern to a repository. In addition, any alteration of glass that did occur in the tuffs is expected to produce sorptive mineral phases, thereby producing an increase in sorptive capacity.

At present, geochemical processes are not expected to significantly affect rock strength during the postclosure period. Fracturing of the tuffs due to chemical changes (e.g., dehydration and phase transitions) in the rocks is not expected under the range of thermal conditions predicted. Furthermore, the waste package is being designed to withstand the impacts that could occur from falling rock, and the information needs for the design are addressed in Issue 1.10 (Section 8.3.4.2).

The engineered-barrier system could be affected if the chemical characteristics of the ground water contacting it were to be disturbed significantly. No currently operating geochemical processes are thought, however, to have a potential for significantly affecting the EBS.

The available data do not, therefore, support a statement that the geochemical processes described in the PAC are operating at the site. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

In the development of the preliminary scenario classes, changes of this type were grouped into two categories: changes in the geochemical conditions due to likely events (for example, to the heat generated by the emplaced wastes) and disturbances to the geochemical conditions due to unlikely natural events. The former category is addressed by information needs for the nominal-case scenario class, and the latter is addressed by certain disturbed-performance scenario classes. Table 8.3.5.17-9 lists the relevant scenarios that will be considered in the overall system performance assessment to address the concern of this PAC. Scenarios concerning surface-water impoundments, irrigation, and mining near the controlled area are not considered to have credible significant effects on geochemical processes (sorption) at the site. They are not listed in Table 8.3.5.17-9. The performance parameters, for which values will be obtained during site characterization, are shown in the table; the site characterization data to be collected to address this PAC are listed by parameter category or set. Table 8.3.5.17-9 also references the section that discusses the data and the associated studies and activities.

The principal geochemical data that will be collected to address this PAC include the stability of sorptive minerals in the tuffs under both the ambient and the postemplacement thermal conditions and ground-water compositions. The sorptive behavior of the tuffs will be determined under a range of conditions intended to cover the effects of expected and unexpected events on the variables controlling sorption properties.

Table 8.3.5.17-9. Scenario classes and parameters associated with potentially adverse condition 8^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Nominal case	Distribution coefficients (K_d s) for Sr, Cs, Pu, Am, C, U, Np, Tc, Zr, I, and Cm in unsaturated-zone units below repository but above water table	$K_d \geq 0$ for I and C. $K_d \geq 0.1$ for other elements under expected temperature range	8.3.1.3 Saturated- and unsaturated-zone sorptive properties	8.3.1.3.4(D)
			Solubility of radionuclides	8.3.1.3.5(D)
			Rock-unit mineralogy, petrology, and chemistry	8.3.1.3.2(D)
			Fracture-filling mineralogy	8.3.1.3.2(D)
			Unsaturated- and saturated-zone ground-water chemistry	8.3.1.3.1(D)
			Unsaturated- and saturated-zone dispersive and diffusive properties	8.3.1.3.6(D)
	Liquid constrictivity/tortuosity factor		Retardation potential changes over 10,000 yr	8.3.1.3.7(D)

Table 8.3.5.17-9. Scenario classes and parameters associated with potentially adverse condition 8^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Igneous intrusions cause changes in rock geochemical properties	Annual probability of igneous intrusions within 0.5 km of C-area ^c boundary	$<10^{-5}$ /yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.4.1.1(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of igneous intrusions on local rock geochemical properties	Potential changes in mineralogy will not be extensive	8.3.1.8 Locations and geometry of intrusions Mineralogic changes	8.3.1.3.3, 8.3.1.8.1.2.1, 8.3.1.17.4.12.1 8.3.1.3.2.2.2, 8.3.1.8.5.2.2
Tectonic processes cause changes in ground-water table or movement that results in mineralogic changes in C-area	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	8.3.1.8 Probability and magnitude of mineralogic changes Rate of mineral alteration	8.3.1.8.4.1.4(D), 8.3.1.8.3.2.2, 8.3.1.8.3.2.3, 8.3.1.8.3.2.4, 8.3.1.8.3.2.6 8.3.1.3.2.2.1, 8.3.1.3.3.3, 8.3.1.3.3.4
Offset on a fault changes travel pathway to one with different geochemical properties	Probability of total offsets >1.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-1}$	8.3.1.8 Offsets, slip rates, and recurrence intervals	8.3.1.8.4.1.3(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2

Table 8.3.5.17 9. Scenario classes and parameters associated with potentially adverse condition 8^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Offset on a fault causes changes in movement of ground water that result in mineralogical changes along the fault zone	Effects of fault offset on travel pathway	Significant changes will not occur	8.3.1.8 Unsaturated-zone flow model Saturated-zone flow model	8.3.1.2.2.9, 8.3.1.2.3.3.3
	Probability of movement and location of Quaternary faults in C-area	$<10^{-4}$ /yr per fault	8.3.1.8 Locations of faults, slip rates, and recurrence intervals	8.3.1.8.4.1.2(D), 8.3.1.17.4.6.1, 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Degree of mineralogic change in fault zone in 10,000 yr	Adverse changes in mineralogy will not occur	8.3.1.8 Nature and age of mineralogic changes along faults	8.3.1.4.2.2.3, 8.3.1.4.2.2.5, 8.3.1.3.2

^aInformation on scenario classes, performance parameters, and tentative parameter goals is from Section 8.3.5.13.

^bStudy or activity directly addresses scenario.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

Potentially adverse condition 9: Ground-water conditions in the host rock that are not reducing.

This PAC is concerned with oxidizing ground-water conditions in the host rock because such conditions may be less favorable than chemically reducing conditions with regard to sorption and solubility relationships for radionuclides that exhibit sensitivity to oxidation-reduction conditions.

Because the host rock at the Yucca Mountain site is located in the unsaturated zone, the ground water in the host rock is oxidizing. It is expected that this condition can be shown not to significantly affect performance, because any potentially adverse effects it may theoretically cause will be compensated for by the low water flux through the repository and the sorptive capacity of the host rock and surrounding units. The strategy for resolution of this PAC is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

The information needed to address this condition (natural processes and waste-emplacement effects) is addressed in the nominal-case scenario class defined in Section 8.3.5.13. In addition, disturbances to the nominal-case conditions due to unlikely natural events and human activities may also need to be considered in evaluating this PAC. The scenario classes and relevant performance parameters from Section 8.3.5.13 are summarized in Table 8.3.5.17-10. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-10. The principal geochemical data to be collected to address this PAC are the major ion composition of the unsaturated zone ground waters. Table 8.3.5.17-10 also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 10: Evidence of dissolution such as breccia pipes, dissolution cavities or brine pockets.

The available information is sufficient to conclude that this potentially adverse condition is not present at the Yucca Mountain site. There are no known dissolution features within the potential host rock or the other rock units at the sites (DOE, 1986b), and the minerals that make up the host rock (alkali feldspars, quartz, cristobalite, and tridymite) are not prone to dissolution in any significant quantities.

Because the available information appears adequate to address this PAC, no further characterization is needed. No scenario classes associated with dissolution will be developed as a part of the evaluation of the geologic repository with respect to the overall system performance objective.

Potentially adverse condition 11: Structural deformation, such as uplift, subsidence, folding, and faulting, during the Quaternary Period.

This PAC is concerned with future structural deformation, similar to the observed Quaternary deformation, that could adversely affect a repository system in such a way that the isolation capabilities of a site would be

Table 8.3.5.17-10. Scenario classes and parameters associated with potentially adverse condition 9^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Nominal case	Distribution coefficients (K_d s) for Sr, Cs, Pu, Am, C, U, Np, Tc, Zr, I, and Cm in unsaturated-zone units below repository and above water table	$K_d \geq 0$ for I and C. $K_d \geq 0.1$ for other elements under expected temperature range	8.3.1.3 Saturated- and unsaturated-zone sorptive properties	8.3.1.3.4(D)
			Solubility of radionuclides	8.3.1.3.5(D)
			Rock-unit mineralogy, petrology, and chemistry	8.3.1.3.2(D)
			Fracture-filling mineralogy	8.3.1.3.2(D)
			Unsaturated- and saturated-zone ground-water chemistry	8.3.1.3.1(D)
	Liquid constrictivity/tortuosity factor		Unsaturated- and saturated-zone dispersive and diffusive properties	8.3.1.3.6(D)

Table 8.3.5.17-10. Scenario classes and parameters associated with potentially adverse condition 9^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
			Retardation potential changes over 10,000 yr	8.3.1.3.7(D)
Extensive irrigation is conducted near the C-area ^c	Expected magnitude of changes in distribution coefficients, solubili- ties, and chemical reac- tivity of the engineered- barrier system in next 10,000 yr for unsatura- ted-zone units below repository but above water table	No goal (human activity)	Same as the nominal case	Same as the nominal case
Large-scale surface water impoundments are constructed near the C-area	Expected magnitude of changes in distribution coefficients, solubili- ties, and chemical reac- tivity of the engineered- barrier system in next 10,000 yr for unsatura- ted-zone units below repository but above water table	No goal (human activity)	Same as the nominal case	Same as the nominal case

Table 8.3.5.17-10. Scenario classes and parameters associated with potentially adverse condition 9^a
(page 3 of 3)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Extensive surface or subsurface mining occurs near C-area	Expected magnitude of changes in distribution coefficients, solubilities, and chemical reactivity of the engineered-barrier system in next 10,000 yr for unsaturated-zone units below repository but above water table	No goal (human activity)	Same as the nominal case	Same as the nominal case

^aScenario classes, performance parameters, and tentative parameter goals are from Section 8.3.5.13.

^bStudy or activity directly addresses scenario.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

impaired. For example, structural deformation could affect radionuclide transport rates from the repository horizon to the boundaries of the accessible environment, if the hydrologic conditions or geochemical characteristics along the transport path were adversely affected.

Quaternary rupture on 32 faults within an 1,100-km² area surrounding the site has been documented (Section 1.3.2). In addition, Quaternary activity has been observed on faults near Yucca Mountain. The region is currently undergoing active lateral crustal extension in response to regional extension within the Great Basin (Section 1.3.2.4). The rate is, however, considered to be low. The strategy for resolution of this PAC is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

The potential effects of structural deformation on the ground-water flow system are addressed by PACs 4 and 5. Tables 8.3.5.17-5 (PAC 4) and 8.3.5.17-6 (PAC 5) summarize the information needed to evaluate these effects. Table 8.3.5.17-11 repeats this information and also includes the information regarding the effects of tectonic activity on waste packages and the geochemical conditions important to waste isolation. The table lists the performance parameters for those scenarios relevant to the effects of tectonic activity, such as faulting, on waste isolation. The characterization programs that will provide the information needed to determine these parameters are also listed in Table 8.3.5.17-11.

Potentially adverse condition 12: Earthquakes that have occurred historically that if they were to be repeated could affect the site significantly.

This PAC is concerned with historic earthquakes that, if they reoccurred in the future, could adversely affect the postclosure performance of a geologic repository.

The Yucca Mountain site is located in the southern Great Basin, a seismically active region (Section 1.4). The pattern of regional seismicity, as defined by historical epicenters within 400 km of Yucca Mountain, consists of the north-south-trending Nevada-California seismic belt, the southern end of the Intermountain seismic belt in southwestern Utah, and the diffuse East-West seismic belt encompassing the Nevada Test Site. Six major historical earthquakes ($M \geq 6.5$) have occurred in the Nevada-California seismic belt, and two have occurred on or near the San Andreas fault. The nearest major earthquake (1872 Owens Valley) was about 150 km west of Yucca Mountain. Yucca Mountain itself is located in a quiescent area characterized by few hypocenters and low seismic-energy density, and the historical record of the region suggests that past seismic activity, if repeated, would not be expected to significantly affect the postclosure performance of a geologic repository. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

The historical record is limited. Therefore, detailed geologic investigations will be combined with ongoing earthquake monitoring activities to assess the effects of future earthquakes at the site. Additional information

Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
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	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	8.3.1.8 In situ stress field Relation of hydraulic properties to strain	8.3.1.17.4.8.1 8.3.1.8.3.3.3(D)
Episodic changes in strain in the rock mass due to faulting causes changes in water-table level	Probability that strain-induced changes increase potentiometric level to >850 m mean sea level	$<10^{-8}$ /yr	8.3.1.8 In situ stress field Relation of hydraulic properties to strain Rate of stress change Saturated-zone flow model	8.3.1.17.4.8.1 8.3.1.8.3.3.3(D) 8.3.1.8.3.2.3(D), 8.3.1.17.12.1 8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Offset on fault creates impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds	Probability of offset >2 m on faults in the C-area in 10,000 yr	$<10^{-1}$	8.3.1.8 Vertical slip rate and recurrence intervals	8.3.1.8.3.1.5(D), 8.3.1.17.3.1.3, 8.3.1.17.4.6.2

Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Offset on faults juxtaposes transmissive and nontransmissive units, resulting in the creation of a perched aquifer, or a rise in the water table, or a change in hydraulic gradients	Probability of changing dip by > 2° in 10,000 yr by faulting	<10 ⁻⁴	8.3.1.8 Rates of vertical slip and tilting	8.3.1.17.4.6.2
	Effects of faulting on flux	Faulting will not affect flux because of low slip rate	8.3.1.8 Unsaturated-zone flow model	8.3.1.8.3.1.4, 8.3.1.2.3.2.9
	Probability of total offsets >1.0 m in 10,000 yr on faults within 0.5 km of C-area	<10 ⁻¹	8.3.1.8 Slip rates and recurrence intervals	8.3.1.8.3.2.6(D), 8.3.1.17.3.1.3, 8.3.1.17.4.6.2
	Effects of fault offset on water-table levels and hydraulic gradients	Water-table rise <100 m Gradients change < factor of 4	8.3.1.8 Fault location and geometry Unsaturated-zone flow model Saturated-zone flow model Quaternary water levels	8.3.1.8.3.2.5, 8.3.1.17.3.1 8.3.1.2.3.2.9 8.3.1.2.1.4.4, 8.3.1.5.3.3.3 8.3.1.5.2.1.5

Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Episodic offset on faults causes local changes in rock hydrologic properties, thereby destroying existing barriers to flow, or creating barriers to flow, or creating new conduits for drainage	Annual probability of 1-m displacement on Quaternary faults within 0.5 km of C-area boundary	Less than 10^{-4} per year	8.3.1.8 Slip rates and recurrence intervals	8.3.1.8.3.3.2(D), 8.3.1.17.3.1.3, 8.3.1.17.4.6.2
	Effects of fault motion on local permeabilities and effective porosities	Change in fracture permeability is < factor of 2; fracture porosity increases	8.3.1.8 Evidence of episodic rock-property changes along faults	8.3.1.4.2.2.3, 8.3.1.4.2.2.4, 8.3.1.4.2.2.5
Offset on a fault changes travel pathway to one with different geochemical properties	Probability of total offsets >1.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-4}$	8.3.1.8 Offsets, slip rates, and recurrence intervals	8.3.1.8.4.1.3(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2
	Effects of fault offset on travel pathway	Significant changes will not occur	8.3.1.8 Unsaturated-zone flow model Saturated-zone flow model	8.3.1.2.2.2.9 8.3.1.2.3.3.3

Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Offset on a fault causes changes in movement of ground-water that result in mineralogical changes along the fault zone	Probability of movement and location of Quaternary faults in C-area	$<10^4$ /yr per fault	8.3.1.8 Locations of Quaternary faults in C-area Slip rates and recurrence intervals	8.3.1.8.4.1.2(D), 8.3.1.17.4.6.1 8.3.1.8.13.1.3, 8.3.1.17.4.6.2
	Degree of mineralogic change in fault zone in 10,000 yr	Adverse changes in mineralogy will not occur	8.3.1.8 Nature and age of mineralogic changes along faults	8.3.1.4.2.2.3, 8.3.1.4.2.2.5
Uplift or subsidence changes drainage, thereby changing flux	Probability of exceeding 30-m elevation change in 10,000 yr	$<10^{-4}$	8.3.1.8 Rates uplift and subsidence	8.3.1.8.3.1.7(D), 8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3
Tectonic folding changes dip of tuff beds in C-area, thereby changing flux	Probability of changing dip by $>2^\circ$ in 10,000 yr by folding	$<10^{-4}$	8.3.1.8 Rates of folding	8.3.1.8.3.1.7(D), 8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6

Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Folding, uplift, or subsidence lowers repository with respect to water table	Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr	$<10^{-4}$	8.3.1.8 Rates of subsidence Rates of folding	8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3 8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6
Tectonic processes cause changes in water table or movement that results in mineralogic changes in C-area	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	8.3.1.8 Probability and magnitude of hydrologic changes Rate of mineral alteration	8.3.1.8.4.1.4(D), 8.3.1.8.3.2.2, 8.3.1.8.3.2.3, 8.3.1.8.3.2.4, 8.3.1.8.3.2.6 8.3.1.3.2.2.1, 8.3.1.3.3.2, 8.3.1.3.3.3
Offset on one or more faults intersects waste package and causes failure ^d	Number of waste packages affected by fault penetrating repository	Less than 0.5% of waste packages intersected by a single fault, with a 95% probability	8.3.1.8 Characteristics of faults that penetrate repository, width and orientation of Quaternary faults, number of waste packages affected by a fault	8.3.2.2.7, 8.3.1.3.3.1, 8.3.1.17.4.2, 8.3.1.17.4.6.1, 8.3.1.17.4.6.2

Table 8.3.5.17-11. Scenario classes and parameters associated with potentially adverse condition 11^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
	Probability of faulting with displacement over 5 cm in repository	Annual probability less than 10 ⁻⁴ of faulting with displacement over 5 cm		
Ground motion causes spalling or failure and closes air gap around waste packages ^d	Expected ground motion at emplacement boreholes in 1,000-yr period	Probability of exceeding ground motion values <0.1 in 1,000 yr	8.3.1.17 Probability of ground motion	8.3.1.17.3.5.2, 8.3.1.17.3.6.2
Folding or distributed shear causes waste-emplacement-borehole deformation and results in waste-package failure ^d	Rate of deformation due to folding or distributed shearing in repository horizon	Waste-emplacement boreholes will be subject to <0.005 shear strain in 1,000 yrs as a result of folding or deformation	8.3.1.8 Nature and age of folding in repository	8.3.1.4.2.2.1, 8.3.1.4.3.2, 8.3.1.17.4.12.1, 8.3.1.8.2.1.2

^aScenario classes, performance parameters, and parameter goals are from Section 8.3.5.13, except where noted.

^bStudy or activity directly addresses scenario.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

^dScenario class, performance parameter, and parameter goal are from Section 8.3.2.2.

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to strengthen the strategy is included in Table 8.3.5.17-11 (PAC 11). This table lists the scenario classes associated with fault movement and ground motion developed in Section 8.3.5.13. The performance parameters needed to evaluate these phenomena and the characterization programs that will provide the information to develop these parameters are also listed in this table.

Potentially adverse condition 13: Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase.

Like PAC 12, PAC 13 is concerned with the potential for seismic activity, including ground motion and faulting, that could adversely affect the performance of the repository in the postclosure period. The information needed for this PAC is the same as that for PAC 12 and will be investigated through PAC 11. The information needs for this PAC are defined in Table 8.3.5.17-11 (PAC 11). The available information is insufficient to determine whether future seismic activity is likely to be more frequent or of higher magnitude than historic seismicity. The maximum earthquake magnitude in the historical record and the record of Quaternary faulting within the geologic setting are assumed to be the strongest indicators of future earthquake potential for the postclosure time frame. Difficulty in interpreting the Quaternary faulting record suggests that the historical record may not reveal the largest earthquake that could occur at Yucca Mountain. Given this interpretation, it is possible that the geologic setting of the Yucca Mountain site may experience earthquakes of higher magnitude or frequency than have been historically observed. The strategy for resolution of this PAC is to demonstrate that although the condition may be present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste. The characterization work that will provide the information needed for resolving this PAC is listed in Table 8.3.5.17-11.

Potentially adverse condition 14: More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located.

This PAC is concerned with the potential for future seismic activity to adversely affect the postclosure performance of a geologic repository. The frequency and magnitude of earthquakes at Yucca Mountain during the several years of close monitoring is the same as or less than that for the southern Basin and Range Province. Furthermore, it is not expected that future seismicity at the site will be more frequent or of higher magnitude than is typical of the region in which the geologic setting is located. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

The information needed to evaluate this PAC is identical to that needed for PACs 12 and 13, and the information needs for this PAC are included in Table 8.3.5.17-11 (PAC 11). Data to be collected to address PAC 11 are expected to be adequate for resolving PAC 14.

Potentially adverse condition 15: Evidence of igneous activity since the start of the Quaternary Period.

This PAC is concerned with igneous activity during the next 10,000 yr that could adversely affect the performance of a repository system. Igneous activity could cause direct releases of radionuclides to the accessible environment as a result of an extrusive event. Igneous activity could also affect releases indirectly by disrupting the geohydrologic conditions at a site (increasing the ground-water table altitude, increasing percolation flux through the repository horizon, changing head gradients in the saturated zone, or creating surficial discharge points within the accessible environment) or altering the rock-mass hydrologic or geochemical characteristics along the potential radionuclide transport pathways.

Although the volcanic rocks in the region of Yucca Mountain are predominately silicic tuffs and rhyolite domes formed during middle Tertiary, the youngest volcanic rocks are mostly basalt flows. These basalts were probably formed as recently as 0.2 to 0.3 million years ago; however, the dating methods have significant uncertainties. These basalts were formed in isolated Strombolian eruptions of small volume and short duration. The strategy for resolution of this PAC is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

The likelihood and extent of igneous activity during the next 10,000 yr and its effects on site characteristics will be investigated during site characterization. Table 8.3.5.17-12 shows the scenario classes associated with igneous activity that will be considered in the overall system performance assessment. The table also lists the performance parameters for which values will be obtained during site characterization. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-12. Table 8.3.5.17-12 also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 16: Evidence of extreme erosion during the Quaternary Period.

This potentially adverse condition is concerned with the potential for erosional processes to adversely affect the isolation capabilities of the site. Repository performance could be directly affected through denudation of the underground facility or indirectly affected through disturbance of the hydrologic system, such as the creation of new ground-water discharge points within the controlled area.

Erosional processes in the area of Yucca Mountain site have been, and continue to be, dominated by a general pattern of upland erosion, piedmont transport, and basin deposition (Section 1.1.3.3.2). Average downwasting rates over the past 1 to 5 million yr have been 0.5 to 2.0 cm per thousand years. Assuming that these rates would continue, the total downwasting would amount to a maximum of approximately 20 cm during the next 10,000 yr. Large-scale rapid mass wasting has not played a major role in the erosional regime at the site. Although generally stable, episodes of rapid erosion have

Table 8.3.5.17-12. Scenario classes and parameters associated with potentially adverse condition 15^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Igneous intrusion penetrating repository resulting in failure of waste packages ^c	Probability of igneous intrusion penetrating repository	Annual probability less than 10^{-5}	8.3.1.8 Probability of intrusion	8.3.1.8.2.1.1(D), 8.3.1.8.1.1.4
	Effects of igneous intrusion penetrating repository	Less than 5% of waste packages disrupted	8.3.1.8 Geometry of intrusions	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Number of waste packages disrupted	8.3.1.8.1.2.1, 8.3.2.2.6.2, 8.3.2.2.7.1
Volcanic eruption penetrates repository and causes direct releases to the accessible environment	Annual probability of volcanic eruption that penetrates the repository	$<10^{-6}$ /yr	8.3.1.8 Probability of eruption	8.3.1.8.1.2(D), 8.3.1.8.1.1.4
	Effects of volcanic eruption penetrating repository, including area of repository disrupted	Given occurrence, $<0.1\%$ of repository area disrupted with a conditional probability of <0.1 of being exceeded in 10,000 yr	8.3.1.8 Effects of eruption	8.3.1.8.1.2.1, 8.3.1.8.1.2.2

Table 8.3.5.17-12. Scenario classes and parameters associated with potentially adverse condition 15^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Volcanic eruption causes flows or other changes in topography that result in impoundment or diversion of drainage	Annual probability of volcanic events within C-area ^d	$<10^{-5}$ /yr	8.3.1.8 Probability of volcanic event	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of a volcanic event on topography and flow rates	Show topographic changes are not great enough to affect flux	8.3.1.8 Topographic effects of eruption	8.3.1.8.1.2.1, 8.3.1.8.1.2.2
Igneous intrusion, such as a sill, that could result in a significant change in average flux	Annual probability of igneous intrusion in the C-area	Show $<10^{-5}$ /yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of an igneous intrusion on flux	Show igneous intrusion will not affect flux because of depth, location, and extent of intrusion	8.3.1.8 Locations and geometry of possible intrusions at site Unsaturated-zone flow model Saturated-zone flow model	8.3.1.8.1.2.1, 8.3.1.17.4.12.1 8.3.1.2.2.6 8.3.1.2.3.3

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Table 8.3.5.17-12. Scenario classes and parameters associated with potentially adverse condition 15^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Igneous intrusion causes barrier to flow or thermal effects that alter water-table level (or hydraulic gradients)	Annual probability of an igneous intrusion within 0.5 km of C-area boundary	$<10^{-5}$ /yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Barrier-to-flow effects of igneous intrusions on water-table levels	Water table rise <100 m	8.3.1.8 Locations and geometry of possible intrusions at site	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Thermal effects of igneous intrusions on water-table levels	Water table rise <100 m	8.3.1.8 Locations and geometry of possible intrusions at site	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Saturated-zone flow model	8.3.1.2.1.4.4, 8.3.1.2.3.3.3
	Thermal effects of igneous intrusions on hydraulic gradients	Gradients change < factor of 4	8.3.1.8 Thermal effects near intrusion	8.3.1.8.1.2.1

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Table 8.3.5.17-12. Scenario classes and parameters associated with potentially adverse condition 15^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Igneous intrusions cause changes in rock hydrologic pro- perties	Annual probability of igneous intrusions within 0.5 km of C-area boundary	$<10^{-5}$ /yr	8.3.1.8 Probability of igneous intru- sion	8.3.1.8.3.3.1(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Effects of igneous intrusions on local permeabilities and effective porosities	No significant changes in rock hydrologic pro- perties	8.3.1.8 Locations and geometry of possible intrusions	8.3.1.8.1.2.1, 8.3.1.17.4.12.1
			Effects of intrusions on hydraulic pro- perties	8.3.1.8.3.3.1
Igneous intrusions cause changes in rock geochemical properties	Annual probability of igneous intrusions within 0.5 km of C-area boundary	$<10^{-5}$ /yr	8.3.1.8 Probability of igneous intru- sions	8.3.1.8.4.1.1(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1

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Table 8.3.5.17-12. Scenario classes and parameters associated with potentially adverse condition 15^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
	Effects of igneous intrusions on local rock geochemical properties	Potential changes in mineralogy will not be extensive	8.3.1.8 Mineralogic changes Rates of mineral alteration	8.3.1.8.5.2.2 8.3.1.3.2.2.1, 8.3.1.3.3.2, 8.3.1.3.3.3

^aScenario classes, performance parameters, and parameter goals are from Section 8.3.5.13, except as noted.

^bStudy or activity directly addresses the scenario.

^cScenario class, performance parameter, and parameter goal are from 8.3.2.2.

^dC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

occurred locally in areas of concentrated fluvial activity. In these areas, rates of stream incision, averaged over the past 0.15 to 0.3 million yr, range from 5.3 to 37.5 cm per thousand years. These rates would amount to a maximum of approximately 3.8 m over the next 10,000 yr. Therefore, it is not likely that erosion would significantly affect the ability of the Yucca Mountain site to meet the performance objectives related to waste isolation. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Because of these low rates, disturbed-performance scenario classes associated with erosional processes have not been developed for the Yucca Mountain site. Furthermore, no information needs associated with the nominal-case scenario are identified for erosion. The underground facility will be at least 200 m below the surface at all points. Therefore, direct releases resulting from denudation are considered to be not credible during the next 10,000 yr. Even the rates associated with stream incision are not expected to affect the ground-water flow important to waste isolation. Although erosion-related site data are limited, no new site data are necessary to address this condition. Some erosion data will be collected for purposes other than characterizing extreme erosion (Section 8.3.1.6), and these data will be used to test the hypothesis that this PAC is not present at the site.

Potentially adverse condition 17: The presence of naturally occurring materials, whether identified or undiscovered, within the site, in such a form that: (i) Economic extraction is currently feasible or potentially feasible during the foreseeable future; or (ii) Such materials have a greater gross value or net value than the average for areas of similar size that are representative of and located within the geologic setting.

This PAC is concerned with the potential for future human activities associated with resource exploration and exploitation at the site that could adversely affect the isolation capabilities of the site. Such activities include exploratory drilling, surface and subsurface mining, and ground-water withdrawal. These activities could result in direct radionuclide releases to the accessible environment if radioactive material were brought up to the surface along with the resource or in the course of exploration. The activities could also indirectly affect isolation if the geohydrologic or geochemical conditions of the site were disturbed.

There are no known occurrences of economic mineral resources at the Yucca Mountain site (Section 1.7). Preliminary analyses of drill-core samples at Yucca Mountain suggest there are no mineral occurrences in any significant abundance that could be economically feasible to extract in the near future. Comparison of the site with similar regions, where mineral resources have been found, indicates that there are some similarities in rock types and depositional environments for economic minerals; however, the occurrences at Yucca Mountain are not expected to be unique or of a higher value. The potential for energy resources (uranium, hydrocarbon, oil, and gas) at the site is considered very low. Deep boreholes in the region have

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failed to detect the presence of any significant quantities of hydrocarbon, oil, or gas. Most of the southern Great Basin, including the Yucca Mountain site, has a potential for low- to moderate-temperature geothermal development. Data from wells at Yucca Mountain, however, suggest low heat flow and the great depth to water would preclude geothermal energy development at the site.

Ground-water resources exist near the Yucca Mountain site. The extent of the resource is unknown; however, the limited ground-water resources in southern Nevada make the ground-water resources proximal to the site attractive for future extraction. The ground-water resources within the site, however, are not considered feasible for economic extraction because of depth to the ground water, topographic conditions, land-use restrictions at the repository site, and the expected availability of ground-water resources outside of the controlled-area boundary. Ground-water withdrawal near the controlled area is discussed in PAC 2.

The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

The potential for human activities that are associated with resource exploration and extraction at the Yucca Mountain site and their effects on the site characteristics will be investigated during site characterization. Scenario classes associated with human activities have been developed for this purpose. Table 8.3.5.17-13 shows the scenario classes that will be evaluated in the overall system performance assessment and the performance parameters associated with those scenarios for which values will be obtained. Because of the unpredictable nature of human activities, goals cannot be set for many of these parameters (see Section 8.3.5.13 and the discussion of PAC 2). Nevertheless, investigations will be conducted to obtain information needed to evaluate these parameters, and these investigations are also listed in this table. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-13. Table 8.3.5.17-13 also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 18: Evidence of subsurface mining for resources within the site.

This potentially adverse condition is concerned with the potential for past or present mining-related activities to adversely affect the performance of a repository. There is no evidence of mining activity within 10 km of the Yucca Mountain site (Section 1.6.4). Surface exploration of the area found no evidence of abandoned underground mines, surface mines, or prospecting drillholes.

The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site. The available evidence is sufficient to address this PAC, and no additional site data are called for. Information needed to evaluate future mining activities is identified in Table 8.3.5.17-13.

Table 8.3.5.17-13. Scenario classes and parameters associated with potentially adverse condition 17^a

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Exploratory drilling intercepts a waste package and brings waste up with core or cuttings	Presence and readability of C-area ^c markers over next 10,000 yr	>50% chance that markers are readable over next 10,000 yr	8.3.1.9 Rates of processes decreasing survival period, visibility, or readability of markers	8.3.1.9.3.1.1(D), 8.3.1.9.1.1
	Expected drilling rate (number of boreholes/km ² /yr) in C-area over the next 10,000 yr	Expected drilling rate $\leq 3 \times 10^{-4}$ / km ² /yr	8.3.1.9 Types and locations of inferred resources Expected exploratory methods	8.3.1.9.2.1 8.3.1.9.3.1.1
	Distribution of depths of exploratory drillings	No goal (human activity)	8.3.1.9 Expected exploratory methods	8.3.1.9.2.1, 8.3.1.9.3.1.1
	Distribution of diameters of exploratory drill holes	No goal (human activity)	8.3.1.9 Expected exploratory methods	8.3.1.9.2.1, 8.3.1.9.3.1.1

^aScenario classes, performance parameters, and parameter goals are from Section 8.3.5.13.

^bStudy or activity directly addresses the scenario.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

Potentially adverse condition 19: Evidence of drilling for any purpose within the site.

This PAC is concerned with the potential for past or present drilling to adversely affect the performance of a repository, e.g., by providing pathways for transport of radionuclides from the repository.

A study has been made of the available records, and all the area within a 10-km radius around the perimeter drift outline has been physically examined during surface mapping operations. A total of 184 drillholes within the 10-km radius has been reported (Section 1.6.1). Two of these drillholes, the J-12 and J-13 water wells, were completed for water supply for the Nuclear Rocket Development Station work in 1957 and 1963, respectively. The other 182 holes were drilled under the control of the Nevada Test Site Operations Office for the NNWSI Project during exploratory work to investigate the site. If the wording of this PAC related the significance of drillholes to the ability of the site to isolate waste, the strategy for PAC resolution would be to test the hypothesis that the PAC is not present; however, since the PAC, as stated, refers only to evidence of drilling, the strategy for PAC resolution is to demonstrate that although the condition is present, it will not affect significantly the ability of the geologic repository to meet the performance objective relating to isolation of the waste.

Scenarios associated with drilling for purposes other than those of previous drilling activities at the site will be investigated in the overall system performance assessment. These scenario classes are discussed by PAC 17, and the information needed to evaluate this PAC is identified in Table 8.3.5.17-13.

Potentially adverse condition 20: Rock or ground-water conditions that would require complex engineering measures in the design and construction of the underground facility or in the sealing of boreholes and shafts.

This PAC is concerned with a preclosure condition that could affect postclosure performance. According to the NRC's statements of consideration for 10 CFR Part 60, complex engineering measures are not inherently unacceptable. The concern lies in the reliability of the measures. Preclosure failure of such measures could conceivably affect postclosure performance, for example, through collapse of underground openings or flooding of the repository. The isolation capability of the repository system during the postclosure period could then be inferior to that which would exist if closure had been intentional.

Presently available data indicate that measures beyond those that are accepted mining practices would not be required to compensate for unfavorable rock characteristics (Chapters 2 and 6) and ground water conditions (Chapter 3). The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Rock characteristics will be investigated further during site characterization to satisfy the information needs of both design and performance

issues. However, no other information associated with particular scenario classes has been identified for this PAC. Present rock and ground-water conditions are included in the nominal-case scenario class as described in Section 8.3.5.13. Additional studies beyond those described in the sections cited above are presently believed not to be necessary.

Potentially adverse condition 21: Geomechanical properties that do not permit design of underground openings that will remain stable through permanent closure.

This PAC is concerned with a preclosure condition that could affect postclosure performance. Failure of an underground opening during the preclosure period could result in the enlargement of existing fractures or opening of new fractures that could potentially affect radionuclide transport. In addition, fracturing due to failure of an underground opening could potentially increase the amount of ground water reaching the waste package.

No measures beyond those generally acceptable in the mining industry are expected to be required to maintain stable underground openings through the preclosure period (Chapter 6). The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Additional studies beyond those described for the nominal-case scenario class (Section 8.3.5.13, 8.3.2.2 and 8.3.2.5) are presently believed not to be necessary. The final plans for maintaining stable underground openings will be presented as part of the license application design.

Potentially adverse condition 22: Potential for the water table to rise sufficiently so as to cause saturation of an underground facility located in the unsaturated zone.

This PAC is concerned with the saturation of an underground facility initially located in the unsaturated zone. A water-table rise that would flood an underground facility could result from climatic conditions (also considered in PAC 6), human activity (also considered in PAC 2), or tectonic processes or events (also considered in PACs 3 and 5).

Climate change, human activities, structural deformation, and igneous activity are all possible at the site. The effects of these processes are not, however, expected to produce a water-table rise high enough to saturate the underground repository. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Table 8.3.5.17-14 shows the scenarios that will be considered in the overall system performance assessment and that address water-table rise during the postclosure period. The table also shows the performance parameters for which values will be obtained during site characterization to address these scenarios. The site characterization data to be collected to

Table 8.3.5.17-14. Scenario classes and parameters associated with potentially adverse condition 22^a
(page 1 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Climate change causes an increase in altitude of water table	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 be < + 100 m	8.3.1.5	8.3.1.5.2.2.3(D)
			Future climate model	8.3.1.5.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.5.1.5
			Paleodischarge areas	8.3.1.5.2.1.3
			Analog recharge data	8.3.1.5.2.1.4
			Vein-deposit distribution, age, and origin	8.3.1.5.2.1.5
Extensive irrigation is conducted near the C-area ^c	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)	8.3.1.9	8.3.1.9.3.2.2(D),
			Irrigation characteristics	8.3.1.9.3.2
			Infiltration rates	8.3.1.2.2.1.2
			Unsaturated-zone flow model	8.3.1.2.2.9
			Saturated-zone flow model	8.3.1.2.3.3.3

Table 8.3.5.17-14. Scenario classes and parameters associated with potentially adverse condition 22^a
(page 2 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Large-scale surface- water impoundments are constructed near the C-area	Expected magnitude of change in water-table level due to placement of artificial lake near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9	8.3.1.9.3.2.2(D),
			Impoundment	8.3.1.9.3.2
			characteristics	
			Infiltration	8.3.1.2.2.1.1
			rates	
			Unsaturated-zone	8.3.1.2.2.9
			flow model	
			Saturated-zone	8.3.1.2.3.3.3
			flow model	
Extensive surface or subsurface mining occurs near C-area	Expected magnitude of change in water-table level due to mine water use or mine dewatering near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9	8.3.1.9.3.2
Extensive ground-water withdrawal occurs near C-area	Expected magnitude of change in water-table level due to extensive ground-water withdrawal near C-area in next 10,000 yr	No goal (human activity)	8.3.1.9	8.3.1.9.3.2.1(D), 8.3.1.9.2.2

Table 8.3.5.17-14. Scenario classes and parameters associated with potentially adverse condition 22^a
(page 3 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Episodic changes in strain in the rock mass due to faulting causes changes in water-table level	Probability that strain-induced changes increase potentiometric level to > 850 m mean sea level	$<10^{-5}$ /yr	8.3.1.8 Magnitudes and rates of strain, relation of properties to strain Saturated-zone flow models	8.3.1.8.3.2.3(D), 8.3.1.17.4.8.1, 8.3.1.17.4.8.4, 8.3.1.8.3.3.3 8.3.1.2.1.4.4, 8.3.1.2.3.3.3
Folding, uplift, or subsidence lowers repository with respect to water table	Probability that repository will be lowered by 100 m through action of folding, uplift, or subsidence in 10,000 yr	$<10^{-4}$	8.3.1.8 Rates of subsidence Rates of folding	8.3.1.8.3.1.6, 8.3.1.17.4.9.2, 8.3.1.17.4.10.3 8.3.1.4.2.2.1, 8.3.1.4.2.2.4, 8.3.1.4.3.2, 8.3.1.8.2.1.6
Offset on faults juxtaposes transmissive and nontransmissive units, resulting in a rise in the water table	Probability of total offsets > 1.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	$<10^{-1}$	8.3.1.8 Offsets, slip rates, and recurrence intervals	8.3.1.8.3.1.5(D), 8.3.1.8.3.2.6(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.1.2

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Table 8.3.5.17-14. Scenario classes and parameters associated with potentially adverse condition 22^a
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Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Igneous intrusion causes barrier to flow or thermal effects that alter water-table level	Effects of fault offset on water-table levels	Show water-table rise < 100 m	8.3.1.8 Locations of faults Saturated-zone flow model	8.3.1.17.4.6, 8.3.1.17.4.7, 8.3.1.17.4.12, 8.3.1.2.3.3.3
	Annual probability of igneous intrusion within 0.5 km of C-area boundary	Show < 10 ⁻⁵ /yr	8.3.1.8 Probability of igneous intrusion	8.3.1.8.3.1.2(D), 8.3.1.8.1.1.4, 8.3.1.8.3.1.1
	Barrier-to-flow effects of igneous intrusion on water-table levels	Show water-table rise < 100 m	8.3.1.8 Locations and geometry of possible intrusions at site Saturated-zone flow model	8.3.1.8.1.2.1, 8.3.1.17.4.12.1 8.3.1.2.1.4.4, 8.3.1.2.3.3.3

Table 8.3.5.17 14. Scenario classes and parameters associated with potentially adverse condition 22^a
(page 5 of 5)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
	Thermal effects of igneous intrusions on water- table levels	Show water-table rise < 100 m	8.3.1.8 Locations and geometry of possible intrusions at site Saturated-zone flow model Thermal effects near intru- sive bodies	8.3.1.8.1.2.1, 8.3.1.17.4.12.1 8.3.1.2.1.4.4, 8.3.1.2.3.3.3 8.3.1.8.1.2.1

^aScenario classes, performance parameters, and parameter goals are from Section 8.3.5.13.

^bStudy or activity directly addresses the scenario.

^cC-area = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

address this PAC are listed by parameter category or set in Table 8.3.5.17-14. Table 8.3.5.17-14 also references the section that discusses the data to be collected and the associated studies and activities.

Potentially adverse condition 23: Potential for existing or future perched water bodies that may saturate portions of the underground facility or provide a faster flow path from an underground facility located in the unsaturated zone to the accessible environment.

This PAC is concerned with perched-water bodies that could affect the transport of radionuclides by increasing flux through the unsaturated zone. These perched-water bodies could result from structural deformation at a site or from a climate change that produces a significant increase in infiltration.

The site is located in the southern Great Basin, a tectonically active region (Section 1.3); however, the effects of tectonism are not expected to create perched-water bodies that could saturate portions of the underground repository. Although the potential for existing perched-water bodies at the site cannot be ruled out on the basis of currently available information, it is unlikely that large bodies exist, because they have not been encountered in the program-related drilling performed to date. The strategy for resolution of this PAC is to test the hypothesis that this condition is not present at the Yucca Mountain site.

Table 8.3.5.17-15 shows the scenarios that have been identified that could create perched-water bodies in the unsaturated zone at the site. These scenarios are being considered in the overall system performance assessment. The table also shows the performance parameters for which values will be obtained during site characterization. The categories and sets of site characterization data to be collected to address this PAC are listed in Table 8.3.5.17-15. Table 8.3.5.17-15 also references the section that discusses the data to be collected and the associated studies and activities.

Existing perched-water bodies, if any, at the site will be identified by the program of hydrologic testing and modeling proposed for the site. The development of an unsaturated-zone flow model, using the data from the hydrologic testing program, will support an evaluation of the potential for perched-water bodies to have formed at the site under present conditions.

Potentially adverse condition 24: Potential for the movement of radionuclides in a gaseous state through air-filled pore spaces of an unsaturated geologic medium to the accessible environment.

Gaseous transport has been identified as a potentially significant transport mechanism for a repository located in the unsaturated zone (Section 8.3.5.13). Carbon-14 is expected to be the most important radionuclide species to be transported in this mode. The total-system performance assessment is therefore investigating gas-phase C-14 releases from the waste form and the characteristics and mechanisms of gas-phase transport of C-14 in the

Table 8.3.5.17-15. Scenario classes and parameters associated with potentially adverse condition 23^a
(page 1 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Offset on fault creates impoundments, alters drainage, creates perched aquifers, or changes dip of tuff beds	Probability of offset >2 m on faults in the C-area ^c in 10,000 yr	<10 ⁻¹	8.3.1.8 Offsets, vertical slip rates, and recurrence intervals	8.3.1.8.3.1.5(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.12
	Probability of changing dip by >2° in 10,000 yr by faulting	<10 ⁻¹	8.3.1.8 Rates of vertical slip and tilting	8.3.1.17.4.6.2
	Effect of faulting on flux	Faulting will not affect flux because of low slip rate	8.3.1.8 Unsaturated-zone flow model	8.3.1.8.3.1.4, 8.3.1.2.2.9
Offset on fault juxtaposes transmissive and nontransmissive units, resulting in the creation of a perched aquifer or a rise in water table	Probability of total offsets >1.0 m in 10,000 yr on faults within 0.5 km of C-area boundary	<10 ⁻¹	8.3.1.8 Offsets, vertical slip rates, and recurrence intervals	8.3.1.8.3.2.6(D), 8.3.1.8.3.1.3, 8.3.1.17.4.6.2, 8.3.1.17.4.12

Table 8.3.5.17-15. Scenario classes and parameters associated with potentially adverse condition 23^a
(page 2 of 2)

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
	Effects of fault offsets on water-table levels	Water-table rise <100 m	8.3.1.8 Credible offsets Hydraulic properties of faults Unsaturated-zone flow model	8.3.1.8.3,1.3 8.3.1.8.3.3.2 8.3.1.8.3.1,4, 8.3.1.2.2,9
Climatic change causes increase in infiltration over C-area	Expected magnitude of flux change due to climatic change over next 10,000 yr	Flux change will be <5 mm/yr	8.3.1.5.2 Future climate model Infiltration characteristics Unsaturated-zone flow model	8.3.1.5.2.2,2, 8.3.1.5.1.6 8.3.1.2.2.1.2 8.3.1.2.2.9

^aScenario classes, performance parameters, and parameter goals are from Section 8.3.5.13.

^bStudy or activity directly addresses scenario.

^cC-zone = the controlled area, i.e., the actual area chosen according to the 10 CFR 60.2 definition of controlled area.

unsaturated rock units overlying the repository in the nominal-case scenario class (Section 8.3.5.13).

Available evidence suggests that this condition may be present. The strategy for resolution of this PAC is to demonstrate that although the condition is present, it will not significantly affect the ability of the geologic repository to meet the performance objectives relating to isolation of the waste.

The information needs for the nominal-case scenario relevant to movement of C-14 in the gaseous state in the unsaturated zone are summarized in Table 8.3.5.17-16. The investigations supporting those information needs are also listed in this table. The site characterization data to be collected to address this PAC are listed by parameter category or set in Table 8.3.5.17-16. Table 8.3.5.17-16 also references the section that discusses the data to be collected and the associated studies and activities.

Discussion of the favorable conditions

This section provides individual discussions of the favorable conditions (FCs) listed in 10 CFR 60.122. For each FC, the discussion identifies the tentative strategy (present or not present) called for in Step 1 of Figure 8.3.5.17-2. Also, the potential contribution of the FC to performance is discussed, and the site characterization data needed for addressing the FC are identified.

Favorable condition 1: The nature and rates of tectonic, hydrogeologic, geochemical, and geomorphic processes (and any of such processes) operating within the geologic setting during the Quaternary Period, when projected, would not affect or would favorably affect the ability of the geologic repository to isolate waste.

Available evidence indicates that there were processes operating during the Quaternary that, if projected into the future, would contribute to isolating waste. Certain geochemical conditions, for example, would retard the transport of radionuclides to the accessible environment. These geochemical processes include the sorbing of radionuclides by the mineralogic assemblages along the flow path and the precipitating of radionuclides out of solution. Also, the rates of erosional processes during the Quaternary were relatively low and, if continued into the future, would not disrupt the performance of the repository system. The strategy for resolving this FC with respect to these Quaternary processes is to demonstrate that they would favorably affect the ability of the repository to isolate waste.

Some aspects of the tectonic setting, however, could be disruptive if they were to continue into the future. Both faulting and volcanic activity were present within the geologic setting during the Quaternary and, depending on the extent of these processes, could adversely affect the hydrologic system by raising the water table level, changing the flow path through the unsaturated zone, changing gradients in the saturated zone, or creating surficial discharge points within the controlled area. Also, the hydrologic system within the geologic setting during the Quaternary, though generally favorable, was influenced by cyclic fluctuations in precipitation. This

Table 8.3.5.17-16. Scenario classes and parameters associated with potentially adverse condition 24^a

Scenario class	Performance parameter	Tentative parameter goal	SCP section and parameter category or set	Direct (D) ^b or associated study or activity
Nominal case (undisturbed performance)	Fraction of carbon-14 that could be released in gas phase	<10%	8.3.5.10.4 Model of spent-fuel release	8.3.5.10.3.3.1(D),
	Mean residence time of released carbon-14 dioxide in unsaturated-zone units	>30,000 yr	8.3.1.2.2, 8.3.1.3.8.2 Gas composition, transport mechanisms, flow paths, water chemistry and physics	8.3.1.2.2.3, 8.3.1.3.8.1.1(D), 8.3.1.3.8.1.2(D)

^aScenario classes, performance parameters, and parameter goals are from Section 8.3.5.13.

^bStudy or activity directly addresses scenario.

resulted in sometimes greater flux and higher water-table altitudes than presently exist. If these tectonic and hydrogeologic conditions were to reoccur in the future, ground-water travel time to the accessible environment could be decreased and subsequently the rate of radionuclide transport increased. The strategy for resolving this FC with respect to these potentially disruptive processes is to demonstrate that they will not affect the ability of the repository to isolate waste.

The overall strategy for resolving this FC is to test the hypothesis that it is present at the Yucca Mountain site. The various programs that are planned for site characterization will investigate the processes operating within the setting during the Quaternary and use the information as a basis for predicting future processes, events, and conditions. Overall, the geologic setting is expected to exhibit sufficient favorable characteristics to ensure waste isolation. The descriptions of the various site conditions are given in Chapters 1 through 5, and the discussions of the various characterization programs are given in Section 8.3.1. The data needed to evaluate the effects of the potentially disruptive conditions are discussed above in the issue-resolution strategies for PACs.

Favorable condition 2: For disposal in the saturated zone, hydrogeologic conditions that provide: (i) a host rock with low horizontal and vertical permeability, (ii) downward or dominantly horizontal hydraulic gradient in the host rock and surrounding hydrogeologic units, and (iii) low vertical permeability and low hydraulic potential between the host rock and surrounding hydrogeologic units.

Because disposal at the Yucca Mountain site will be in the unsaturated zone, this favorable condition is not present at the site.

Favorable condition 3: Geochemical conditions that: (i) promote precipitation or sorption of radionuclides, (ii) inhibit the formation of particulates, colloids, and inorganic and organic complexes that increase the mobility of radionuclides, or (iii) inhibit the transport of radionuclides by particulates, colloids, and complexes.

Favorable condition 3 is concerned with conditions that would reduce radionuclide transport through precipitation or sorption. This condition is also concerned with the absence of conditions that would interfere with these processes. These conditions include the formation of or transport by particulates, colloids, and organic and inorganic complexes.

Available evidence indicates that some aspects of favorable condition 3 are expected to exist at the Yucca Mountain site. Conditions present at the site are expected to promote precipitation of some radionuclides. Present evidence indicates that many radionuclide oxides are least soluble in solutions of neutral pH (6-8). Water samples taken from wells near the site have pH values in this range. Conditions at the site are also expected to promote the sorption of radionuclides. Highly sorbing zeolitic and clay minerals are common in the tuffaceous beds of Calico Hills that underlie the proposed

repository horizon. The hydrologic flow path from the proposed host rock is expected to be downward through the unsaturated Calico Hills to the saturated zone, and sorptive processes are expected to retard migrating radionuclides.

Insufficient information is available at this time to state a definite expectation regarding the formation of colloids, particulates, or complexes. Colloids may form and there may be a potential for the transport of radionuclides as colloids or as complexes or by particulates, but the relative significance or importance of these processes is not yet determined.

The strategy for resolving this FC is to demonstrate that the condition is present at the Yucca Mountain site. The geochemistry test program will investigate radionuclide sorption and solubility. Furthermore, the test program will investigate the formation and stability of radiocolloids, the sorption of radionuclides on particulates and colloid material, and the potential for transport and retardation of particulates and colloids. The test program will provide the necessary information to determine the potential for radionuclide retardation, and this information will be used in determining compliance with the waste-isolation performance objective (10 CFR 60.112, Issue 1.1, Section 8.3.5.13).

The investigations that address favorable condition 3 fall into two categories. The first category of investigations study (1) radionuclide sorption in a nonadvective and advective system and (2) the solubility of radionuclides. Investigations and studies in this category are

1. Investigation 8.3.1.3.4 (radionuclide retardation by sorption processes) including Studies 8.3.1.3.4.1 through 8.3.1.3.4.3.
2. Investigation 8.3.1.3.5 (radionuclide retardation by precipitation processes) including Studies 8.3.1.3.5.1 and 8.3.1.3.5.2.
3. Investigation 8.3.1.3.6 (radionuclide dispersion, diffusion, and advection) including Studies 8.3.1.3.6.1 and 8.3.1.3.6.2.

The second category includes investigations that study (1) radiocolloid formation and stability, (2) sorption of radionuclides by particulates or colloids, (3) the transport of radionuclides (retardation) in general and transport by colloids or particulates, and (4) the overall potential for radionuclide retardation. Investigations and studies in this category are

1. Investigation 8.3.1.3.4 (radionuclide retardation by sorption processes) including Study 8.3.1.3.4.1 and Activity 8.3.1.3.4.1.4 (sorption by particulates and colloids).
2. Investigation 8.3.1.3.5 (radionuclide retardation by precipitation processes) including Study 8.3.1.3.5.1 (colloid formation).
3. Investigation 8.3.1.3.6 (radionuclide dispersion, diffusion, and advection) including Studies 8.3.1.3.6.1 and 8.3.1.3.6.2 (transport processes) and Activity 8.3.1.3.6.1.5 (filtration particulate transport).

4. Investigation 8.3.1.3.7 (radionuclide retardation by all processes) including Study 8.3.1.3.7.1 (retardation sensitivity analysis).

The descriptions of these investigations provide detailed discussions of the studies and their interrelationships. Equally informative is the overview to the geochemistry test program (Section 8.2).

Favorable condition 4: Mineral assemblages that, when subjected to anticipated thermal loading, will remain unaltered or alter to mineral assemblages having equal or increased capacity to inhibit radionuclide migration.

Under expected repository conditions, the present high radionuclide-retardation capacity of the tuff units at Yucca Mountain is not expected to be significantly degraded and may, in fact, be increased. Zeolitic minerals (clinoptilolite and mordenite) are expected to contribute most to inhibiting radionuclide migration through sorptive processes. Most of the sorptive zeolites are located below the proposed repository horizon and are not expected to be significantly altered under the expected postemplacement thermal loading.

The minerals that could be affected by thermal loads include feldspar-silica assemblages, the heulandite-smectite assemblage, and volcanic glass. Feldspar-silica assemblages have a low sorbing capacity that is unlikely to decrease significantly under expected repository conditions. The heulandite-smectite assemblage, which together with volcanic glass comprises approximately 2 percent of the host rock, might be affected by the increase in temperature. However, the potential loss of sorption from alteration of these zeolites in the host rock represents a very small proportion of the total sorption potential of the zeolites in the underlying Calico Hills unit, where the thermal effects of the waste are expected to be much lower than in the host rock. Studies of volcanic glass alteration suggest that the glassy rock could alter to silica-feldspar-zeolite-smectite assemblages. The high sorptive properties of the zeolite-smectite assemblages could possibly enhance the overall sorptive capacities along radionuclide migration pathways.

The strategy for resolving this FC is to test the hypothesis that it is present at the Yucca Mountain site. The geochemistry test program will investigate the mineral assemblages already present at Yucca Mountain in order to adequately characterize the potential for future mineral alteration. The test program will (1) evaluate the present ground-water composition to establish the rock, mineral, and water interactions; (2) establish the alteration history of the minerals present at Yucca Mountain; (3) experimentally investigate mineral stability; (4) establish the thermodynamic data base for mineral alteration; and (5) develop a conceptual model of mineral evolution that would allow a prediction of potential future changes in mineralogy due to the expected thermal loading. The potential mineral changes will be assessed in terms of the sensitivity of radionuclide retardation to potential mineral changes, particularly changes in sorptive minerals. The portions of the geochemistry test program that will provide this information are

1. Investigation 8.3.1.3.1 (water chemistry) including Study 8.3.1.3.1.1 (ground-water chemistry model).
2. Investigation 8.3.1.3.2 (mineralogy, petrology, and rock chemistry) including Study 8.3.1.3.2.2 (alteration history) and Activities 8.3.1.3.2.2.1 (past alteration) and 8.3.1.3.2.2.2 (heating experiments on sorbing minerals).
3. Investigation 8.3.1.3.3 (mineral and glass stability) including Studies 8.3.1.3.3.1 through 8.3.1.3.3.3 (the thermodynamic and kinetic experimental and theoretical work to develop a conceptual model of mineral evolution).
4. Investigation 8.3.1.3.7 (radionuclide retardation by all processes).

Favorable condition 5: Conditions that permit the emplacement of waste at a minimum depth of 300 meters from the ground surface. (The ground surface shall be deemed to be the elevation of the lowest point on the surface above the disturbed zone.)

The unsaturated, densely welded, devitrified portion of the Topopah Spring has been selected as the preferred repository horizon. The ranking criteria used to select the horizon included (1) ground-water travel time, (2) allowable gross thermal loading, (3) excavation stability, and (4) relative economics. In the primary area, only 50 percent of the waste could be emplaced at least 300 m below the ground surface. The strategy for resolving this FC is to claim that it is not present at the Yucca Mountain site. It will not be investigated further.

Favorable condition 6: A low population density within the geologic setting and a controlled area that is remote from population centers.

The Yucca Mountain site is located in a county with a population density of 0.5 person per square mile. This is substantially less than the average for the continental United States, which is 76 persons per square mile. Also, the controlled area is located 137 km (85 mi) by air from the city of Las Vegas, Nevada, the nearest highly populated area.

The strategy for resolving this FC is to test the hypothesis that it is present at the Yucca Mountain site. The identification of additional information that might be necessary to address population density and distribution concerns, and subsequently provide additional evidence regarding this favorable condition, is outside the scope of this document. Information required to address population density and distribution concerns will be identified through environmental scoping hearings and presented in the environmental impact statement.

Favorable condition 7: Pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 yr.

Preliminary calculations of the ground-water travel time from the disturbed zone to the accessible environment have been made. Using an upper bound of 0.5 mm/yr for flux through the repository horizon, the mean travel time was calculated to be approximately 43,400 yr, with a range of 9,500 yr to 80,200 yr. These calculations were based on available data and the current understanding of the geohydrologic flow system.

The strategy for resolving this FC is to test the hypothesis that it is present at the Yucca Mountain site. Additional data are needed to refine the unsaturated- and saturated-zone models so that more accurate calculations can be made. Issue 1.6 (Section 8.3.5.12) addresses the NRC performance objective for pre-waste-emplacement ground-water travel time (10 CFR 60.113). This objective requires that the ground-water travel time from the disturbed zone to the accessible environment be at least 1,000 yr for a site to be acceptable. The strategy to demonstrate compliance with the objective, thereby resolving Issue 1.6, is presented in Section 8.3.5.12. The information needs identified in the strategy for Issue 1.6 are expected to be sufficient to determine the extent to which this favorable condition is present at Yucca Mountain, i.e., the extent to which the ground-water travel time exceeds 1,000 yr. This information is given in Section 8.3.5.12.

Favorable condition 8: For disposal in the unsaturated zone, hydrogeologic conditions that provide: (i) low and nearly constant moisture flux in the host rock and in the overlying and underlying hydrogeologic units, (ii) a water table sufficiently below the underground facility such that fully saturated voids continuous with the water table do not encounter the underground facility, (iii) a laterally extensive low-permeability hydrogeologic unit above the host rock that would inhibit the downward movement of water or divert downward moving water to a location beyond the limits of the underground facility, (iv) a host rock that provides for free drainage, or (v) a climatic regime in which the average annual historic precipitation is a small percentage of the average annual potential evapotranspiration.

The strategy for resolving this FC is to test the hypothesis that it is present at the Yucca Mountain site. Each part of the favorable condition will be discussed individually.

(i) Low and nearly constant moisture flux

This favorable characteristic is not expected to exist at the Yucca Mountain site. The moisture flux at the site is expected to be low; however, the actual magnitude of the flux is expected to vary throughout the host rock and overlying and underlying units. This variation results from variations in the matrix and fracture characteristics of the different rock units. Also, structural features such as fault zones result in areas of higher than average moisture flux.

(ii) Extent of fully saturated voids

Saturated void spaces in the unsaturated zone consist of the capillary fringe above the water table and any saturated fractures that extend from the water table upward. The zone of continuous, fully saturated voids (capillary fringe and saturated fractures) is not expected to extend above the top of the Calico Hills nonwelded unit below the repository host rock.

Current data indicate that in the area of Yucca Mountain, the water table is approximately 500 to 750 m below the ground surface. The proposed repository horizon is the densely welded, divitrified portion of the Topopah Spring Member of the Paintbrush tuff. This horizon is approximately 200 to 400 m above the water table.

(iii) Lateral diversion of infiltration

Preliminary evidence suggests that the downward movement of water will not be diverted completely beyond the limits of the underground facility. It is expected, however, that lateral diversion could occur to some extent, thus reducing the overall downward flux through the repository.

The combination of contrasting welded, highly fractured units and nonwelded, porous units with the general 3 to 8° eastward dip of the units could promote lateral diversion to some degree. The nonwelded, highly porous unit of the Paintbrush Tuff overlies the welded, highly fractured Topopah Spring unit. Because the permeability of the Topopah Spring unit is much less than the permeability of the nonwelded unit, a permeability barrier is expected at the contact. Because the pores of the overlying unit are much smaller than the fractures of the Topopah Spring unit, a capillary barrier is also expected. These barriers, together with the dip of the beds, could result in a general, eastward lateral diversion.

Structural features of high permeability could disrupt this lateral movement, however. The Ghost Dance fault, for example, could act as a conduit for downward flow through the repository horizon. The extent to which these conditions are present needs further investigation to determine their likelihood and significance.

(iv) Free drainage

It is expected that the host rock would be freely draining if flux through the host rock were to increase sufficiently to cause fracture flow. The welded Topopah Spring unit is highly fractured, which results in a high bulk permeability. Although matrix flow predominates at lower fluxes, fracture flow would be expected at higher rates. Existing drill-hole data support a position that the fractured, welded tuff is continuous beneath the site; thus, free drainage would be expected throughout the host rock.

(v) Precipitation less than evapotranspiration

Meteorological recording stations at Yucca Mountain have not been in operation long enough to provide historically significant precipitation records. Data available from nearby recording stations (Yucca Flat and Beatty) indicate average annual precipitation values of 145 and 114 mm. The

actual precipitation at Yucca Mountain is expected to be slightly higher. Taking into account the terrain and high elevation of Yucca Mountain, the average annual precipitation has been estimated to be approximately 150 mm. Potential evapotranspiration has been estimated by empirical methods to be approximately 630 mm/yr. This results in an average annual precipitation that is roughly 20 percent of the evapotranspiration.

The concerns of favorable condition 8 will be investigated through the geohydrology test program (Section 8.3.1.2). The concerns of the first four parts of this condition are included in the investigation of the unsaturated-zone hydrologic properties and conditions. These properties, shown in tabular form in Section 8.3.1.2, include fracture and matrix permeability, flux, flow velocities, matric potentials, moisture content, and infiltration rates. Collecting data on these properties will allow more quantitative analyses of the first four parts of this FC. The concerns of the fifth part, precipitation and evapotranspiration at Yucca Mountain, will be investigated through the meteorology test program (Section 8.3.1.12). The information made available through these test programs for the resolution of other issues is expected to be sufficient to determine the extent to which each aspect of this favorable condition is present and could contribute to waste isolation.

Interrelationships of the information needs

The strategies for making the demonstrations required by 10 CFR 60.122 for the potentially adverse conditions and the favorable conditions rely on the investigations and assessments of other issues, as explained in the preceding discussion. All information necessary to make these demonstrations is expected to be identified and obtained through the activities of these other issues. Because the purpose of the demonstrations required for the conditions is to show that the performance objectives can be met given the conditions present at the site, it is also expected that the goals and levels of confidence identified by the other issues are suitable for resolution of this issue. Therefore, there are no information needs identified specifically for this issue.

Nuclear Waste Policy Act
(Section 113)

Section 8.3.5.18

Consultation Draft

HIGHER LEVEL FINDINGS —
POSTCLOSURE SYSTEM AND
TECHNICAL GUIDELINES

***Site Characterization
Plan***

***Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

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8.3.5.18 Issue resolution strategy for Issue 1.9: (a) Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the postclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for geohydrology, geochemistry, rock characteristics, climatic changes, erosion, dissolution, tectonics and human interference; and (b) can the comparative evaluations required by 10 CFR 960.3-1-5 be made?

The DOE has established a set of siting guidelines to be used as a basis for evaluating the suitability of potential repository sites during the site selection process. These siting guidelines, which are set forth in 10 CFR Part 960, are separated into two categories: those that address postclosure conditions (10 CFR 960.4) and those that address preclosure conditions (10 CFR 960.5). The manner in which the siting guidelines must be addressed during the siting process is described by DOE Implementation Guidelines (10 CFR 960.3).

In addition to the preclosure and postclosure guidelines, 10 CFR Part 960 describes two evaluations that will predict radionuclide releases to the accessible environment under expected conditions during the next 100,000 yr (10 CFR 960.3-1-5). These evaluations will be used to compare the expected postclosure performance of acceptable sites. The first comparison will emphasize the performance of the natural barriers; the second will emphasize the performance of the total system.

Issue 1.9 is concerned with the DOE's postclosure guidelines (Issue 1.9(a)) and the two comparative evaluations (Issue 1.9(b)). The discussion that follows explains how the guidelines and the evaluations will be addressed and how the necessary information will be made available. Because the guidelines and the comparative evaluations are distinct, this issue will be described in two parts.

Regulatory basis for Issue 1.9(a) of the postclosure siting guidelines

The postclosure siting guidelines consist of a system guideline and eight technical guidelines. The system guideline is concerned with the effect of the geologic setting of a site as a whole on postclosure performance of the repository system. Each technical guideline, however, is concerned with the effect of some specific aspect of the setting on postclosure performance. Each guideline has a qualifying condition that must be met for a site to be acceptable. In addition, five of the technical guidelines have at least one disqualifying condition. A site is unacceptable if any one of the disqualifying conditions is found to be present. The technical guidelines also identify favorable conditions and potentially adverse conditions that describe characteristics of the setting that, if present, could contribute to or detract from the postclosure performance of a site.

The Implementation Guidelines require that the qualifying and disqualifying conditions of the system and technical guidelines be evaluated and that specific findings be made for each condition at principal decision points in the siting process. These findings are stated in 10 CFR Part 960, Appendix III, and are shown in Table 8.3.5.18-1.

Table 8.3.5.18-1. Findings for qualifying and disqualifying conditions

Disqualifying condition--lower-level findings

- Level 1 (a) The evidence does not support a finding that the site is disqualified.
- (b) The evidence supports a finding that the site is disqualified.

Disqualifying condition--higher-level findings

- Level 2 (a) The evidence supports a finding that the site is not disqualified on the basis of that evidence and is not likely to be disqualified.
- (b) The evidence supports a finding that the site is disqualified or is likely to be disqualified.

Qualifying condition--lower-level findings

- Level 3 (a) The evidence does not support a finding that the site is not likely to meet the qualifying condition.
- (b) The evidence supports a finding that the site is not likely to meet the qualifying condition, and therefore the site is disqualified.

Qualifying condition--higher-level findings

- Level 4 (a) The evidence supports a finding that the site meets the qualifying condition and is likely to continue to meet the qualifying condition.
- (b) The evidence supports a finding that the site cannot meet the qualifying condition or is unlikely to be able to meet the qualifying condition, and therefore the site is disqualified.
-

There are four levels of findings. Disqualifying and qualifying conditions both require a lower-level and a higher-level finding. Lower-level findings must be made to determine if a site may be nominated as suitable for characterization or recommended as a candidate site for characterization. Higher-level findings, however, must be made to determine if a site may be recommended for the development of a repository. Disqualifying conditions require Level 1 and Level 2 findings, and qualifying conditions require

Level 3 and Level 4 findings. Each level has both a positive finding and a negative finding associated with it.

Table 8.3.5.18-2 shows the findings previously made for the postclosure guideline qualifying and disqualifying conditions. These findings and the evidence supporting them are given in the NNWSI Project environmental assessment (DOE, 1986b). The available evidence was sufficient to support positive higher-level findings for the qualifying and disqualifying conditions of the dissolution technical guideline and positive lower-level findings for the qualifying and disqualifying conditions of the other postclosure technical guidelines and the postclosure system guideline. To determine if the Yucca Mountain site is suitable for the development of a repository, therefore, higher-level findings must be made for the remaining qualifying and disqualifying conditions.

The DOE Siting Guidelines do not require any findings similar to lower-level or higher-level findings to be made for the favorable or potentially adverse conditions of the technical guidelines. As stated in the Supplementary Information for 10 CFR Part 960, Overview of the Guidelines (DOE, 1984c), these conditions were intended to be used to predict the suitability of a site and provide a preliminary indication of system performance before the start of detailed site characterization studies. These conditions were considered and used in the identification of potentially acceptable sites, and in the nomination and recommendation of sites as suitable for characterization. By the completion of site characterization, however, sufficient data will be available to directly evaluate site performance against the qualifying conditions of the system and technical guidelines. Therefore, the favorable and potentially adverse conditions will not be considered in specific terms as they were for the environmental assessment (DOE, 1986b).

Approach to resolving Issue 1.9(a)

To resolve Issue 1.9(a), sufficient evidence must be available to support either a positive or negative higher-level finding for each qualifying and disqualifying condition associated with postclosure repository performance. Each of the qualifying conditions makes reference either directly or through the system guideline to regulatory requirements of the NRC (specifically, 10 CFR Part 60). To support higher-level findings for the qualifying conditions, evidence must show that the geologic setting was taken into consideration in the evaluations of compliance with the associated NRC regulatory requirements and that the geologic setting as a whole (for the system guideline) and the various aspects of the setting (for the technical guidelines) will not prevent compliance with the NRC regulations. The disqualifying conditions are also related to NRC regulations, but not always as explicitly as the qualifying conditions.

Figure 8.3.5.18-1 shows the strategy for resolving Issue 1.9(a). The first step is to eliminate from further consideration the qualifying and disqualifying conditions for which higher-level findings have already been made. This is the case for the qualifying and disqualifying conditions of the dissolution technical guideline. Next, for each remaining condition, it is determined whether the evidence presently available is sufficient to support a higher-level finding. This evidence consists of the information

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Table 8.3.5.18-2. Preliminary findings on postclosure system and technical guidelines^a

Postclosure guideline (10 CFR 960)		Preliminary finding ^b
960.4-1 (a)	Postclosure system Qualifying condition	Level 3(a)
960.4-2-1 (a)	Geohydrology Qualifying condition	Level 3(a)
(d)	Disqualifying condition	Level 1(a)
960.4-2-2 (a)	Geochemistry Qualifying condition	Level 3(a)
960.4-2-3 (a)	Rock characteristics Qualifying condition	Level 3(a)
960.4-2-4 (a)	Climate Qualifying condition	Level 3(a)
960.4-2-5 (a)	Erosion Qualifying condition	Level 3(a)
(d)	Disqualifying condition	Level 1(a)
960.4-2-6 (a)	Dissolution Qualifying condition	Level 4(a)
(d)	Disqualifying condition	Level 2(a)
960.4-2-7 (a)	Tectonics Qualifying condition	Level 3(a)
(d)	Disqualifying condition	Level 1(a)
960.4-2-8-1 (a)	Natural resources Qualifying condition	Level 3(a)
(d) (1)	Disqualifying condition	Level 1(a)
(d) (2)	Disqualifying condition	Level 1(a)
960.4-2-8-2 (a)	Site ownership and control Qualifying condition	Level 3(a)

^aPreliminary findings from DOE (1986b).

^bSee Table 8.3.5.18-1 for an explanation of the finding levels.

FIG83561/7-21-87/VB

Figure 8.3.5.18-1. Issue resolution strategy for Issue 1.9(a) (postclosure higher-level findings).

presented in the NNWSI Project environmental assessment (DOE, 1986b) and in Chapters 1 through 7 of the SCP. If the evidence is sufficient, the finding and the evidence are documented.

For the qualifying and disqualifying conditions for which there is not adequate evidence available, the planned site characterization studies are reviewed to determine if the conditions will be investigated. This is accomplished by evaluating the resolution strategies of the other postclosure performance issues (Issues 1.1 through 1.6 and Issue 1.8) that assess the ability of the site to comply with the NRC's postclosure regulatory requirements (10 CFR 60). As discussed previously, the qualifying and disqualifying conditions are linked to NRC regulatory requirements, and evidence to support a higher-level finding must show that the condition does not prevent compliance with the referenced requirements. Therefore, if the concerns of the qualifying and disqualifying conditions are being considered in the resolution strategies of the issues that assess compliance with the regulations, it can be expected that the evidence to support higher-level findings will be made available through the information and analyses that support resolution of the issues. A correlation of the qualifying and disqualifying conditions and the issues that will supply the information is shown in Table 8.3.5.18-3.

After ensuring that the qualifying and disqualifying conditions will be investigated, the information necessary to assess compliance will be obtained during site characterization. Upon completion of the assessments, the results will be evaluated to determine if sufficient evidence is available to support higher-level findings. If the evidence is sufficient, the findings and the evidence will be documented. If the evidence shows that a negative higher-level finding must be made for any one of the conditions (i.e., that a disqualifying condition is present or that a qualifying condition is not present), then the site will be disqualified. This evaluation will continue until positive higher-level findings can be supported for all the conditions or until a negative higher-level finding must be made.

If, in evaluating the results of the assessments, insufficient information is found to support either a positive or a negative higher-level finding for a qualifying or disqualifying condition, additional data and analyses may be necessary to satisfy existing information needs. The resolution strategies of the appropriate performance issues will be reviewed to determine if, in fact, the condition was adequately considered and the information needs satisfied. If not, the strategies for the appropriate performance issues will be revised, and new information needs will be identified as necessary, additional data will be collected, and compliance will be reassessed. This process continues until there is sufficient evidence to support either a positive or a negative higher-level finding for every qualifying and disqualifying condition. As discussed previously, findings are not required for the favorable conditions or the potentially adverse conditions at this stage in the siting process. Therefore, site conditions that may favorably affect performance will be considered only to the extent necessary in the assessment of compliance with the NRC regulations (Issues 1.1 through 1.6 and Issue 1.8).

However, since the potentially adverse conditions describe processes or events that could adversely affect postclosure performance, it would be

Table 8.3.5.18-3. Postclosure performance issues that address the concerns of the qualifying and disqualifying conditions of the postclosure guidelines covered by Issue 1.9(a)
(page 1 of 2)

Guideline	Issue 1.1 (total system performance)	Issue 1.2 (individual protection)	Issue 1.3 (ground-water protection)	Issue 1.4 (containment by waste package)	Issue 1.5 (engineered barrier system release rates)	Issue 1.6 (ground- water travel time)
System guideline						
Qualifying condition	x	x	x	x	x	x
Geohydrology						
Qualifying condition	x	x	x	x	x	x
Disqualifying condition	x					
Geochemistry						
Qualifying condition	x	x	x	x	x	x
Rock characteristics						
Qualifying condition	x	x	x	x	x	x
Climate						
Qualifying condition	x					
Erosion						
Qualifying condition	x					
Disqualifying condition	x					
Dissolution						
Qualifying condition ^a	x					
Disqualifying condition ^a	x					

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Table 8.3.5.18-3. Postclosure performance issues that address the concerns of the qualifying and disqualifying conditions of the postclosure guidelines covered by Issue 1.9(a) (page 2 of 2)

Guideline	Issue 1.1 (total system performance)	Issue 1.2 (individual protection)	Issue 1.3 (ground-water protection)	Issue 1.4 (containment by waste package)	Issue 1.5 (engineered barrier system release rates)	Issue 1.6 (ground- water travel time)
Tectonics						
Qualifying condition	x					
Disqualifying condition	x					
Natural resources						
Qualifying condition	x					
Disqualifying condition 1	x					
Disqualifying condition 2	x					
Site ownership						
Qualifying condition ^b						

^aHigher-level finding has been made in the environmental assessment (DOE, 1986b); see Table 8.3.5.18-2.

^bNot addressed by the issues and is outside the scope of site characterization and this document.

prudent to ensure that they are being considered in the appropriate performance assessments performed in support of the other performance issues. The concerns of the potentially adverse conditions of 10 CFR Part 960 are very similar to the concerns of the potentially adverse conditions of the NRC's Siting Criteria (10 CFR 60.122), which are addressed by Issue 1.8 (Section 8.3.5.17). The strategy for addressing the potentially adverse conditions of the NRC Siting Criteria is to link each of the conditions to the site characteristics and disruptive scenarios considered in the assessments of postclosure performance of the total repository system (Issue 1.1, Section 8.3.5.13) and the engineered barrier system (Issue 1.4, Section 8.3.5.9, and Issue 1.5, Section 8.3.5.10). This will ensure that the effects on postclosure performance of each of the potentially adverse conditions of NRC Siting Criteria will be evaluated. Because of the similarity of the NRC's potentially adverse conditions to the DOE's potentially adverse conditions, the DOE's analysis indicates that the information and evaluations performed to support resolution of Issue 1.8 will ensure that the effects of the DOE's potentially adverse conditions on postclosure performance will be adequately evaluated.

The following discusses the qualifying condition of the postclosure system guideline and the qualifying and disqualifying conditions of the postclosure technical guidelines. The ties of each condition to the NRC regulations are explained; and the postclosure performance issue resolution strategies that will be relied upon are identified. The information relevant to each guideline, which will be collected during site characterization and used in the resolution of the other issues, is also given.

System guideline qualifying condition

The qualifying condition of the postclosure system guideline is stated in 10 CFR 960.4-1(a) as follows:

The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, Subpart B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60....

This qualifying condition is concerned with the overall compatibility of the geologic setting with the isolation of waste. To satisfy this condition, evidence must demonstrate that the characteristics of the geologic setting were investigated and that they do not prevent compliance with the EPA's postclosure performance requirements (40 CFR Part 191, Subpart B), or prevent the use of engineered barriers to ensure compliance with these requirements or those separate requirements established by the NRC for particular barriers (10 CFR 60.113).

The EPA's requirements are implemented by the NRC through 10 CFR 60.112 (the overall system performance objective). This regulation requires that the geologic setting be selected to ensure that radioactive releases to the accessible environment during the postclosure period will conform to generally applicable environmental standards for radioactivity as established by the EPA. The requirements of 40 CFR Part 191, Subpart B, as implemented by 10 CFR Part 60, are addressed through Issues 1.1, 1.2, and 1.3. Issue 1.1

assesses radioactive releases to the accessible environment during the next 10,000 years (40 CFR 191.13). Issue 1.2 evaluates individual doses in the accessible environment (40 CFR 191.15). Issue 1.3 is concerned with the protection of special sources of ground water (40 CFR 191.16).

The NRC's requirements for particular barriers after permanent closure are contained in 10 CFR 60.113, which establishes the requirements for the engineered barrier system with respect to waste package containment period, and limits on the rate of releases from the engineered barrier system. Requirements for the geologic setting with respect to the pre-waste emplacement ground-water travel time are also given. These requirements are addressed by Issues 1.4, 1.5, and 1.6, respectively.

The information that will be used to support a higher-level finding for this qualifying condition, therefore, is a compilation of all the site characteristics evaluated through the issue resolution strategies of Issues 1.1 through 1.6, and evidence that these site characteristics will not prevent the resolution of these six issues.

Issues 1.1, 1.2, and 1.3 are discussed in Sections 8.3.5.13, 8.3.5.14, and 8.3.5.15. Issues 1.4, 1.5, and 1.6 are discussed in Section 8.3.5.9, 8.3.5.10 and 8.3.5.12. All the site information that will be considered and evaluated in the resolution of these issues is given in these sections, and represents the information upon which a higher-level finding for the system guideline qualifying condition will be based.

Geohydrology technical guideline

The geohydrology technical guideline has one qualifying condition and one disqualifying condition.

Qualifying condition. The qualifying condition for the geohydrology technical guideline is stated in 10 CFR 960.4-2-1(a) as follows:

The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

The qualifying condition for the geohydrology technical guideline requires that the present and expected geohydrologic setting permit compliance with the postclosure system guideline qualifying condition (Section 960.4-1). As explained in the discussion of the system guideline qualifying condition, the requirements of that qualifying condition are addressed by Issues 1.1 through 1.6.

The geohydrology qualifying condition also specifically requires that the geohydrologic setting permit compliance with the requirements of 10 CFR 60.113 for radionuclide containment within the waste package, limits allowable releases from the engineered barrier system, and establishes a minimum

travel time for ground water from the underground facility to the accessible environment. These three performance requirements are addressed by Issues 1.4, 1.5, and 1.6 (Sections 8.3.5.9, 8.3.5.10, and 8.3.5.12), respectively, and have already been considered with respect to the information needed to support a higher-level finding for the system guideline qualifying condition (10 CFR 960.4-1).

The evidence to support a higher-level finding for this qualifying condition, therefore, will be made available through the information and analyses used to support resolution of Issues 1.1 through 1.6. The evidence will show how the geohydrologic setting will be considered in the resolution of these issues. Table 8.3.5.18-4 shows the general characteristics of the geohydrologic setting that will be considered by each issue. A more detailed discussion of how these characteristics will be evaluated in the resolution of each issue is presented in the SCP section addressing that issue.

Disqualifying condition. The disqualifying condition for the geohydrology technical guideline is stated in 10 CFR 960.4-2-1(d) as follows:

A site shall be disqualified if the pre-waste emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 yr along any pathway of likely and significant radionuclide travel.

This disqualifying condition is essentially the same as the NRC's pre-waste emplacement ground-water travel time objective, stated in 10 CFR 60.113(a)(2). Issue 1.6 addresses the NRC's ground-water travel time objective. Through the resolution of Issue 1.6, the site information and the calculational models necessary to determine the travel times and ultimately demonstrate compliance with the objective will be compiled. All the information necessary to support a higher level finding for the geohydrology disqualifying condition, therefore, will be provided by Issue 1.6. This information is discussed in greater detail in Section 8.3.5.12.

Geochemistry technical guideline

The geochemistry technical guideline has one qualifying condition and no disqualifying conditions.

Qualifying condition. The qualifying condition for the geochemistry technical guideline is stated in 10 CFR 960.4-2-2(a) as follows:

The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

The qualifying condition for the geochemistry technical guideline requires that the present and expected geochemical setting permit compliance

Table 8.3.5.18-4. Geohydrologic characteristics considered in making a higher-level finding for the qualifying condition of the geohydrology technical guideline, and issues for which the information will be obtained

Issue	Information
1.1	Same characteristics as used by Issue 1.6 below Disruptive conditions Increase in percolation flux Change in water-table altitude Change in saturated zone head gradients Creation of surficial discharge points
1.2	Same characteristics as used by Issue 1.6 below
1.3	Regional hydrogeologic reconnaissance of the site Regional ground-water flow system Ground-water uses Site hydrogeologic system Aquifer communication Aquifer contamination potential
1.4	Water flow mechanism in the host rock Quantity of water flow in contact with waste packages
1.5	Water flow mechanism in the host rock Quantity of water flow in contact with waste packages
1.6	Unsaturated zone characteristics Flux Moisture content Pressure head (matric potential) Saturation Moisture retention curve Permeability Saturated zone characteristics Flux Pressure head Saturated permeability Aquifer geometry Water table altitude

with the postclosure system guideline qualifying condition (Section 960.4-1). As explained in the discussion of the system guideline qualifying condition, the requirements of the system guideline qualifying condition are addressed by Issues 1.1 through 1.6.

The geochemistry qualifying condition also specifically requires that the geochemical setting permit compliance with the requirements of 10 CFR 60.113 for radionuclide containment within the waste package, limits on allowable releases from the engineered barrier system, and a minimum travel time for ground water from the underground facility to the accessible environment. These three performance requirements are addressed by Issues 1.4, 1.5, and 1.6 (Sections 8.3.5.9, 8.3.5.10, and 8.3.5.12), respectively, and have already been considered with respect to the information needed to make a higher-level finding for the system guideline (10 CFR 960.4-1).

The evidence to support a higher-level finding for this qualifying condition, therefore, will be made available through the information and analyses used to support the resolution of Issues 1.1 through 1.6. The evidence will show how the geochemical setting will be considered and that these characteristics will not prevent the resolution of these issues. Table 8.3.5.18-5 shows the general characteristics of the geochemical setting that will be considered during the resolution of each issue. A more detailed discussion of how these characteristics will be evaluated in the resolution of each issue is presented in the SCP section addressing that issue.

Rock characteristics technical guideline

The rock characteristics technical guideline has one qualifying condition and no disqualifying conditions.

Qualifying condition. The qualifying condition for the rock characteristics technical guideline is stated in 10 CFR 960.4-2-3(a) as follows:

The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in Section 960.4-1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology.

The qualifying condition for the rock characteristics technical guideline requires that the present and expected characteristics of the host rock and surrounding units permit compliance with the postclosure system guideline qualifying condition (Section 960.4-1). As explained in the discussion of the system guideline qualifying condition, the requirements of that qualifying condition are addressed by Issues 1.1 through 1.6.

The rock characteristics qualifying condition also specifically requires that the rock characteristics permit compliance with the requirements of 10 CFR 60.113 for radionuclide containment within the waste package, limits on allowable releases from the engineered barrier system, and a minimum travel time for ground water from the underground facility to the accessible environment. These three performance requirements are addressed by

Table 8.3.5.18-5. Geochemical characteristics considered in making a higher-level finding for the qualifying condition of the geochemistry technical guideline, and issues for which the information will be obtained

Issue	Information
1.1	Coupling factors and radionuclide retardation factors Gas-phase Carbon-14 transport characteristics Disruptive conditions Changes in ground-water chemistry Changes in unsaturated zone K_d values Changes in saturated zone K_d values
1.2	Coupling factors and radionuclide retardation factors Gas-phase Carbon-14 transport characteristics
1.3	No geochemistry information needed
1.4	Ground-water chemistry in host rock
1.5	Ground-water chemistry in host rock
1.6	No geochemistry information needed

Issues 1.4, 1.5, and 1.6 (Sections 8.3.5.9, 8.3.5.10, and 8.3.5.12), respectively and have already been considered with respect to the information needed to make a higher-level finding for the system guideline (10 CFR 960.4-1).

The evidence to support a higher-level finding for this qualifying condition, therefore, will be made available during the information and analyses used to support resolution of Issues 1.1 through 1.6. The evidence will show how the rock characteristics of the geologic setting will be considered in the resolution of these issues. Table 8.3.5.18-6 shows the rock characteristics of the geologic setting that will be considered by each issue. A more detailed discussion of how these characteristics will be evaluated in the resolution of each issue is presented in the SCP section addressing that issue.

Climatic changes technical guideline

The climatic changes technical guideline has one qualifying condition and no disqualifying conditions.

Qualifying condition. The qualifying condition for the climatic changes technical guideline is stated in 10 CFR 960.4-2-4(a) as follows:

Table 8.3.5.18-6. Rock characteristics considered in making a higher-level finding for the qualifying condition of the rock characteristics technical guideline, and issues for which the information will be obtained

Issue	Information
1.1	Unsaturated zone characteristics Effective porosity Location of geologic unit contacts Fault zone characteristics Bulk density Fracture frequency Saturated zone characteristics Effective thickness Effective porosity Fracture compressibility Matrix-fracture interface constrictivity-tortuosity factors Fracture frequency Fault zone characteristics
1.2	Same as those used by Issue 1.1
1.3	No rock characteristics information required
1.4	No rock characteristics information required
1.5	No rock characteristics information required
1.6	Unsaturated zone characteristics In situ temperature Bulk density Effective porosity Hydrologic unit contact altitudes Fault displacement Fault locations Saturated zone characteristics Bulk density Effective porosity Aquifer geometry Lithologic unit contact altitudes Fault displacement Fault locations Fracture characteristics

The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting.

The future climatic conditions at a site could affect the geohydrologic characteristics of the site during the next 10,000 yr, thereby affecting radionuclide releases to the accessible environment. The qualifying condition for the climatic changes technical guideline requires that the future climatic conditions permit compliance with the postclosure system guideline qualifying condition (10 CFR 960.4-1). As explained in the discussion of the system guideline qualifying condition, the requirements of that qualifying condition are addressed by Issues 1.1 through 1.6.

The requirements of 40 CFR 191.15 and 40 CFR 191.16, which are addressed by Issues 1.2 and 1.3, and of 10 CFR 60.113, which is addressed by Issues 1.4, 1.5, and 1.6, are only concerned with the undisturbed performance of the repository system (the requirement of 10 CFR 60.113 addressed by Issue 1.6 considers pre-waste-emplacement conditions). Since climatic change is considered a disruptive condition over the 10,000 yr performance period, the evidence to support a higher-level finding for this qualifying condition will be made available through the information and analyses used to support resolution of Issue 1.1, which will consider the long-term performance of the system and take disruptive processes and events into account. The evidence will consist of demonstrations that future climatic conditions have been investigated and that these conditions will not prevent the resolution of this issue. Table 8.3.5.18-7 shows the effects of future climatic conditions that will be considered during the resolution of Issue 1.1. The way in which these effects will be evaluated in the resolution of Issue 1.1 is discussed in Section 8.3.5.13.

Erosion technical guideline

The erosion technical guideline has one qualifying condition and one disqualifying condition.

Qualifying condition. The qualifying condition for the erosion technical guideline is stated in 10 CFR 960.4-2-5(a) as follows:

The site shall allow the underground facility to be placed at a depth such that the erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likelihood of potentially disruptive erosional processes, the DOE will consider the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period.

Table 8.3.5.18-7. Effects of future climatic conditions considered in making a higher-level finding for the qualifying condition of the climatic change technical guideline and in the resolution of Issue 1.1

Issue	Information
1.1	Changes in: Infiltration through host rock Water table altitude Head gradients in saturated zone Creation of surficial discharge points

Future erosional processes could affect the transport of radionuclides to the accessible environment by decreasing the thickness of the overburden, or by creating surficial discharge points between the underground facility and the boundary of the accessible environment. The qualifying condition for the erosion technical guideline requires that the future erosional processes permit compliance with the postclosure system guideline qualifying condition (10 CFR 960.4-1). As explained in the discussion of the system guideline qualifying condition, the requirements of that qualifying condition are addressed by Issues 1.1 through 1.6.

The requirements of 40 CFR 191.15 and 40 CFR 191.16, which are addressed by Issues 1.2 and 1.3, and of 10 CFR 60.113, which are addressed by Issues 1.4 and 1.5, are only concerned with the undisturbed performance of the repository system (the requirement of 10 CFR 60.113 addressed by Issue 1.6 considers pre-emplacement conditions). As discussed in Section 8.3.5.17, erosion has been considered in the identification of disruptive scenarios, and erosional processes at the Yucca Mountain site have been evaluated and no disruptive scenarios associated with erosional processes have been found that are credible at the Yucca Mountain site during the next 10,000 yr. Evidence to support this position is presented in Chapter 1. Therefore, sufficient evidence is available to support a higher-level finding for the erosion technical guideline qualifying condition.

Disqualifying condition. The disqualifying condition for the erosion technical guideline is stated in 10 CFR 960.4-2-5(d) as follows:

The site shall be disqualified if site conditions do not allow all portions of the underground facility to be situated at least 200 m below the directly overlying ground surface.

A positive higher-level finding can be made for the disqualifying condition on erosion on the basis of the geologic unit selected for the repository location and the conceptual design for the repository, which place

the repository at a depth in excess of 200 m from the overlying ground surface (Chapter 6).

Dissolution technical guideline

The dissolution technical guideline has one qualifying condition and one disqualifying condition. The qualifying condition is stated in 10 CFR 960.4-2-6(a) as follows:

The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified.

The disqualifying condition is stated in 10 CFR 960.4-2-6(d) as follows:

The site will be disqualified if it is likely that, during the first 10,000 yr after closure, active dissolution, as predicted on the basis of the geologic record, would result in a loss of waste isolation.

Positive higher-level findings have been made previously for these two conditions for the Yucca Mountain site. The evidence supporting these higher-level findings is presented in Chapter 6 of the NNWSI environmental assessment (DOE, 1986b). Since higher-level findings have been made, the dissolution technical guideline does not need to be considered further.

Tectonics technical guideline

The tectonics technical guideline has one qualifying condition and one disqualifying condition.

Qualifying condition. The qualifying condition for the tectonics technical guideline is stated in 10 CFR 960.4-2-7(a) as follows:

The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1. In predicting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, stratigraphic, geophysical, and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period.

Future tectonic activity at a site could affect the geohydrologic and rock characteristics of a site during the next 10,000 yr, thereby affecting radionuclide releases to the accessible environment. The qualifying condition for the tectonics technical guideline requires that future tectonic activity permit compliance with the postclosure system guideline qualifying condition (10 CFR 960.4-1). Predictions of future tectonic activity will be based on the evidence of such activity during the Quaternary. As explained

in the discussion of the system guideline qualifying condition, the requirements of that qualifying condition are addressed by Issues 1.1 through 1.6.

The requirements of 40 CFR 191.15 and 40 CFR 191.16, which are addressed by Issues 1.2 and 1.3, and of 10 CFR 60.113, which are addressed by Issues 1.4 and 1.5, are only concerned with the undisturbed performance of the repository system (the requirement of 10 CFR 60.113 addressed by Issue 1.6 considers pre-emplacement conditions). Since tectonic processes and events are considered to represent disruptive conditions over the 10,000 yr period of performance, the evidence to support a higher-level finding for this qualifying condition will be made available through the information and analyses used to support resolution of Issue 1.1, which will consider the long-term performance of the system and take disruptive processes and events into account. The evidence will consist of demonstrations that the potential for future tectonic activity has been investigated and that any activity will not prevent the resolution of this issue. Table 8.3.5.18-8 shows the effects of future tectonic activity that will be considered during the resolution of Issue 1.1. The way in which these effects will be evaluated in the resolution of Issue 1.1 is discussed in Section 8.3.5.13.

Disqualifying condition. The disqualifying condition for the tectonics technical guideline is stated in 10 CFR 960.4-2-7(d) as follows:

A site shall be disqualified if, based on the geologic record during the Quaternary Period, the nature and rates of fault movement or other ground motion are expected to be such that a loss of waste isolation is likely to occur.

This disqualifying condition is concerned with future fault movement or other tectonics-related ground motion disrupting the geologic setting during the next 10,000 yr such that isolation will be adversely effected. The DOE defines isolation in 10 CFR 960.2 as "inhibiting the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits." The prescribed limits are those limits set forth by the EPA in 40 CFR Part 191, Appendix A and implemented by 10 CFR 60.112. As previously discussed, the requirements of 10 CFR 60.112 are addressed by Issues 1.1, 1.2, and 1.3. But, since Issues 1.2 and 1.3 are only concerned with undisturbed repository performance, disruptive fault movement and other tectonics-related ground motion need only be considered in addressing Issue 1.1. The evidence necessary to support a higher-level finding for this disqualifying condition, therefore, will be made available through the resolution of Issue 1.1.

The effects of ground motion on postclosure repository performance have been evaluated. It has been determined that the only adverse effect of ground motion would be the closure of the air gap between the waste container and the borehole wall by collapse of the wall. This would provide a pathway for moisture to reach the container. This potentially disruptive scenario is being investigated through Issue 1.1. Thus, the information to support a higher-level finding will be made available through the investigations of Issue 1.1.

Table 8.3.5.18-8. Effects of future tectonic activity considered in making a higher-level finding for the qualifying condition of the tectonics technical guideline and in the resolution of Issue 1.1

Issue	Information
1.1	<p>Structural deformation</p> <ul style="list-style-type: none"> Rupturing waste packages Increasing water table altitude Increasing percolation flux Altering hydraulic gradients Diverting flow pathways <p>Igneous activity</p> <ul style="list-style-type: none"> Causing direct releases Rupturing waste packages Altering hydraulic gradients Diverting flow pathways Increasing water table altitude <p>Ground motion</p> <ul style="list-style-type: none"> Closure of borehole air gap

Human interference technical guideline

This technical guideline has two parts. The first part is concerned with natural resources and has one qualifying condition and two disqualifying conditions. The second part is concerned with site ownership and control, and has one qualifying condition.

Natural resources qualifying condition. The natural resources qualifying condition of the human interference technical guideline is stated in 10 CFR 960.4-2-8-1(a) as follows:

This site shall be located such that--considering permanent markers and records and reasonable projections of value, scarcity, and technology--the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

The presence of natural resources at a site has the potential to encourage retrieval activities that could interfere with the isolation of waste. Human activities could result in direct interference, if the waste containers were penetrated and waste brought to the surface, or in direct activities, such as a shortening of travel pathways by ground-water removal. The natural

resource qualifying condition requires that the extent of natural resources at the site be such that retrieval activities in the future would not be likely, so that compliance with the postclosure system guideline would not be prevented. As explained, the requirements of the system guideline are addressed by Issues 1.1 through 1.6.

The requirements of 40 CFR 191.15 and 40 CFR 191.16, which are addressed by Issues 1.2 and 1.3, and of 10 CFR 60.113, which are addressed by Issues 1.4, 1.5, and 1.6, are only concerned with the undisturbed performance of the repository system (the requirement of 10 CFR 60.113 addressed by Issue 1.6 considers pre-waste-emplacement conditions). Since human intrusion due to the potential for natural resources is considered a disruptive scenario, the evidence to support a higher-level finding for this qualifying condition will be made available through the information and analyses used to support resolution of Issue 1.1, which will consider the long-term performance of the system and take disruptive processes and events into account. The evidence will consist of demonstrations that the potential for future human interference has been investigated and will not prevent the resolution of this issue. Table 8.3.5.18-9 shows the future human activities that will be considered during the resolution of Issue 1.1. The way in which these effects will be evaluated in the resolution of Issue 1.1 is discussed in Section 8.3.5.13.

Natural resources disqualifying conditions. There are two disqualifying conditions for the natural resources section of the human interference technical guideline. They are stated in 10 CFR 960.4-2-8-1(d) as follows:

A site shall be disqualified if

1. Previous exploration, mining, or extraction activities for resources of commercial importance at the site have created significant pathways between the projected underground facility and the accessible environment; or
2. Ongoing or likely future activities to recover presently valuable natural mineral resources outside the controlled area would be expected to lead to an inadvertent loss of waste isolation.

This disqualifying condition is essentially the inverse of the natural resources qualifying condition discussed previously. (In establishing the disruptive scenarios associated with human activities that could occur at the site, previous exploration, mining, and extraction activities are investigated.) Therefore, the same evidence that will support a higher-level finding for the qualifying condition will be sufficient to support a higher-level finding for this disqualifying condition.

Site ownership and control qualifying condition. The site ownership and control qualifying condition of the human interference technical guideline is stated in 10 CFR 960.4-2-8-2(a) as follows:

The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR Part 60, ownership, surface and subsurface rights, and control of access that are required in order

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Table 8.3.5.18-9. Effects of human activities considered in making a higher-level finding for the qualifying condition of the human interference technical guideline and in the resolution of Issue 1.1

Issue	Information
1.1	<ul style="list-style-type: none">Irrigation<ul style="list-style-type: none">Changes in flux through repository horizonChanges in water-table altitudeChanges in head gradients in saturated zoneGround-water withdrawal<ul style="list-style-type: none">Change in water-table altitudeChanges in head gradients in saturated zoneSurface and subsurface mining<ul style="list-style-type: none">Change in water-table altitudeChanges in head gradients in saturated zoneConstruction of surface water impoundments<ul style="list-style-type: none">Changes in flux through repository horizonChanges in water-table altitudeChanges in head gradients in saturated zoneExploratory drilling<ul style="list-style-type: none">Potential for and effects of interception of waste by exploratory drilling

that potential surface and subsurface activities at the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in Section 960.4-1.

The concern of this qualifying condition is an institutional one related to acquiring sufficient land for the controlled area in compliance with the requirements of 10 CFR 60.121. DOE ownership and control of this land is expected to decrease the potential for future human interference activities. The institutional concerns of this guideline condition are outside the scope of site characterization as defined by the NWPA and, hence, are outside the scope of the SCP. The issue of land acquisition will be addressed in future environmental program planning (see Section 8.3.1.11).

Regulatory basis for Issue 1.9(b) of the postclosure siting guideline

Following the characterization of candidate sites and before recommending a site for development of a repository, the DOE will require comparisons of the postclosure performance of the repository systems proposed for each candidate site. The Implementation Guidelines (10 CFR 960.3-1-5) provide

rules for these site comparisons. The guidelines state that these comparisons will "evaluate predicted releases of radionuclides to the accessible environment." These releases will be evaluated by combining "releases of different radionuclides... by the methods specified in Appendix A of 40 CFR Part 191."

Two evaluations are required to predict releases for 100,000 yr after repository closure; 10 CFR 960.3-1-5 states that

First, the sites shall be compared by means of evaluations that emphasize the performance of the natural barriers at the site. Second, the sites shall be compared by means of evaluations that emphasize the performance of the total repository system. These second evaluations shall consider the expected performance of the repository system; be based on the expected performance of waste packages and waste forms, in compliance with the requirements of 10 CFR 60.113, and on the expected hydrologic and geochemical conditions at each site; and take credit for the expected performance of all other engineered components of the repository system.

In making the comparative evaluations, the DOE will only consider natural processes and events that are considered likely to occur or exist at the site over the next 100,000 yr. To emphasize the performance of the natural barrier system in the first evaluation, the DOE will assume equivalent engineered barrier performance for all sites. The range of performance levels considered will vary by a factor of 10 above and below the release rate limits stated in 10 CFR 60.113. For the second evaluation, the DOE will evaluate the performance of the total system, allowing each site to take credit for the expected performance of the engineered barrier system components.

Approach to resolving Issue 1.9(b)

Issue 1.1 addresses the NRC's overall system performance objective (10 CFR 60.112). For the resolution of Issue 1.1, an assessment of the total system performance is made to predict the performance of the total repository system over the next 10,000 yr. This assessment will consider both nominal and disturbed conditions. Nominal conditions are those processes and events that have a probability greater than 0.1 of occurring or existing at the site during the next 10,000 yr. Disturbed conditions are those processes and events that have a probability between 0.1 and 0.0001 of occurring or existing during the next 10,000 yr at the site. Processes and events that have a probability of less than 0.0001 of occurring or existing at the site during the next 10,000 yr will not be considered.

Scenario classes have been identified to describe the events and processes. These scenario classes (both the nominal and disturbed) are described in Section 8.3.5.13. Through the resolution strategy of Issue 1.1, performance measures and parameters have been identified to address the scenario classes.

To resolve Issue 1.9(b), the DOE will rely on the same strategy used to resolve Issue 1.1, with a few modifications. The nominal scenario class will be expanded to include those processes and events that have a probability of

greater than 0.1 of occurring during the next 100,000 yr. This means that certain scenario classes considered to represent disturbed conditions over the 10,000-yr performance period may fall within the nominal scenario class for the 100,000-yr performance period. The same total system model and submodels used to resolve Issue 1.1 will be used for Issue 1.9(b), however, additional information may be necessary. Disturbed scenario classes--those within a probability of less than 0.1 of occurring at the site during the next 100,000 yr--need not be considered.

Figure 8.3.5.18-2 shows this strategy. The first step is to evaluate the nominal and disturbed-performance scenario classes that are being considered in the assessment of the 10,000-yr performance of Issue 1.1. Those conditions that are within the 10,000-yr nominal-performance scenario class will also be considered in the nominal-performance scenario class for the 100,000-yr evaluation. In addition, some of the disturbed-performance scenario classes of the 10,000-yr assessment may become part of the nominal-performance scenario class of the 100,000-yr evaluation. Also, some events and processes eliminated from consideration in the 10,000-yr assessment may need to be considered in the 100,000-yr nominal-performance scenario class. Also, any events or processes that were in the 10,000-yr disturbed-performance scenario classes or not considered at all because of low probability of realization with respect to the 10,000-yr assessment may need to be included in the nominal class of the 100,000-yr calculation. In both cases, this will depend upon the probability of occurrence of the events of these scenario classes, i.e., if the probability of realization during the next 100,000 yr is greater than 0.1. The determination of events and processes that need to be considered, as in the assessment of 10,000-yr performance, are identified based on available evidence and professional judgment and will be revised as necessary based on new information.

The next step, once the nominal performance scenario class of events and processes is established, is to determine what information is required to evaluate the scenario class and assess the performance of the repository during the next 100,000 yr. This is accomplished by evaluating the data requirements of Issue 1.1. As mentioned previously, the models used in the 10,000-yr performance are sufficient to evaluate 100,000-yr performance. The only additional information would be the information needed to address events and processes that were not included in either the nominal or disturbed-performance scenario classes of Issue 1.1, or the information necessary to address events or processes over 100,000 yr that would not be adequately addressed by data for the 10,000-yr period.

Once these data needs are established, site characterization is conducted. The necessary information is collected during this phase, and the 100,000-yr performance of the repository is assessed, based on the 100,000-yr nominal-performance scenario class and using the same techniques, models, etc., as those used in the resolution of Issue 1.1. With respect to a radionuclide source term, two evaluations are made, in accordance with 10 CFR 960.3-1-5. The first will assess the performance of the repository system, using as a source term a range of release rates bounded by a factor of ten above and below the rates specified in 10 CFR 60.113. This same range of radionuclides will be used in assessing all potential sites, thus emphasizing the isolation capabilities of a site's natural barriers. The second assessment will use as a radionuclide source term the actual expected performance

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Figure 8.3.5.18-2. Resolution strategy for Issue 1.9(b).

of the engineered barrier system. This will allow full assessment of all aspects of the repository system at a site.

If during these evaluations insufficient information is available to assess the 100,000-yr performance, the data base will be reviewed. If the information identified is found adequate, but the data to satisfy the information needs are not, additional data will be collected. Otherwise, additional information needs may be necessary to assess 100,000-yr performance.

This reevaluation will continue until a satisfactory assessment of 100,000-yr performance is attained. The results of both evaluations will then be documented and used to compare sites in the recommendation of a site for development of a repository.

The steps of this resolution strategy have been completed through the identification of information needs. It has been determined, using the same information, evaluations, and judgment used in constructing the scenario classes of Issue 1.1, that the only conditions that need to be added to the nominal-performance scenario class of Issue 1.1 to form the nominal-performance scenario class for Issue 1.9(b) are those conditions associated with climatic events and processes. Over the 10,000-yr period, the DOE has determined that disruptive climatic changes have a probability of occurring of less than 0.1 and are therefore considered in the disturbed-performance scenario classes. However, over the 100,000-yr period these changes are expected to have a probability of occurring of greater than 0.1, and therefore need to be included in the 100,000-yr nominal-performance scenario class. The tectonic events and processes that were determined to have a probability of realization of less than 0.1 during the next 10,000 yr (and are, therefore, included in the disturbed-performance scenario classes of Issue 1.1) are expected to also have a probability of realization of less than 0.1 for the 100,000-yr period and hence need not be considered. Also, the disturbed-performance scenario classes of Issue 1.1 that were associated with human activities need not be considered in the 100,000-yr assessments since they are not natural events or processes. As for the other events and processes that were part of the nominal-performance scenario class of Issue 1.1 and will also be part of the nominal-performance scenario class of Issue 1.9(b), the information required for the 10,000-yr assessment will be sufficient for the 100,000-yr assessment.

The information needed to supplement that information required by Issue 1.1 to assess 100,000-yr performance is shown in Table 8.3.5.18-10. This information will be obtained through the climate test program (Section 8.3.1.5). This information, with the information and analyses of Issue 1.1, is expected to be sufficient to make the two 100,000-yr performance evaluations as required by 10 CFR 960.3-1-5. In addition, the data required to evaluate the tectonic-related disturbed-performance scenario classes of Issue 1.1 will provide evidence to support the position that, over the 100,000-yr period, tectonic events would not be part of the nominal-performance scenario class. As mentioned, the positions taken with regard to the events and processes included in the 100,000-yr nominal-performance scenario class will be modified as necessary as new site data becomes available.

Table 8.3.5.18-10. Scenarios and parameters associated with the 10,000-yr disturbed-performance scenario class that need to be added to the 100,000-yr nominal-performance scenario class (page 1 of 2)

Scenario class (from 8.3.5.13)	Performance parameter (adapted from 8.3.5.13)	Tentative parameter goal (adapted from 8.3.5.13)	SCP section and parameter category or set	Direct (D) ^a or associated study or activity
Climatic change causes increase in infil- tration over C-area ^b	Expected magnitude of flux change due to climatic changes over next 100,000 yr	Show expected flux change will be less than 5 mm	8.3.1.5.2 Future climate model	8.3.1.5.2.2.2(D) 8.3.1.5.1.6
			Infiltration characteristics	8.3.1.2.2.1
			Unsaturated-zone flow model	8.3.1.2.2.6
Climatic change causes an increase in alti- tude of water table	Expected magnitude of change in water-table level due to climatic changes over the next 100,000 yr	Show expected magnitude of water-table rise will be less than 100 m	8.3.1.5.2 Future climate model	8.3.1.5.2.2.3(D) 8.3.1.5.1.6
			Saturated-zone recharge/flow models	8.3.1.2.3.3
			Paleoclimate synthesis	8.3.1.2.1.5
			Quaternary dis- charge areas	8.3.1.2.2.1.3
			Analog recharge data	8.3.1.2.2.1.4
			Distribution, origin, and age of vein deposits	8.3.1.2.2.1.5

Table 8.3.5.18-10. Scenarios and parameters associated with the 10,000-yr disturbed-performance scenario class that need to be added to the 100,000-yr nominal performance scenario class (page 2 of 2)

Scenario class (from 8.3.5.13)	Performance parameter (adapted from 8.3.5.13)	Tentative parameter goal (adapted from 8.3.5.13)	SCP section and parameter category or set	Direct (D) ^a or associated study or activity
Climatic change causes appearance of surficial discharge points within C-area	Expected locations of surficial discharge points within C-area over the next 100,000 yr; magnitude of discharge at each location	Show that no surficial discharge points could appear within C-area, given a water-table rise less than 160 m	Same as information given for an increase in altitude of water table	
Climatic change causes an increase in the gradient of the water-table within the C-area	Expected magnitude of change in water-table gradient due to climatic change over the next 100,000 yr	Show average gradient to the C-area boundary will be less than 2×10^{-3}	Same as information given for an increase in altitude of water table	

^aStudy or activity directly addresses scenario.

^bNotation for indicating the various areas or zones around the repository: C-area = the controlled area, i.e., the actual area chosen according to the 40 CFR 191.12 definition of controlled area.

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Section 8.3.5:19

Consultation Draft

**COMPLETED ANALYTICAL
TECHNIQUES**

Site Characterization Plan

***Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

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U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

8.3.5.19 Substantially completed analytical techniques

Postclosure performance assessments by the NNWSI Project will evaluate the potential for containment and isolation of waste emplaced in the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain as discussed in Issues 1.1 through 1.9 (Sections 8.3.5.9, 8.3.5.10, and 8.3.5.12 through 8.3.5.18). The objective of the postclosure performance assessments is to determine whether Yucca Mountain site characteristics are such that the regulatory standards set forth in 10 CFR 960.4, 10 CFR 60.112, and 40 CFR 191.13 can be met.

Preclosure performance assessments will evaluate the potential for constructing and operating a repository in the Topopah Spring Member of the Paintbrush Tuff at Yucca Mountain, as discussed in Section 6.4 and addressed by Issues 2.1 through 2.5 and Issue 4.1 (Sections 8.3.5.2 through 8.3.5.6). The objective of the preclosure performance assessments is to determine if the site characteristics are such that the standards set forth in 10 CFR 960.5, 10 CFR 60.111, 40 CFR 191 Part A, and 10 CFR Part 20 can be met.

Over the next few years, preclosure and postclosure performance assessments will be made using many analytical techniques that have already been developed. Analytical techniques considered substantially completed are those that already exist and could be used, with little additional work or only minor modifications, to conduct performance assessment analyses. These analytical techniques have not yet been fully verified and validated for application to the conditions that exist at the NNWSI Project repository site at Yucca Mountain. Preliminary verification is currently in progress. Validation activities have been initiated but, for the most part, are still being developed.

The substantially completed analytical techniques are summarized here for postclosure performance issues and in Section 6.4.1 for preclosure performance issues. Section 8.3.5.20 describes plans to verify the accuracy of the techniques and to validate the models that these techniques embody and also discusses the techniques that still require significant development.

8.3.5.19.1 Postclosure performance-assessment analytical techniques

Computer codes that have been developed and are suitable for use in assessing the postclosure performance of a repository in the Topopah Spring Member of the Paintbrush Tuff of Yucca Mountain are listed in Table 8.3.5.19-1. These computer codes fall into four broad categories, depending on the models they embody: (1) those suitable for assessing the performance of the waste package, (2) those suitable for assessing the behavior of the rock and the water in the rock near the repository where heat effects are important and cannot be completely decoupled from the geomechanical and hydrological calculations, (3) those suitable for assessing site behavior on a scale at which temperature effects do not have to be accounted for directly, and (4) those suitable for assessing the behavior of the entire repository system and for probabilistic calculations of total releases to the accessible environment. The fourth category includes simplified versions of some of the models in the first three categories. In addition to the computer codes listed in Table 8.3.5.19-1, some simple analytical techniques,

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Table 8.3.5.19-1. Computer codes for use in performance assessment

Performance assessment task	Performance measures	Type of analysis	Potential codes ^a	Related issue in which the code may be used ^b
Waste package	Canister temperature	Conductive and convective heat and mass transfer	ADINAT NORIA, COYOTE, ARRAY F, TACO2D	1.4
	Waste containment time, waste release rate	Material degradation, dissolution, decay, leaching Geochemistry	WAPPA ORIGEN2, MORSE-L, NIKE2D, EQ3/EQ6, PANDORA, PHR81	1.4, 1.5
Repository	Rock stress-strain, displacement, permeability changes	Rock stress and fracture alterations induced by excavation; thermal loads, moisture changes; backfilling	ADINAT SPECTROM 31, SPECTROM 41, JAC2D	1.4, 1.5, 1.6
	Unsaturated water travel times, radionuclide release rates	Water flow in unsaturated media; coupled water and heat flow; coupled water flow and radionuclide migration	NORIA/FEMTRAN, WAFE/TRACR3D, TOUGH	1.5, 1.6
Site	Ground-water travel time	Probabilistic analysis of ground-water travel time distributions along flow paths at Yucca Mountain	GWTT	1.6
	Unsaturated and saturated water and radionuclide transport	Water flow paths; radionuclide migration	SAGUARO/FEMTRAN, TRUST/TRUMP, NWFT, TRACR3D, ISOQUOD, EDOC, VSFAST,	1.1, 1.2, 1.3, 1.6
	Dose to man	Biosphere transport and human uptake	PABLM, DACRIN	1.2
Total integrated system	Radionuclide release	Simple systems model of water flow in unsaturated media; leaching; flow and migration in unsaturated media; flow and migration in saturated media	TOSPAC, NWFT, SPARTAN	1.1, 1.2, 1.3
	Ground-water contamination			
	Individual dose			
	Dose to man	Biosphere transport and human uptake	PABLM, DACRIN,	1.2
	Atmospheric transport	Inhalation dose at accessible environment boundary	AIRDOS-EPA	1.3

^aThe list of potential codes does not exclude use of other codes.

^bIssues 1.1, 1.2, 1.3, 1.4, 1.5, and 1.6 are discussed in Sections 8.3.5.13, 8.3.5.14, 8.3.5.15, 8.3.5.9, 8.3.5.10, and 8.3.5.12, respectively.

such as hand calculations, may be used in performance-assessment analyses. The information needs under each postclosure performance issue discussed in Sections 8.3.5.9 through 8.3.5.17 contain the descriptions of the analyses that will be done. Therefore, the last column entry in Table 8.3.5.19-1 lists the issue(s) that the code might be used to resolve so that the reader can determine what analyses might be done using these codes.

Table 8.3.5.19-2 briefly describes each code, its documentation, and its availability for use by the NNWSI Project. There are three reasons for listing several codes for each type of application: (1) where analytic solutions do not exist and while benchmarking activities are ongoing, several codes that can be compared are needed for verification exercises; (2) the complexity (i.e., dimensions, level of detailed physical parameter descriptions, etc.) of the analyses that must be done have not yet been determined; and (3) the capabilities of the codes are usually different.

8.3.5.19.2 Preclosure performance-assessment analytical techniques

Computer codes suitable for use in assessing the preclosure safety of the Yucca Mountain repository site are listed in Table 8.3.5.19-3. These computer codes fall into two broad categories: preclosure repository-systems analyses and preclosure repository-consequence analyses. Computer codes for preclosure repository-systems analyses perform (1) initiating-event identification and quantification such as for criticality, fire, seismic activity, and flood; (2) systems-reliability studies such as analyses of fault trees and failure modes and effects; (3) human-reliability analysis; (4) common-cause failure analysis; (5) accident-sequence quantification; and (6) uncertainty, sensitivity, and importance analyses. Computer codes for preclosure repository-consequence analyses include (1) source-term characterization, (2) in-repository-consequence analysis, (3) environmental transport and offsite-consequence analyses, (4) economic-consequence analyses, and (5) uncertainty and sensitivity analyses. In addition to the computer codes listed in Table 8.3.5.19-3, some simple analytical techniques, such as hand calculations, may be used in preclosure safety assessment. The last column in Table 8.3.5.19-3 lists the issues in which the codes may be used. Table 8.3.5.19-4 gives a brief description of each code identified as a potential code to be used by the NNWSI Project and its status. The preclosure risk assessment methodology (PRAM) program is assessing the NNWSI set of computer codes, along with those of the Salt Repository Project and the Basalt Waste Isolation Project, to determine the most appropriate computer codes to be used uniformly by all the repository projects.

Unlike the computer codes used for postclosure performance assessment, most of the computer codes used in preclosure safety assessment are adopted from codes used for other nuclear-safety assessments (e.g., assessments of reactors). Since these computer codes have been used extensively in safety assessment, they do not require extensive verification and validation. Some exceptions to this statement are the ORIGEN-type codes, which are used by all the waste-management subsystems, and the computer codes developed specifically by each repository project, such as computer codes to model the consequences inside the surface and underground facilities.

Table 8.3.5.19-2. Brief description of codes from Table 8.3.5.19-1
(page 1 of 5)

Code name	Code analysis capabilities	Material models	Status of documentation	Status of use by NNWSI Project ^a
ADINAT 1,2,3d	Linear, nonlinear, transient, steady state, thermal conduction	Temperature, space-dependent variation of heat, thermal conductivity; boiling model; multiple layers; anisotropic properties, generates input to SANDIA-ADINA	Bathe 1975; 1977	SNLA (a,o)
AIRDOS-EPA	Predictions of radionuclide concentrations in air, rates of deposition, intake rates, and doses	Modified Gaussian plume equation, Nuclear Regulatory Commission terrestrial food-chain models, dose-conversion factors	Moore et al., 1979	SNLA (a)
ARRAY F 3D	Thermal conduction and radiation; solutions by superposition of exponentially decaying point sources	Analytic solution of a heat source in an infinite medium; all material properties constant	Klett et al., 1980	SNLA (a,o)
COYOTE	Linear and nonlinear transient heat conduction with energy sources	Temperature, time, and space-dependent variation of specific heat and thermal conductivity; boiling in partially saturated media approximated through latent heat consideration; multiple material layers; jointed rock model	Gartling, 1982	SNLA (a,o)
DACRIN	Organ dose to man from acute or chronic inhalation of radioactive aerosols	ICRP Task Group Organ Models; atmospheric dispersion; effective radiation doses to organs and the gastrointestinal tract	Houston et al., 1974	PNL (a)
EQ3/EQ6	EQ3: Equilibrium distribution of chemical species in an aqueous solution; saturation state of fluid with respect to minerals. EQ6: Mass transfer and effects of heating and cooling of the aqueous solutions; irreversible reaction in rock-water system	EQ3: Fixed temperature and pressure; empirical models of minerals in stable phase assemblage; EQ6: Reaction path models include precipitation, reaction progress in open/closed system	Wolery, 1979	LLNL (a,o,d)
FEMTRAN	Convective, dispersive, and diffusive transport of dissolved constituents; sorption, first order decay; development with first order decay complete; decay chain capabilities in developmental stage	Unsaturated porous media; retardation by sorption; chemical reactions, decay, moisture-dependent retardation factor; assumes local equilibrium for sorption	Martinez, 1985	SNLA (a,o,d)

Table 8.3.5.19-2. Brief description of codes from Table 8.3.5.19-1
(page 2 of 5)

Code name	Code analysis capabilities	Material models	Status of documentation	Status of use by NNWSI ^a Project
GWT	Probability distributions of ground-water travel times along distribution of flow paths, simplified Darcy's law in both matrix and fractures	Frequency distribution for saturated conductivity; effective porosity in multi-layers throughout repository; implicit assumptions for correlation lengths; probability distribution functions generated for flow paths; probability distribution functions calculated for areally integrated ground-water travel times.	Sinnock et al., 1986	SNLA (o)
HDOC	Two-phase nonlinear mass and heat transport in porous media, radionuclide decay; method of dynamics of contours	Transient, 1D, nonlinear flow; solute transport includes advection and diffusion with decay and retardation of radionuclides		Los Alamos (a,o,d)
ISOQUOD	Regional saturated hydrologic analysis of aquifer systems in multilayered media	Heterogeneous, multi-dimensional saturated media, Darcy's law applied with transient leakage coefficient, storage/sink terms, transmissivity	Pinder, 1976	SNLA (o)
JAC2D	Linear and nonlinear static stress analysis of 2D solids	Temperature-dependent, elastoplastic strain hardening; temperature-dependent secondary creep, soil with thermal loading; jointed rock with thermal loading	Thomas, 1982	SNLA (o,d)
MORSE-L	Atomic displacements from slowing of alpha particles and fission fragments; attenuation and absorbed dose rate from gamma rays	Gamma-ray interaction with atoms in water, metal barrier, and waste to produce alpha particles and spontaneous fission	Wilcox, 1972	LLNL (o)
NIKE2D	Stress in waste package from external loads, thermal expansion and thermal gradients, volume expansion of corrosion products, residual stress from fabrication	Mechanical and thermal stress, yielding, and unstable crack propagation	Hallquist, 1983	LLNL (o)
NORIA	Transport of water, water vapor, air and energy through partially saturated porous media; four nonlinear parabolic equations solved simultaneously	Material properties either constant or function of dependent and independent variables through user-defined sub-routines; ideal gas law	Bixler, 1985	SNLA (a,o,d)

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Table 8.3.5.19-2. Brief description of codes from Table 8.3.5.19-1
(page 3 of 5)

Code name	Code analysis capabilities	Material models	Status of documentation	Status of use by NNWSI Project ^a
NWFT	Flow and transport in saturated porous media	2D network representation of 1D paths for flow and transport of 3-member decay chains; properties vary between flow segments, constant along each segment	Campbell et al., 1980	SNLA (a,o)
ORIGEN2	Composites, radiation, spectra, and hazard units of the fuel cycle to compute isotope generation	Bateman equations, specular equilibria where appropriate; space- and spectrum-averaged cross sections; one-group flux		SNLA (a)
PABLM	Internal doses and dose commitments to man for acute or chronic ingestion of radionuclides	ICRP models for doses by ingestion for population or maximum individual for air pathway	Napier et al., 1980	SNLA (a); PNL (a)
PANDORA	Physical and chemical degradation of waste package barriers, radionuclide flux	Radiation, thermal, mechanical corrosion, and leach models; 1D flow and transport in porous media	O'Connell and Drach, 1986	LLNL (d)
PHR81	Geochemical speciation and mass transfer	Ion association model; pH, redox-potential, mass transfer functions of reaction progress equilibrium; solid phases, distribution of aqueous species, saturation state of aqueous phase with respect to mineral phase; temperature variations		Los Alamos (a)
SAGUARO	Richard's equation for flow through partially saturated porous media using Darcy's law; capillary effects; assumes single-phase incompressible fluid; includes energy transport by conduction, convection, dispersion; development complete on all but vapor transport	Pressure, temperature, time, and space-dependent specific heat, thermal conductivity and internal heat generation, moisture content, permeability; moisture-dependent permeability; thermal expansion, multiple material layers, anisotropic material properties	Eaton et al., 1983; Gartling and Hickox, 1982	SNLA (a,o,d)

Table 8.3.5.19-2. Brief description of codes from Table 8.3.5.19-1
(page 4 of 5)

Code name	Code analysis capabilities	Material models	Status of documentation	Status of use by NNWSI Project ^a
SPARTAN	Water flow and radionuclide transport through dual porosity media; Darcy's law and convective transport of sorbing radionuclides	Release rates, cumulative releases, and ratios of releases to EPA standards calculated as functions of geometry, repository area, flow path, water flux, effective porosity, initial inventory, water solubility, canister lifetime, and retardation factors	Lin, 1985	SNLA (o)
SPECTROW41 and SPECTROW31	Thermoplastic and plastic analyses of stresses, displacement, plasticity zones and failure zones due to extraction and canister emplacement in a repository	Nonisotropic, 3D elastic and thermal properties; ubiquitous joint element; failure modes include Von Mises and Mohr-Coulomb-Drucker-Prager	Svalstad, 1983	RESPEC (o)
TAC02D	Transient and steady-state thermal conduction in 2D		Burns, 1982	LLNL (o)
TOSPAC	Infiltration through unsaturated porous media, radionuclide decay and leaching, saturated and unsaturated flow and transports of decaying radionuclides in porous media	1D space-dependent material properties; 3-member decay chains; solubility-limited leaching, assumed source dissolution and diffusion model; equilibrium adsorption; dispersive, diffusive, convective transport	Peters et al., 1985	SNLA (o)
TOUGH	Transport of water, water vapor, and heat in partially saturated porous media		Pruess and Wang, 1984	LBL (o), LLNL (a,o,d), USGS (a)
TRACR3D	Saturated and unsaturated, fractured and porous media; multicomponent ground-water flow and radionuclide migration	Transient, 3D, nonlinear flow, one- or two-phases (air and water), tracer in one phase, molecular dispersion, radioactive decay, adsorption, capillary pressure, buoyancy, spatial variation of material properties, saturated and unsaturated seepage from fractures	Travis, 1983	Los Alamos (a,o,d)
TRUMP	Diffusive-advective transport of sorbing radionuclides	Transient, 1, 2, or 3D molecular diffusion and advection of radioactive tracers in single phase, equilibrium sorption		LBL (a,o)

Table 8.3.5.19-2. Brief description of codes from Table 8.3.5.19-1
(page 5 of 5)

Code name	Code analysis capabilities	Material models	Status of documentation	Status of use by NNWSI Project ^a
TRUST	Conservation of fluid mass in variably saturated, deformable porous medium	Permeability, compressibility nonlinearly related to stress; permeability, saturation related to pore water pressure in unsaturated zone	Reisenauer et al., 1982	LBL (a,o,d)
VFAST	Saturated and unsaturated, water flow in porous media; radionuclide migration	Transient, 1D, nonlinear flow		USGS (o)
WAFE	Two-phase nonlinear mass and heat transport in porous media	Transient, 2D, nonlinear flow; anisotropic properties; equations of state for liquid and vapor water; multicomponent (air and water)	Travis, 1985	Los Alamos (o)
WAPPA	Physical and chemical degradation of waste package barriers, radionuclide flux	Radiation, thermal, mechanical corrosion, and leach models	INTERA, 1983	LLNL (a,o,d), SNLA (a,o)

^aAbbreviations as follows: SNLA = Sandia National Laboratories, Albuquerque; LBL = Lawrence Berkeley Laboratory; LLNL = Lawrence Livermore National Laboratory; Los Alamos = Los Alamos National Laboratory; USGS = U.S. Geological Survey; INTERA = INTERA Environmental Consultants, Inc.; RESPEC = RESPEC, Inc.; PNL = Pacific Northwest Laboratory; a = codes available; o = codes operational; d = codes under development.

Table 8.3.5.19-3. Computer codes for use in preclosure safety assessment

Categories of preclosure safety assessment	Type of analysis	Potential codes	Issue in which the code may be used ^a
Systems analyses	Criticality	KENO-IV	2.1, 2.2
	Systems reliability	SETS	2.3
	Shielding code	ANISN	2.1, 2.2, 2.3
Consequence analyses	Source-term characterization	ORIGEN-2	2.1, 2.2, 2.3
	Public exposures	GASDOSE	2.1
	Public exposures	AIRDOS-EPA	2.1, 2.2
	Public exposures	CRRIS system	2.1, 2.2, 2.3
	Public exposures	DACRIN	2.3

^aIssues 2.1, 2.2, and 2.3 are discussed in Sections 8.3.5.3, 8.3.5.4, and 8.3.5.5, respectively.

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Table 8.3.5.19-4. Brief description of codes from Table 8.3.5.19-3

Code name	Code description	Status of documentation	Status of use by NNWSI Project
AIRDOS-EPA	Routine-release dose consequences (Clean Air Act compliance)	User manual extant; no verification; some limited validation	Under evaluation
ANISN	Discrete-ordinate for shielding	User manual extant; no verification and validation data	Used in preparation of existing project documentation
CRRIS	New EPA-funded radioactive-release dose consequences	Documentation in preparation; limited verification and validation	Under evaluation
DACRIN	Accident-release, airborne-pathway dose consequences	User manual extant; limited validation only	Under evaluation
GASDOSE	See AIRDOS-EPA	Proprietary	Used in preparation of existing project documentation
KENO-IV	Monte-Carlo criticality and shielding	User manual extant; has been validated	Under evaluation
ORIGEN-2	Radionuclide inventory of spent fuel	User manual extant; verification and validation underway	Under evaluation
SETS	Fault-tree and event-tree analysis	User manual extant; no verification and validation data	Under evaluation

Chapter 8

Nuclear Waste Policy Act
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Section 8.3.5.20

Consultation Draft**ANALYTICAL TECHNIQUES
REQUIRING DEVELOPMENT** ***Site Characterization
Plan******Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

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Washington, DC 20585

8.3.5.20 Analytical techniques requiring significant development

8.3.5.20.1 Analytical techniques

The analytical techniques that require significant development are those for which analysis approaches are still being formulated, solution methods are still being developed, or codes are still being written or debugged. Analytical techniques that still require significant development include the following: (1) the simplified physical models that will be used in the probabilistic analyses; (2) the techniques for implementing statistical methods that will be used to do probabilistic estimates of ground-water travel time, release rates from the engineered-barrier system, and cumulative releases to the accessible environment, as described in Sections 8.3.5.12.2, 8.3.5.10.3, and 8.3.5.13.4; and (3) systematic techniques that will be used for screening scenarios, as described in Section 8.3.5.13.3. In addition, the analytical techniques described in Tables 8.3.5.19-1 and 8.3.5.19-2 in Section 8.3.5.19 may require more development if validation or site characterization activities show that the models do not properly simulate conditions at the site.

Some analytical techniques are used specifically in the assessments of preclosure safety. Those that may require significant development for preclosure safety assessment will be determined by the preclosure risk assessment methodology (PRAM) program, as described in Section 8.3.5.1. Minimal development is expected to be needed in most technical areas. Potential areas that may require development include source-term characterization and data development.

A number of methods and practices that will be useful in assessing the performance of a repository might be termed "analytical techniques"; they are discussed in other sections of the SCP. Section 8.3.5.13 describes the selection and characterization of scenarios for releases of radioactive material from the total repository system. The section also explains in detail the basic construction of complementary cumulative distribution functions for assessing these releases. In addition to the models listed in Section 8.3.5.19, the assessment of releases will require some special-purpose models, as Section 8.3.5.13 explains. Topics such as verification, benchmarking, and validation are described in Section 8.3.5.19 and in this section, 8.3.5.20. Although no detailed site-specific plans for sensitivity and uncertainty analyses are now available, they will be an important part of the performance assessments as well as the guidance for site characterization. The preliminary work that has been done to date is described in the detailed performance allocations throughout Section 8.3.5. Professional judgment will be essential to preparing adequate performance assessments; its central role is described in Section 8.3.5.8.

8.3.5.20.2 Plans for verification and validation

Analytical techniques to be used for performance assessments in support of a license application must be verified and validated in accordance with

the guidance of NUREG-0856 (Silling, 1982). The NUREG-0856 guidance is implemented for the NNWSI Project in the standard operating procedure SOP-03-02. Plans for verification and validation of the analytical techniques and models used for performance assessments of Yucca Mountain will be contained in a series of reports that will describe (1) an overall strategy for the verification and validation process, (2) how the site characterization data obtained as a result of the activities described in this site characterization plan will be used in the validation process, (3) how data from natural and man-made analogs or other sites will be used, and (4) how professional judgment and peer review will be used in the validation process. The final results of the verification and validation of all performance-assessment codes will be documented. The following discussion summarizes the program for verification and validation that is intended to provide the certification of performance-assessment codes and models.

Verification of analysis methods

All analytical techniques used for final performance assessments of the suitability of the Yucca Mountain site must be verified. These techniques include the completed techniques described in Section 8.3.5.19 and the three groups of analytical techniques described in this section, 8.3.5.20. Verification of analytical techniques, according to guidelines in NUREG-0856 (Silling, 1982), is the "assurance that a computer code correctly performs the operations specified in a numerical model." This definition has been applied to any analysis method, however simple (e.g., semianalytic computer code for calculating a single-valued, uniquely determined algebraic expression) or complex (a numerical computer code). To simplify this discussion, it is assumed that the analysis method is a computer code.

The numerical accuracy and stability of the hydrologic and radionuclide transport codes will be verified by comparison with analytic solutions and by benchmarking against other computer codes. The verification process may include code development work where the mathematical model has been inaccurately incorporated into the numerical code or insufficient capabilities in the existing codes are revealed by the numerical comparison activities. Any code used to make performance assessments will be verified. For each code, the following verification steps will be taken:

1. Numerical analysis techniques will be used to define the limits of code accuracy in terms of methods of solution, discretization, and parameter ranges.
2. The numerical accuracy and solution sensitivities will be tested by comparison with analytical solutions wherever possible.
3. The relative numerical accuracy and solution sensitivities to modeling techniques on small-scale, multidimensional problems will be tested, using representative data from Yucca Mountain, by benchmarking between two or more similar computer codes. Sensitivities to mesh and time-step sizes, convergence criteria, etc., will be investigated.
4. Computer codes will be revised, as necessary, to ensure sufficient accuracy and stability.

5. Benchmarking comparisons of codes on problems typical of those required by the issue for which the codes are used will be performed. These comparisons will be made by the NNWSI Project, using codes and data obtained from site characterization of Yucca Mountain, and will be coordinated with the analyses performed for Issues 1.1 through 1.6 (Sections 8.3.5.9, 8.3.5.10, and 8.3.5.12 through 8.3.5.16).
6. The results of the verification will be documented according to the guidelines in NUREG-0856 (Silling, 1982) as implemented in NNWSI Project SOP-03-02.

COVE: a benchmarking activity

Not all applications of the codes are amenable to testing of numerical accuracy by comparison with analytical solutions. Therefore, the code verification (COVE) activity has been initiated for benchmarking the water-flow and radionuclide-transport codes being used for performance assessments. The goals of the COVE activity are to (1) demonstrate and compare the numerical accuracy and sensitivity of certain codes, (2) identify and resolve problems in running typical NNWSI Project performance-assessment calculations, and (3) evaluate computer requirements for running the codes. The following benchmarking problems are being defined:

1. Isothermal transport of water and radionuclides through homogeneous, variably saturated tuff (COVE 1).
2. Isothermal transport of water through layered, variably saturated tuff (COVE 2).
3. Nonisothermal transport of water, vapor, air, and heat in fractured, welded tuff (COVE 3).
4. Isothermal transport of water and radionuclides through saturated, fractured tuff.

Other benchmarking problems will be defined, as required, as the code-verification process develops.

COVE 1 was the first step in benchmarking some of the performance-assessment codes. Isothermal calculations for the COVE 1 benchmarking have been completed using the hydrologic flow codes SAGUARO, TRUST, and GWVIP; the radionuclide transport codes FEMTRAN and TRUMP; and the coupled flow and transport code TRACR3D. The COVE 1 participants are listed in Table 8.3.5.20-1. Hayden (1985) presents the results of the three cases of the benchmarking problem solved for COVE 1, a comparison of the results, questions raised regarding sensitivities to modeling techniques, and conclusions drawn regarding the status and numerical sensitivities of the codes.

Table 8.3.5.20-1. Participants and codes used in COVE 1 benchmarking problem

Participant	Code
Los Alamos National Laboratory	TRACR3D
Lawrence Berkeley Laboratory	TRUST/TRUMP
Pacific Northwest Laboratory	TRUST
Sandia National Laboratories	SAGUARO/FEMTRAN
Environmental Consultants, Inc.	GWVIP

Work is currently in progress on both COVE 2 and COVE 3. The goals of COVE 2 and COVE 3 are the same as for COVE 1. However, the emphasis is on modeling site-scale problems of the type that will be required for performance-assessment calculations. Both one- and two-dimensional problems have been defined under both isothermal and nonisothermal conditions. Isothermal water flow through several layers of unsaturated tuff with different hydrologic properties is modeled in COVE 2. The participants in COVE 2 and the codes they are using are listed in Table 8.3.5.20-2. In COVE 3, temperature and saturation profiles are being calculated in a nonisothermal condition in tuffs of the Topopah Spring Member, simulating post-waste-emplacement conditions in the near field. The participants in COVE 3 and the codes they are using are listed in Table 8.3.5.20-3. The COVE 2 and COVE 3 activities will be fully documented in NNWSI Project reports.

Table 8.3.5.20-2. Participants and codes used in COVE 2 benchmarking problem

Team	Code
U.S. Geological Survey	TOUGH, VSFAST
Lawrence Berkeley Laboratory	TRUST
Sandia National Laboratories	SAGUARO, NORIA
Sandia National Laboratories	TOSPAC
Los Alamos National Laboratory	HDOC, TRACR3D
Pacific Northwest Laboratory	FEMWATER, TOUGH

Table 8.3.5.20-3. Participants and codes used in COVE 3 benchmarking problem

Team	Code
Lawrence Berkeley Laboratory	TOUGH
Sandia National Laboratories	NORIA
Lawrence Livermore National Laboratory	WAFE

International code comparisons

The NNWSI Project is participating in two international code comparison projects to supplement its benchmarking activities. These comparisons will establish the general applicability, acceptability, and flexibility of the codes and will provide independent assessment and peer review. The HYDROCOIN (Hydrologic Code Intercomparison) project examines hydrologic models and codes and their use in performance assessments for high-level nuclear waste repositories. The INTRACOIN (International Nuclide Transportation Code Intercomparison) study examines models and codes that describe the transport of radionuclides in geologic media.

Both of these code comparison projects have three principal activities: (1) level 1, benchmarking and verification of codes, (2) level 2, validation of models, and (3) level 3, sensitivity and uncertainty analyses of the models and codes. Several level 1 benchmarking analyses have been performed by the NNWSI Project on test cases that are pertinent to conditions at the Yucca Mountain site. The results are documented in the INTRACOIN Final Report for Level 1 (1985) and in the HYDROCOIN report (Cole, 1986).

Validation of physical concepts

The models used for performance-assessment analyses will be validated. Validation is defined in NUREG-0856 (Silling, 1982) as "assurance that a model, as embodied in a computer code, is a correct representation of the process or system for which it is intended." These models include the "completed analytical techniques" described in Section 8.3.5.19 and the three groups of analytical techniques described previously in this section, 8.3.5.20. The models embodied in computer codes for use in performance-assessment analyses are described in the performance issues under Key Issue 1. The validity of the resulting computer codes for describing the flow of water and the associated radionuclide transport will be assessed, to the extent possible, by comparison with laboratory experiments, field and in situ testing, observations of natural analogs, and peer review.

Complete validation of a model usually entails comparing predictions made by the model with experimental results over times and distances similar to those for which the model eventually will be used. Clearly, such complete

validation of repository models is not possible, especially for the 10,000-yr period over which repository performance needs to be evaluated.

Because this global check on performance predictions is precluded, a degree of partial validation is planned. Partial-validation activities will be focused on those aspects of modeling that are especially important for demonstrating compliance with performance requirements. Validation activities will be further focused to address the following key steps in modeling:

1. The system to be modeled is described, with special attention to those geometrical and physical parameters that might influence performance measures.
2. The conditions and environment in which the system is expected to operate (both internal operating conditions and external states of nature) are described.
3. The physicochemical processes that could affect system performance are enumerated.

The degree to which these steps in modeling are partially validated will depend on the influence each step has on performance and the degree to which modeling uncertainty must be reduced to provide reasonable assurance that the system will perform within regulatory limits. Scientific activities (including field studies on unstressed geologic systems, field experiments in which stresses are applied, in situ experiments at depth, natural analog studies, and theoretical scoping calculations) will be undertaken to provide a body of knowledge to peer reviewers, who will assess whether an adequate degree of partial validation has been achieved. Models for different subsystems will require a different mix of scientific activities to achieve an appropriate degree of partial validation, as discussed at a very general level by Eisenberg et al. (1987).

The NNWSI Project plans to perform partial model validation in two stages: the partial validation needed for licensing will take place during the several years of site characterization and further validation needed for closing the repository will be undertaken throughout the several decades of performance confirmation. Although limited testing cannot provide complete validation, it can help to provide confidence that the model is representing the physical system to a degree adequate for modeling. The methods that will be used to provide this confidence will include the following:

1. The use of laboratory experiments, field investigations, and natural analogs to provide data for comparing with model output. Some experiments may be designed specifically to provide data appropriate for validating particular models or parts of models.
2. Formalized peer review of model development and application. (This review will extend to the validation of simplified system models for total-system performance assessment by comparison with more complex models.) Because validation through comparison with experimental data is not possible for repository codes, expert judgment will be required to establish whether validation has provided reasonable

assurance. This expert judgment will be provided through peer review groups developed within the NNWSI Project and OCRWM. Additionally, as Section 8.3.5.8 points out, the strategy for postclosure performance assessment relies strongly on peer reviews by experts from inside and outside the DOE, e.g., by the NRC.

A number of needs for model validation have already been identified (DOE, 1986b), namely:

1. Conceptual hydrologic models of flow in the unsaturated zone at Yucca Mountain.
2. The expected physical and chemical environment in the repository for 10,000 yr after closure.
3. The conditional distribution of waste-disposal-container lifetime in the postclosure repository environment.
4. Transport of radionuclides in the gas and vapor phase within the overburden.

Plans to develop models to address these and other similar items are presented in other sections of the SCP; for example, Section 8.3.1.2.2.10 discusses the development of hydrologic models for the unsaturated zone. The techniques to be used to validate these models are discussed briefly within these sections. Additional development and application of techniques for model validation will be performed during site characterization and will be presented in future semiannual progress reports. After the issuance of a validation-strategy report for the entire OCRWM program, the NNWSI Project will develop an overall approach (integrated over the Project) to model validation. The Project will also issue a plan for implementing that approach.

The validation process will proceed from small-scale analyses of phenomena to large-scale analyses of assumptions regarding bulk behavior. The small-scale analyses should show that the underlying assumptions regarding physical interactions in the system are correct by comparison with controlled laboratory and in situ experiments. The large-scale analyses will attempt to show by comparisons with field and in situ testing that the heterogeneities and simplifying assumptions made to extrapolate from the small to large scale are valid. Peer review will be essential in assessing the validity of codes to be used in calculations involving large spatial or temporal scales.

The preceding general principles for validation have been expanded upon for the hydrologic and radionuclide transport codes. The following activities will test the modeling assumptions in these codes, guide further model development where necessary, and calibrate and validate the models with field results obtained during site characterization:

1. Laboratory experiments that investigate movement of water through fractures and matrix will be modeled. Isothermal experiments will be used in the validation of the assumed governing equations of water movement for the multidimensional site-scale analyses and the radionuclide-release analyses. Nonisothermal experiments will be

used to address the validation of the representation of physical properties and dominant flow mechanisms in the analyses for flow in the radionuclide source-term formulation.

2. In situ experiments from the exploratory shaft will be modeled for the validation of models of water flow. The goal of this step is to establish in part the validity of the computer codes for predicting how flux, permeability, and flow mechanisms may change because of heat loads, changes in climatic conditions, alterations in the in situ stress state, and transient recharge events.
3. Laboratory and in situ experiments from the exploratory shaft will be modeled to address the validity of radionuclide transport and retardation models in both isothermal and nonisothermal codes.
4. Natural analogs, if available and applicable, will be modeled as part of the validation process.
5. Peer review will be used extensively to evaluate modeling assumptions, guide model development, and assess the validity of the code.

To perform the activities listed previously, the following information about the hydrogeology and transport characteristics of the site is a partial list of what is needed from the laboratory, field, and in situ tests:

1. Movement of water through single fractures, through matrix blocks, and through a porous fractured rock mass for various saturation, thermal, and stress conditions.
2. Heat-induced movement of water and vapor in welded tuff.
3. Vertical distributions of moisture content, pressure, permeabilities, and water age in the unsaturated zone at Yucca Mountain.
4. In situ infiltration and bulk properties as functions of applied flux conditions, temperatures, and pressures.
5. Field data for potentiometric head and dispersion in the saturated zone.
6. Radionuclide sorption, diffusion, and precipitation data from laboratory and in situ tests.

The previously mentioned items are general activities and information items that may be used in the validation process for various flow and transport codes. Specific validation activities for particular codes will be performed as part of the resolution of the issues that use the codes.

The validity of the simplified physical models mentioned in Section 8.3.5.20.1 will be assessed, to the extent possible, by comparison with laboratory experiments, field and in situ testing, observations of natural analogs, and peer review. The applicability of the simplified models may also be assessed by comparison with more detailed models. This will help to

ensure that the simplified models have captured the essential features of the more detailed models and that their use will produce consistently conservative estimates of travel times and radionuclide release rates.

The statistical-analysis methods and scenario-screening methods mentioned in Section 8.3.5.20.1 will be evaluated for use in performance assessments by a careful review of the theoretical bases for the methods, by review and acceptance of the application of the methods by qualified peers, and by comparison with accepted methods commonly used for related applications.

Nuclear Waste Policy Act
(Section 113)

Section 84

Consultation Draft

PLANNED SITE PREPARATION
ACTIVITIES

Site Characterization Plan

***Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

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U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

8.4 PLANNED SITE PREPARATION ACTIVITIES

The objectives of this section are (1) to describe the activities required to prepare the site for characterization and (2) to describe the design and construction plans for the exploratory shaft facility (ESF) in sufficient detail to evaluate if a) the ESF will adequately support the tests defined in Section 8.3, b) the planned sequencing of tests is consistent with the construction sequence, c) adequate flexibility has been incorporated into the ESF design and construction plans, and d) construction of, or testing in, the exploratory shafts or in the underground test facilities will adversely impact the waste isolation integrity of the site. An integral link exists between the plans presented here and the planned tests and studies in Section 8.3. Therefore, there is extensive cross referencing between the two sections.

The preparations necessary before surface-based testing and underground construction and testing are implemented are discussed in Section 8.4.1. The design and construction plans for the exploratory shafts and underground test facilities are discussed in Section 8.4.2.

Recent changes to the ESF are currently being developed into design criteria for preliminary design. Therefore, the descriptions provided in Section 8.4.2 are conceptual, and further details will be provided in semi-annual progress reports to the SCP and the subsystem design requirements document. Designs will be available for review before the start of each construction activity.

The final design of the repository is not available at this time. However, the requirements for the ESF design state that interfaces between the repository and the ESF should be considered so that ESF configurations that could impact a future repository design are avoided and configurations that could be potentially incorporated into the repository design are preferred.

Section 8.4.2 also presents summary descriptions of the underground tests planned as part of the site characterization program and provides a layout of planned excavations, including preliminary design dimensions. In addition, it discusses the flexibility to be incorporated into design and construction plans and the potential impact of the ESF construction and testing on the waste isolation integrity of the site. This section is based on conceptual design although it reflects ongoing design development.

8.4.1 SURFACE SITE PREPARATION ACTIVITIES

This section discusses the activities on the surface that are necessary to prepare the land for site characterization and testing. Section 8.4.1.1 describes the activities to be performed before surface-based testing. Section 8.4.1.2 describes the activities required at the ESF site before shaft sinking.

8.4.1.1 Preparations for surface-based testing

Surface-based tests consist of geologic, geophysical, hydrologic, and other tests and surveys that will be performed at both the surface and in exploratory boreholes. Descriptions of these planned tests and surveys are given in Sections 8.3.1 and 8.3.2. The purpose of this section is to describe the surface work that is necessary to prepare the land for these activities. Potential environmental effects of conducting surface-based tests have been addressed in Chapter 4 of the final environmental assessment for Yucca Mountain (DOE, 1986b) and in the preliminary analysis of proposed changes to the ESF design and construction schedule (Spaeth, 1987).

Geologic, geophysical, and hydrologic tests will be performed from the surface by measuring the physical characteristics of the rock through magnetic, gravity, or electrical surveys; obtaining samples of outcrop rock for laboratory analysis; measuring properties of core obtained from exploratory holes; measuring properties of rock at depth from boreholes by logging; recording the pattern and speed of sound waves generated and transmitted through the rock; and examining and mapping features exposed by trenches and pavements. Surface preparation is not necessary to measure magnetic, gravity, or electrical properties of the rock nor to obtain samples of rock from outcrops for later analysis. These activities will, therefore, not be addressed in this section.

Many of the geologic, geophysical, and hydrologic tests will be performed by using core from exploratory holes or by measuring physical or chemical characteristics of the subsurface rock by lowering equipment (i.e., logging tools) into the exploratory holes. The type and amount of surface preparation for these tests depend on the type of exploratory hole to be drilled. Shallow holes typically 50 ft (15 m) deep and generally less than 150 ft (50 m) such as neutron holes and shallow infiltration test holes can be drilled by using truck-mounted drill rigs. Current plans call for drilling approximately 300 to 350 of these holes. The rigs are mounted on all-terrain trucks and may not require a bladed access road nor the clearing and grading of drill pads. Therefore, surface preparations for these tests are expected to be minimal and may include the disturbance of small areas for equipment laydown or disposal of cuttings from the drilling operation, as shown in Figure 8.4-1.

Other exploratory holes may require more extensive surface preparation, including clearing and grading the site and staging area, blading a parking area and equipment yard, blading and leveling a drill pad, excavating fill dirt from adjacent or nearby areas, and constructing a mud-and-cuttings pit. Current plans call for drilling 45 to 80 exploratory holes that would require such surface preparation activities. Figure 8.4-2 shows a typical drill site, which requires such surface preparation activities. An average of 2.5 acres per drill site would be disturbed by site preparation activities including such activities as construction of access roads from existing roads to the drill sites. Roads would be bladed smooth and sprinkled with water to aid in soil compaction and to provide dust control.

To examine and map features a short distance below the surface, trenches will be dug with a bulldozer or backhoe. Current plans call for excavating several trenches during site characterization; the locations and number of

Figure 8.4-1. Typical site plan for shallow geologic exploratory holes.

Figure 8.4-2. Typical site plan for deep geologic exploratory holes.

these trenches (to the extent that they are known now) can be found in Section 8.3.1.17. Excavated material will be stored on the surface next to the trench. An access road may be bladed to the trench site if a road is necessary for either the studies planned at the site or the equipment to be used to excavate the trench.

To perform detailed studies of bedrock features, water or air under moderately high pressure will be sprayed on the surface to remove the regolith and expose the bedrock. These exposed areas of bedrock are called pavements. A one-lane dirt track from the nearest existing road to the pavement site will be cleared and leveled for access so that the area can be cleared and studied.

As discussed in Section 8.3.1.17, a variety of seismic reflection and refraction surveys may be conducted at and near the site. These surveys would be conducted by using 50- to 4,000-lb (23- to 1,800-kg) dynamite charges in shot holes from 20 to several hundred feet deep, drilled in a linear array. Some seismic reflection surveys will be done by using above-surface detonations. These drillholes do not require drill pads; however, off-road vehicle access may be necessary.

8.4.1.2 Preparations for underground construction and testing

The exploratory shaft facility (ESF) consists of surface facilities and underground facilities. Preparations for underground construction and testing require construction and installation of the surface facilities described in this section. The underground facilities, which include exploratory shaft 1 (ES-1), exploratory shaft 2 (ES-2), the main test level operations area, and the exploratory drifts, are described in Section 8.4.2. The surface facilities include the pads and roads, utilities, buildings, shaft collars, shaft hoist, and headframes and equipment necessary to support the construction and operation of the facility. Each of these facilities is discussed in the following sections.

The ESF will be located at Coyote Wash (Bertram, 1984) on the eastern side of Yucca Mountain at an elevation of approximately 1,260 m. Figure 8.4-3 shows the location of the ESF in relation to the Nevada Test Site. It also shows the administrative boundaries of the NTS, the Nellis Air Force Range (NAFR), and the Bureau of Land Management (BLM). Figure 8.4-4 shows the location of facilities such as utility lines, access roads, and buildings to be used during ESF construction. A conceptual illustration of the ESF is presented in Figure 8.4-5 and the conceptual surface layout is shown in Figure 8.4-6. The road, power lines, and water lines have been built to the NTS boundary. There are currently no other facilities or utilities in place to support the planned ESF construction activities. The first tasks will concentrate on the preparation of surface areas, completion of roads and utilities, and construction of support facilities.

The layout of the ESF is currently in conceptual design; the requirements call for minimizing the impact of construction while providing an efficient arrangement of mining equipment laydown areas, hoists, and support buildings. These requirements specify that facilities that involve the use

Figure 8.4-3. Relationship of Yucca Mountain site to exploratory shaft facility.

Figure 8.4-4. Location of facilities required during construction of the exploratory shaft facility.

Figure 8.4-5. Conceptual illustration of the exploratory shaft facility.

Figure 8.4-6. Conceptual surface layout of the exploratory shaft facility site.

or disposal of liquids be located beyond the proposed repository boundary to minimize the impact of site characterization on natural behavior of that area. Existing office facilities located approximately 13 miles (21 km) from the ESF at Jackass Flats will be used to the extent practical (Figure 8.4-4).

8.4.1.2.1 Pads and roads

Several leveled pads will be required to accommodate the various facilities needed for ESF construction and operations. These include the pads for the exploratory shafts with their associated buildings, water tank, equipment storage areas, explosive storage area, mine waste water pond, sewage collection system, and muck-storage area. An existing pad will be used for the concrete batch plant.

The pad for ES-1 and ES-2 will be situated on a cut-and-fill rock shelf approximately 200 ft (60 m) north of and above the confluence of two small ephemeral stream channels that are tributaries of the Coyote Wash drainage system. The location of Coyote Wash is shown in Figure 8.4-3. Site preparation will require cut and fill to provide level pads for the two exploratory shafts, the surface structures, and the parking and storage areas. Additional fill material will be obtained from "borrow" areas.

Surface preparation for the other pads includes clearing vegetation and grading the site into a level pad large enough to accommodate the particular facility.

The access road from Jackass Flats has been improved to the boundary of the NTS to accommodate heavy equipment. The road is 24 ft (7 m) wide, has 8-ft (2.5-m) shoulders, and is surfaced with a double oil-and-chip layer. Additional roads to the exploratory shaft site pad, the explosives storage area, and the water storage tank will be constructed.

Access to the ESF from the east will be controlled by a chain-link fence and gates. Where appropriate, the natural terrain will be used as a barrier to vehicle access from elsewhere on the site.

8.4.1.2.2 Utilities and communications systems

The utility systems will provide electrical power, water, and sewage facilities necessary to support surface and subsurface operations at the ESF. The communications systems will provide surface communications facilities and fire protection and life safety support system monitoring.

The aboveground electrical supply and power for the underground distribution systems will be provided by a surface substation to be constructed at the exploratory shaft site. The substation will be supplied from an existing 69-kV overhead power line that extends from the canyon substation in Jackass Flats to the NTS boundary (Figure 8.4-4). The substation will be equipped with transformers to supply power to the hoists, air compressors, ventilation fans, and the balance of the site.

A power line will be added to the existing power poles to provide power to the water supply booster pump station from the site substation. Night lighting will be provided by pole-mounted area floodlights. Standby electrical supply will be provided by diesel generators.

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 (0.6 m) 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 5 km from the proposed repository boundary. One pumping station is at well J-13, and a booster pumping station is about halfway (based on elevation) to the site. Water will be pumped to a 150,000-gal (600-m³) water tank, which will be located west of the site at an elevation of approximately 4330 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 the requirements of the subsystem design requirements document (SDRD) (DOE, 1987c). The water supply system will be designed to accommodate reasonable changes in the surface and underground facilities.

Sanitary waste will be collected and disposed of in a sewage system located east of the proposed repository boundary. The sewage system will be designed to accommodate sewage from approximately 200 persons during a 24-h period.

The communications systems include telephone service, monitoring systems, integrated data system interfaces, and equipment for transmitting data to the existing Administration and Engineering (A&E) Building at Jackass Flats.

8.4.1.2.3 Buildings

Temporary buildings will be assembled or moved onto the ESF site as they are needed during the construction and operations phases. The site pad will accommodate a limited number of buildings, and, as one construction phase is complete, buildings may be converted for different uses or removed from the site. Prefabricated metal buildings will be constructed to provide space for a shop with adequate repair facilities, a warehouse, and a hoist house. Trailers will be located on the ESF pad and used for change rooms, office and sample preparation space, and a first aid station. Most functions not directly in support of construction will be conducted from the A&E Building (Figure 8.4-4), which will provide a visitors' center and office space.

Three magazines will be required for storing explosive materials: one for explosives, one for detonators, and one for primer makeup. The magazines will be located away from the exploratory shaft site (Figure 8.4-4).

Appropriate codes, standards, and specifications for the surface facilities will be identified and specified in the ESF SDRD (DOE, 1987). The surface facilities will be designed for a 5-yr minimum life unless otherwise specified. Design bases are defined in the ESF SDRD.

8.4.1.2.4 Shaft collars

The purpose of the shaft collar is to provide a stable upper foundation for (1) supporting the shaft concrete liner, (2) anchoring the hoist and headframe assembly (Figure 8.4-7), and (3) mounting the pipes and vents needed for the underground facility services. The collars for both ES-1 and ES-2 will be constructed by using similar design and construction methods. The collars will be in bedrock and consist of reinforced concrete extending from the surface to approximately 88 ft (27 m) below the surface. Drill and blast techniques will be used to excavate the solid rock for the shaft collars. The rock will be removed mechanically by a crane with a clamshell bucket.

8.4.1.2.5 Mine plant and support facilities

The mine plant and support facilities provide the aboveground equipment and systems to support the subsurface construction. Major equipment provided in the mine plant includes ventilation fans with controls, as well as surface ductwork in the shaft collar; air compressors with controls and supply lines to the shaft collar; water-supply piping with controls and waste-water piping from the shaft collar to the mine waste-water pond; and other equipment as required. Major construction support facilities include the concrete batch plant, muck-storage area, mine waste-water storage pond, laydown areas for supplies and equipment, and other facilities as required.

The ventilation system will be designed according to the ESF SDRD (DOE, 1987c). 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 monitor the underground facilities for radon, methane, oxygen, carbon monoxide, temperature, humidity, and air speed.

Details on the balance of the mine plant systems are currently in conceptual design and will be available in future updates of the SDRD and the conceptual design report.

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 the shaft collars and liners. Approximately 1 acre (4,047 m²) will be used for the batch plant at a location (Figure 8.4-4) beyond the proposed repository boundary. Crushed rock, sand, and cement will be stored in this area.

The mine waste-water pond, located east of the exploratory shaft (Figure 8.4-4) and beyond the repository boundary, will be bermed and lined. Drilling fluids that will be used underground, including air-water mist, bentonitic mud with water control agents, and polymer foam, as well as other waste fluids will be pumped from the underground facility to this pond. The design life of the pond will be a minimum of 25 yr. The pond will be able to hold approximately 375,000 gal (1.4 x 10⁶ L) of waste water.

Figure 8.4-7. Typical hoist, headframe, and collar.

The muck-storage area will be located east of the exploratory shaft (Figure 8.4-4) and beyond the proposed repository boundary. The rock debris removed during the construction of the shafts, the main test level operations area, and the exploratory drifts will be transported to the surface and hauled to the muck-storage area. This area was selected because it would not constrain the size of the muck-storage pile if additional mining were necessary. The area will accommodate more than the 160,000 yd³ (122,300 m³) of rock debris that is currently planned to be produced during shaft and drift mining of the ESF. Dust from the dumping operation will be controlled by appropriate dust suppression techniques.

8.4.1.2.6 Hoist and headframe

The hoists, hoist house, and headframes for both ES-1 and ES-2 shafts will be erected and installed following the construction of the shaft collars (Figure 8.4-7). The hoists will provide the necessary hoisting capacity for muck removal, personnel conveyance, and movement of materials to and from the surface. The hoists will be outfitted with standard controls, brakes, and other safety systems. Details of the hoist systems will be developed as part of the preliminary design, and information will be included in updates of the SDRD. Emergency exit is provided through multiple backup systems. At the first level, two hoists are provided and each can serve as a backup to the other. At the next level, standby power systems are available to both hoists in the event of a power failure. If neither hoist is functional, the ladder in ES-1 can be used for emergency exit.

8.4.2 UNDERGROUND TEST FACILITIES

This section presents an overview description of the underground portion of the ESF as currently planned and designed. The design concepts for the major elements of the design (elements such as the location, dimensions and features of the two exploratory shafts, the location and extent of the lateral exploration drifts driven for investigating certain geologic features, the underground boundary of the ESF, and the design of the central facility) as presented in this section are not expected to change significantly. The more specific details of the design may change as the design progresses or is modified to better meet the goals for site characterization.

The design process for the ESF is consistent with that typically used for major DOE construction projects and the systematic development of designs being used by the Office of Geologic Repositories (OGR). Basic program requirements are established in the generic requirements document (DOE, 1987). These requirements ensure compliance with major regulations and functional requirements for the system. Site specific requirements are then determined based on the physical characteristics and design approach taken at a particular site. The specific design, functional, and performance requirements for the ESF at Yucca Mountain are provided by the NNWSI Project ESF SDRD (DOE, 1987). Additional detailed design criteria will be developed during the conduct of the design and revisions to this document made

accordingly. Likewise, even more detailed information will be developed by the designer and used to support the basis for the design.

The location of the ESF within the underground facilities of the conceptual repository is shown on Figures 8.4-8 and 8.4-10. The interfaces between the ESF and the repository are shown on Figure 8.4-9, including the coordinates and elevations of important interface locations that are being used as a common basis for both repository and ES design.

Figure 8.4-10 presents the interface between the ESF and the repository in greater detail and allows information pertinent to other features of both the ESF and the repository to be identified. Specific features identified on Figure 8.4-10 include:

1. The boundary coordinates for the "Dedicated Testing Area." The coordinates C¹, D, H, and J on the figure locate the corners of an approximately square area in which the facilities of the ESF and any drillholes or drifts supporting testing will be contained (excluding the lateral exploration drifts used for investigating geological features). This area was established as an area of independence in which the designers of the ESF have flexibility to make design modifications without impacting the design of the repository (potential impacts on waste isolation are addressed in Section 8.4.6).
2. The coordinates and elevations of the common points of the ESF and the repository, points C¹ and D.
3. The estimated coordinates of the locations where the lateral exploration drifts will intersect the target geological features; namely, the Ghost Dance fault to the northwest, the Drill Hole Wash structure to the northeast, and the imbricate normal fault zone to the southeast of the ESF core facility. The coordinates are given for the range of potential intersections resulting from the tolerance applied to the subsurface projection from the surface indication for these structures.
4. The drainage philosophy that is to be used in the dedicated testing area (see Note 4 on Figure 8.4-10).
5. The slopes for the repository drifts in the vicinity of the ESF. This includes the long lateral drifts in the ESF that will become a part of the repository, if it is constructed.
6. The areas where waste will be stored if the repository is constructed. This information is presented to show the proximity of the waste to the ESF.

Approximately 3,000 ft of drifting (mining) are required to construct the central area of the ESF. An additional 5,000 ft of drifting will be required to construct the lateral exploration drifts.

Figure 8.4-11 presents the current design for the central area of the ESF. The arrangement of the central area, as shown on this figure, is not

Figure 8.4-8. Location of the ESF within the underground facilities of the repository.

Figure 8.4-10. Detailed repository layout in vicinity of exploratory shaft facility

Figure 8.4-11. Central area of the exploratory shaft facility

expected to change significantly; however, the dimensions of the various openings may change as design analyses are completed. The location and orientation may be modified as the interaction between characterization activities and construction phasing are considered further.

A schematic cross-section of ES-1 and ES-2 is presented on Figure 8.4-12. The underground facilities, as shown in Figure 8.4-12, consist of the following:

1. Exploratory shaft 1 (ES-1) with a 12-ft (3.66-m) finished inside diameter and a depth of approximately 1,430 ft (436 m).
2. A landing and a demonstration breakout room (DBR) off ES-1 at the upper DBR level located at an approximate depth of 600 ft (183 m).
3. Landings and approximately 4,000 ft (1,219 m) of drifts at the main test level located at an approximate depth of 1,055 ft (320 m), including test alcoves, test drifts, and the core operations area that provides flexibility for shops and support facilities.
4. A drill room at the Calico Hills level off ES-1 located at a depth of approximately 1,360 ft (415 m).
5. Exploratory shaft 2 (ES-2), with a 12-ft (3.66-m) finished diameter and a depth of approximately 1,100 ft (335 m) for ventilation, materials handling, and emergency exit.
6. Three exploratory drifts having a combined length of about 5,600 ft (1,700 m) from the main test level core operations area to various geologic structures.

The approximate depths of the underground facilities were selected to meet specific characterization objectives. Of these, the main test level selection is the most critical. Chapter 6 describes the proposed repository design and the placement of the emplacement drifts within the tuff media. Since it is important that the ESF characterize tuff representative of the repository media, the main test area should be in the same stratum in which the repository will be located. Because the strata of Yucca Mountain dip from west to east, the repository will also be similarly inclined. As a result of the effort to reduce the degree of inclination along which the repository would be constructed, the repository conceptual design indicates that the level at which the repository actually crosses the ESF would be about 1,055 ft (320 m) below the surface at that location.

This section also briefly describes the construction and in situ tests that will be performed, discusses the potential impact of the ESF on the waste isolation integrity of the site and the relationship between the ESF and the repository, and presents the general requirements and a summary schedule for construction.

Mapping, sampling, and testing within the shaft(s) are designed to (1) obtain geologic information about the units overlying the repository horizon, (2) provide hydrologic information on the overlying units and at the stratigraphic boundaries, (3) provide information on rates of downward water

Figure 8.4-12. Schematic cross-section of exploratory shafts 1 and 2.

movement, and (4) provide for geomechanical testing of the overlying units to assist in design engineering, design confirmation, or both. The major focus of ESF testing, however, is to characterize the Topopah Spring unit within the prospective repository horizon.

Because the rock at Yucca Mountain is dominated by near-vertical fracturing, vertical shafts would not be expected to intersect a large fracture population. Therefore, testing within the vertical shafts is not designed to provide detailed information concerning (1) horizontal drift stability in a vertically fractured media, (2) horizontal variability or homogeneity in the Topopah Spring Member, (3) fracture spacing, characteristics, and relationships, and (4) hydrologic parameters and characteristics within the Topopah Spring Member.

It is planned that most of the mapping and testing in the exploratory shafts will be performed in ES-1, primarily to provide a complete and complementary suite of tests in the overlying rock units. Minimal testing is planned in ES-2; however, unanticipated structural or hydrologic features and stratigraphic contacts will be mapped as they are encountered in ES-2.

The facilities listed in this section will be constructed according to a sequence dictated by operational, testing, and safety criteria. Current plans call for starting construction of ES-1 first, then ES-2. When ES-1 reaches the upper DBR level, the upper DBR will be mined. Since there will be little or no testing during the sinking of ES-2, this shaft is expected to be completed first. Construction of the ES-2 is unlikely to affect any of the tests in ES-1. Plausible mechanisms by which the construction of ES-2 could impact testing in ES-1 have not been identified. The impacts, if they were to occur, likely would be in either the areas of mechanical interference or hydrologic interference. Mechanical interference would be manifested by either effects on stress state or displacements. The separation of approximately 300 ft (88 m) is over 20 times the unfinished shaft diameter. Excavation-induced effects in an elastic medium become insignificant at distances of approximately three shaft diameters away from the excavation (Brady and Brown, 1985). The actual situation at Yucca Mountain involves fractured rock masses. However, the shaft lining provides confinement to the rock mass. The degree to which construction of ES-2 could have a mechanical impact on tests in ES-1 is expected to be roughly comparable to that predicted on the basis of elastic behavior. Accordingly, there is no expectation for mechanical interference between the shafts.

Unsaturated-zone hydrologic tests to be conducted in ES-1 are not expected to be influenced by the presence of ES-2. Over the distance involved (300 ft), ES-2 is expected to cause only negligible alterations, if any, to the potential fields (e.g., pressure, temperature, moisture content) in the vicinity of ES-1. In any event, these potentials, which control the movement of moisture in both the vapor and liquid phases, will likely be overshadowed by the artificially induced potentials developed over the course of the various experiments. As the radius of influence of the experiments is expected to be relatively small when compared with the inter-shaft distance, the presence of ES-2 is not expected to affect, hydrologically, any experimental results.

In the unexpected event that any indications are observed that sinking ES-2 might impact tests in ES-1, the schedule for ES-2 construction could be modified. When ES-2 is completed, some drift space for equipment and materials staging may be developed at the bottom of the shaft. Next, the connecting drift between the two shafts will be constructed in time to effect the connection when ES-1 reaches the main test level. When ES-1 and ES-2 are connected, the balance of the core operations area drifts will be mined, and then the individual test alcoves and drifts will be mined. Mining of the long exploratory drifts will begin when the test facilities are complete.

Certain items in the ESF have been classified as permanent items that could be incorporated into a repository at Yucca Mountain. These items will be designated to have the same maintainable life and quality as specified for the repository. They include:

1. Underground openings. All spaces created by mining or drilling, including those zones within the rock altered by that process.
2. Shaft liners. All components placed between the inside limits of the shaft and the accessible extent of the underground opening.
3. Operational seals. Any material placed in an underground opening or the peripheral rock to control the flow of water or gas (the NNWSI Project position is that operational seals will not be required for the Yucca Mountain ESF).
4. Ground support. Any means used to reinforce rock or control the movement of rock, except for removable or replaceable hardware.

Design details and the construction sequencing for ES-1 and ES-2 are described in detail in Sections 8.4.2.1 and 8.4.2.2 respectively. Section 8.4.2.3 describes the main test level and Section 8.4.2.4 describes the lateral exploratory drifts. The tests to be conducted in the shafts and the main test level are described in Section 8.4.2.5.

8.4.2.1 Exploratory shaft 1

This section describes the exploratory shaft 1 (ES-1) and the various steps in its construction. ES-1 is the shaft where most of the in-shaft-related site characterization tests, which are briefly described in Section 8.4.2.5, will be performed. Additional testing at any depth may be done in ES-1, if necessary.

The completed ES-1 (Figure 8.4-12), will be a concrete-lined, 12-ft (3.66-m) finished-diameter vertical hole extending about 1,430 ft (436 m) from a leveled pad located at about the 4,130-ft (1,260 m) elevation on the east flank of Yucca Mountain. The shaft will provide access to breakout rooms and stations at three specific depths: the upper demonstration breakout room (DBR) level, the main test level, and the Calico Hills level. The completed shaft will be equipped with the necessary internal structures, conduits, piping, ventilation ducts, and conveyances to move people and

materials in and out of the underground facilities and to support the mining and testing activities.

Because the water table is 280 to 404 ft (85 to 123 m) below any planned excavation, no ground water is expected during shaft sinking and mining of the test areas. Any water encountered during shaft sinking will be collected, measured, and disposed of at the surface in the mine waste water pond. The portable water removal system planned for the water introduced during shaft mining is considered adequate to handle any unanticipated perched water. The shaft will also be equipped with water control features (e.g., water rings, sumps, and discharge pumps) as determined appropriate by ongoing design studies.

The upper DBR level will be located near the upper boundary of the potential repository horizon. The upper DBR will be a horizontal drift that, during construction, will accommodate a number of rock mechanics tests. These tests are described briefly in Section 8.4.2.5.

At the main test level, ES-1 will intersect a lateral drift that will be mined following the sinking of exploratory shaft 2 (ES-2). The main test level stations in ES-1 and ES-2 will provide access to the operations area and the exploratory drifts, described in Sections 8.4.2.3 and 8.4.2.4, where a majority of underground site characterization testing will take place.

ES-1 will extend through the lower boundary of the potential repository horizon and into a transition zone between the Topopah Spring Member and the Calico Hills tuff. At the Calico Hills level a station and drill room will be constructed within the nonwelded Calico Hills tuff. The Calico Hills drill room will be used to study rock characteristics as described in Section 8.3.1.4.2.2.3.

The shaft will extend approximately 80 ft (24 m) below the Calico Hills drill room to its total depth (Figure 8.4-12) to provide access to, and characterization of, the zeolitic zone of the Calico Hills unit. At its total depth, ES-1 will penetrate about 50 ft (15 m) into the nonwelded zeolitic interior of the tuffaceous beds of Calico Hills and will leave about 280 ft (85 m) of the Calico Hills tuff undisturbed above the static water level. The bottom of the shaft will have a sump for collecting and pumping out any water that may be present during the construction or operations of the ESF. The extension of the shaft below the Calico Hills level will also provide space required to accommodate requirements for mine hoisting safety such as conveyance overrun and rope stretch.

Descriptions of the construction activities are presented in the following sections for each construction phase. ES-1 construction is subdivided into construction phases that are separated by major test activities.

8.4.2.1.1 Construction of exploratory shaft 1 to the upper demonstration breakout room

After the headframe, sinking deck, and associated equipment are in place, the shaft-sinking operation will be generally routine, except for testing, down to the upper DBR level. A typical sequence of operations will commence by drilling a number of small-diameter blast holes into the rock. The number, depth, and location of the holes will be determined by the rock conditions and previous blasting results. The blast holes will then be loaded with explosives and the detonation timed so that the blast is controlled (i.e., to enhance the vertical advance, limit damage to rock zone, and produce acceptable-sized rock fragments). Procedures to control blasts will be developed before ESF construction begins.

Controlled blasting techniques are used to improve contour conditions about an opening by reducing overbreak and minimizing crack propagation. Several specific blasting techniques fall under the term controlled blasting: line drilling, cushion blasting, presplitting, and smooth blasting. The first two methods are specialized and have limited practical use underground. Presplitting, also called preshearing, involves detonating lightly loaded charge in closely spaced perimeter holes before the adjacent interior area is excavated by blasting. When executed properly, presplitting creates a fracture plane between the holes that limits the subsequent transfer of energy to the final shaft or drift wall. Smooth blasting, also called contour blasting, is similar to presplitting except that the perimeter holes are detonated after the main blast, breaking a relatively thin slab of rock to the newly created interior free face.

For both of these methods, the linear charge concentration in the perimeter holes is relatively small compared with fully loaded conventional blastholes. The resultant shock waves from adjacent perimeter holes cause localized stress concentrations in the rock and at the blasthole surfaces, and influence the direction and magnitude of a propagating fracture plane. The end result is a plane of weakness between holes that outlines and limits the extent of the blast activity.

Regardless of the techniques used, the results of any blast excavation primarily are dependent on the characteristics of the rock encountered. Although controlled blasting works well in some formations, in others it does not work at all. Trial and error is the best method for determining a practical controlled blast design. When successfully executed, the remainder of perimeter blastholes (half-hole casts) can be seen about the contour of the opening.

The controlled blasting technique considered most suitable for underground development at Yucca Mountain is smooth blasting. Smooth blasting, when compared with presplitting, requires fewer holes and one less step in the mining cycle. Five factors influence the performance of smooth blasting: geology and rock characteristics, drill precision, blast pattern layout, charge concentration, and detonators and sequencing.

After the blast holes are prepared, the sinking deck and associated equipment will be raised to protect them from damage. The miners will then exit the shaft and the explosives will be detonated. Following each blast,

air will be exhausted to remove smoke, dust, and fumes before the miners enter the shaft to muck out the rubble. Mechanical mining, a postulated technique for use in repository construction, will not be used in ESF construction because it is not necessary or justified given the limited amount of excavation to be done.

Normally, the shaft miners will spray the rubble with water for additional dust control before mucking. Water usage will be controlled in ES-1, however, to limit any potential impact on testing. All water used for dust suppression will be tagged with a suitable tracer to distinguish water introduced during drilling or testing from natural water. Humidity in the supply and exhaust ventilation will be monitored and recorded.

After venting of smoke, dust, and fumes, the miners will reenter the shaft and will start to remove the muck with a mucking machine hung below the sinking deck and a muck bucket suspended from the main hoist (Figure 8.4-7). After the shaft has been advanced 6 ft (2 m) or more, all rubble has been mucked out and any loose rock cleaned off the walls, the miners will stow their equipment. Then the scientists can enter and conduct shaft-wall mapping, sampling, and other tests in the freshly exposed interval of wall rock. The primary purpose of ES-1 is to provide access for scientific investigations; therefore, the time devoted to testing will be as long as the scientists require to successfully accomplish the mapping, sampling, or other testing objectives using methods and procedures that are as efficient as reasonably possible. These testing activities are described briefly in Section 8.4.2.5.1 and in detail in Sections 8.3.1.2, 8.3.1.3, 8.3.1.4, and 8.3.1.15.

When the scientists have completed their work, they will exit the shaft and the miners will prepare the next blasting round. After several blasting rounds, the shaft-liner concrete will typically be placed in 20-ft (6-m) segments. Where specified by the scientists, blockouts will be installed to protect extensometer anchors, piping to control water seepage (if present), and pressure-cell instrument lines before the liner is poured. The unreinforced concrete liner is expected to be at least 1 ft (0.3 m) thick through the welded tuff units. While the freshly placed concrete is setting, the miners will move up the shaft approximately 60 ft (18 m) and install a 20-ft (6-m) section of shaft internal fittings and other equipment, including manway ladders and landings, conveyance guides, utility piping, and instrument conduits (Figure 8.4-13). When this work is completed, the miners will move back to the shaft bottom and muck out the rubble remaining from the previous blasting round. The scientists will then conduct their tests, and the sequence of activities will be repeated down to the proposed depth of the upper DBR. At selected depths, radial-borehole and shaft convergence tests will be conducted as described in Section 8.4.2.5.1.

At about 50 ft (15 m) above the selected breakout depth, the shaft wall will be bolted and reinforced to provide a secure anchor into the bedrock for added support to the reinforced liner interval (brow) located immediately above the breakout. The brow will be reinforced with both rock bolts and vertical steel tendon rods set within the concrete from the anchor down to the breakout level. The purpose of the reinforcement is to remove heavy vertical loading on the wall rock at the breakout level so that mining of the

Figure 8.4-13. Conceptual illustration of exploratory shaft 1 internal structure

upper DBR can proceed safely and with assured long-term stability of the drift opening near the shaft.

8.4.2.1.2 Construction of the upper demonstration breakout room and station

The rationale for the location of the upper DBR is to characterize rock having approximately 15 percent lithophysal void content that may be encountered at places in the proposed repository horizon. This information will help site modeling efforts to predict the thermal and mechanical response within high lithophysal zones of the proposed repository horizon. In addition, the constructability and stability of the drifts will be established for both vertical and horizontal emplacement modes. Work on the upper DBR will actually include mining two types of rooms: (1) the station excavated directly off the exploratory shaft and (2) the upper DBR excavated off the station (Figure 8.4-14).

The station will provide a reinforced area for off-loading equipment and handling muck produced by upper DBR construction. It will provide the flexibility to implement future drifting if required, including a blockout for the installation of a muck pocket. The station excavation will not be greater than an 11-ft (3.3-m) radius east and west from the shaft (Figure 8.4-14) and will be reinforced with rock bolts, wire mesh, steel sets, and lagging. Fractures and other features exposed in the walls and roof of the station will be mapped during construction.

The upper DBR will probably be mined in a single pass. The excavation will be accomplished by drilling rounds of small-diameter shot holes about 7 ft (2 m) into the face, loading them with explosives, and blasting. The hole patterns, explosive loads, and detonation timing will all be designed to enhance the advance, reduce blast damage to the drift walls, and produce acceptable-size rock fragments. Following each blasting round, the drift will be ventilated to remove smoke, dust, and fumes before the miners reenter the drift to muck the rubble. The muck will be transported to the shaft and loaded directly into the muck bucket for removal to the surface.

After the newly excavated drift space is cleaned out and made safe for entry, the scientists will map the fresh surface exposures. Some of the geomechanical tests will begin concurrently with upper DBR mining so initial responses of the rock mass can be measured. Instrumentation used for the upper DBR tests will be wired into the integrated data system. Data collection and analysis can, therefore, begin immediately and will continue while the shaft is mined to its total depth. Stress and permeability test holes will be drilled and data instrumentation installed in the upper DBR before shaft sinking resumes.

8.4.2.1.3 Construction of exploratory shaft 1 to the main test level station

After the test holes described in the previous section have been drilled, the shaft sinking will resume until the main test level is reached. The same construction and testing sequence described in Section 8.4.2.1.1

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Figure 8.4-14. Upper demonstration breakout room.

will be used. In addition to the regular mapping and sampling activities, shaft-sinking operations will be interrupted periodically for other tests described in Section 8.4.2.5.1.

8.4.2.1.4 Construction of the main test level station

At about 50 ft (15 m) above the main test level, a reinforced brow liner will be constructed (discussed in Section 8.4.2.1.1) to reinforce the main test level station. This station will be constructed in essentially the same manner as the upper DBR station described in Section 8.4.2.1.2. The shaft will be deepened approximately 40 ft (12 m) below the station level so that the blockout for the muck pocket can be constructed. Upon completion of the station, the connecting drift from ES-2 will be completed.

8.4.2.1.5 Construction of exploratory shaft 1 to the Calico Hills station

With completion of the main test level station and certain test preparations described in Section 8.4.2.5.1, the miners will continue sinking the shaft through the lower boundary of the potential repository horizon and into the transition zone between the Topopah Spring Member and the Calico Hills tuff. The shaft will be mined by using the same techniques described in Section 8.4.2.1.1.

8.4.2.1.6 Construction of the Calico Hills station

The construction of the Calico Hills station will be essentially the same as that for the upper DBR station and the main test level described in Sections 8.4.2.1.2 and 8.4.2.1.4. A conceptual layout of the Calico Hills station is shown in Figure 8.4-15. A reinforced brow liner (discussed in Section 8.4.2.1.1) will be constructed from 50 ft (15 m) above the breakout. Drill rooms will be excavated from the shaft for testing in the Calico Hills tuff. A slash-out for a small muck pocket will be mined as part of the Calico Hills station development.

8.4.2.1.7 Construction of exploratory shaft 1 to total depth

With completion of the Calico Hills station, ES-1 will be sunk to its total depth of about 1,430 ft (436 m). The shaft will penetrate about 75 ft (23 m) into the tuffaceous beds of Calico Hills, and the lower 50 ft (15 m) will be in the pervasively zeolitized zone. Penetration into the Calico Hills tuff by the ESF is thus minimized, but the zeolitic zone is accessible for in situ testing to investigate the potential for retarding radionuclides by various physical and chemical sorption processes. The shaft-liner thickness may be increased (for structural support) within the nonwelded Calico Hills tuff.

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Figure 8.4-15. Conceptual view of the 1,360-ft level (Calico Hills station) of exploratory shaft 1.

At the shaft bottom, a sump pit will be excavated and pumps installed for water removal. Although water is not expected in the underground facilities, it is possible that perched-water zones, percolation seepages, or water used for dust control at working headings could release a small amount of water to the underground facilities during construction and testing. If a seep or perched-water zone is encountered, the water will be collected as discussed in Section 8.3.1.2.2.4.7. Excess water will be collected in the sump and then pumped to the surface and discharged in the mine waste-water pond. A backup sump pump will also be provided. The quantity of water removed from the shafts will be measured and recorded. The details and capacities of the waste-water removal system are currently being developed as part of a conceptual design study and will be included in future updates of the subsystem design requirements document.

8.4.2.2 Exploratory shaft 2

This section describes ES-2 and the various steps in its construction. ES-2 will be used to provide secondary emergency exit from the facility, to transport people and materials in and out of the underground test facilities, to provide for muck removal, and to provide additional ventilation capacity to the long exploratory drifts. The construction of ES-2 will proceed continuously until it reaches its design depth. A connecting drift to ES-1 and a lower demonstration breakout room (DBR) will also be constructed on the main test level after ES-2 is completed. No specific tests are planned while mining ES-2. The majority of tests are to be carried out in ES-1 and in the horizontal drifts; however, significant structural or hydrologic features and stratigraphic contacts may be mapped if encountered or as needed to verify data obtained in ES-1.

ES-2 is also a 12-ft (3.66-m) finished diameter, concrete-lined vertical hole extending from a leveled pad at the same elevation as ES-1 and to just below the main test level. The completed shaft includes the internal fittings, ventilation duct and plenum area, and conveyances shown in Figure 8.4-16. At the main test level, a station with a muck pocket and equipment staging area will be constructed. The drift space for equipment staging may initially be used for conducting some of the geomechanics tests planned for the lower DBR. The connecting drift to ES-1, located about 300 ft (91 m) southwest, will be mined from ES-2 in time to complete the connection as soon as ES-1 reaches the main test level. When the two shafts are connected, ES-2 will be used to support mining of the test areas and exploratory drifts.

8.4.2.2.1 Construction of exploratory shaft 2 to total depth

The current plan is to construct ES-2 using similar drill, blast, muck, and lining methods as used for ES-1; they are described in Section 8.4.2.1.1. The shaft internal fittings, however, will be installed after the shaft is sunk and lined to its total depth.

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Figure 8.4-16. Conceptual illustration of the internal structure of exploratory shaft 2.

8.4.2.2.2 Construction of the exploratory shaft 2 station and the connecting drift to exploratory shaft 1

The construction of the ES-2 station at the main test level will be essentially the same as that for the ES-1 main test level station described in Section 8.4.2.1.4. A reinforced brow liner will be constructed by using tendon rods and rock bolts. An additional feature at this breakout level will be the construction of a muck pocket and chute adjacent to, but outside, the shaft diameter. The chute will discharge stored muck directly into the skip in the shaft. After the station and equipment staging area have been completed, the drift that will connect ES-2 with ES-1 will be mined by the drill, blast, and muck technique. If ES-1 has not reached the main test level, the connecting drift will be stopped before it reaches the ES-1 intercept point so that the connection can be made after completion of the ES-1 station. Detailed design information about the ES-2 station and the connecting drift will be made available in semiannual progress reports for this document.

8.4.2.2.3 Construction of the lower demonstration breakout room at the main test level

Like the upper DBR (in ES-1), the lower DBR (in ES-2) will be mined to obtain rock mechanics data related to mining methods and constructibility in welded tuff. The mining (Section 8.4.2.1.2) and testing methods (Section 8.3.1.15.1.5.2) will be the same as for the upper DBR. When the DBR testing is completed, the drift space will be available for other testing or mining operations uses. The DBR tests are planned to be performed from ES-2 before extensive drifting operations are started because they will provide engineering data useful for mining the main test level operations area.

8.4.2.3 The main test level operations area

The design of the main test level operations area has been developed to meet several objectives. The overriding objective is to design the facility such that the waste isolation integrity of the site is not compromised (See Section 8.4.2.6). A primary design objective is to provide maximum flexibility within the area of the proposed repository horizon set aside for exploratory shaft testing. The concept consists of having a dedicated testing area (Figure 8.4-10) that will permit the scientists to select the areas for constructing their test alcoves and drifts in the surrounding rock mass. This objective is important for several tests that have special requirements such as orientation relative to rock stress or predominant fracture patterns, minimized induced water, isolation from other mining or drilling operations, and separation from other mined openings. Figure 8.4-11 shows the current design for developing test areas off the core operations drift area to accommodate the scientific objectives.

A second objective is to ensure that the main test level operations area design will be compatible with the design of a repository. In this regard,

the core operations area drifts are designed to minimize constraints on future repository uses such as ventilation or other repository operations.

A third objective is to ensure that the proposed drifts out to the boundary structures to the north and east and to Ghost Dance fault to the west will not compromise site integrity and will not jeopardize future repository emplacement space. This will be accomplished by locating the exploratory drifts along the alignments of the current conceptual repository drifts.

A fourth objective is to provide a centrally located data acquisition system, convenient to the test areas and shafts but adequately isolated from the mining operations.

A fifth objective is to provide a sufficient utilities operations area and dedicated test area to accommodate later performance confirmation tests from the same facility.

A sixth objective is to ensure that the site has been characterized for both the vertical and horizontal emplacement concepts identified in Chapter 6.

Other objectives relate to operational and safety considerations like traffic flow, equipment maintenance, shop space, and ventilation and underground utility requirements. The core operations area concept incorporates all these factors into its design and should, therefore, be operationally efficient, safe, and very flexible in supporting the test effort.

As shown in Figures 8.4-5 and 8.4-10, the main test level will consist of the core area drifts that will provide access to both shafts; access to and between the test areas, equipment maintenance, and shop space; space for the integrated data system with uninterrupted power supply; utility runs; and ventilation. The drifts in the core operations area will be sized (design studies are ongoing) to allow two-way traffic plus all utilities and ventilation ducts. The drifts will be reinforced with rock bolts, wire mesh, and shotcrete as required by design or encountered rock conditions.

8.4.2.3.1 Construction of the main test level

The main test level will be mined by conventional drill, blast, and muck methods. These operations consist of drilling many small-diameter blast holes in the drift face, loading them with explosives, and timing the charges to produce a sequential, controlled blast pattern that will meet the design specifications. The resulting rock rubble (muck) will be loaded and transported to the shaft muck pocket and then transported to the surface in the skip.

After blasting and muck removal and after ensuring safe conditions, the freshly exposed rock will be mapped and photographed (Section 8.3.1.4.2.2.4), and then reinforced with rock bolts, wire mesh, and shotcrete, as required, before preparations are started for the next blast round.

The actual sequence of mining the drifts is still under consideration, but the connecting drift between ES-1 and ES-2 is a high-priority activity for reasons of safety. Since the ES-2 operations shaft may reach the 1,055-ft (320-m) level several months before the ES-1, drift space for equipment and material staging and possibly a room for certain design experiments (i.e., lower DBR tests (Section 8.3.1.15.1.5.2) and stress testing (Section 8.3.1.4.3.1.1)) may be completed first, followed by construction of the connecting drift in time to effect the connection when ES-1 reaches the main test level.

When ES-1 and ES-2 are connected, the balance of the core operations area drifts will be mined, followed by the individual test alcoves and drifts. The details of these test alcoves and drifts will be provided in future design documents. Mining of the long exploratory drifts will begin about the time the test facilities are completed. Operational constraints may be a determining factor in scheduling the drift mining activities.

8.4.2.4 Exploratory drifts

Exploratory drifts are planned to gain access to three specific features within the proposed repository block: (1) the Ghost Dance fault, (2) the Drill Hole Wash structure, and (3) the imbricate normal fault zone to the east. These drifts are necessary to obtain information on the various structures to be encountered at the ends of each drift. The locations of the three drifts are shown in Figures 8.4-5 and 8.4-10. The lengths of the drifts have been estimated based on projections of the fault planes from the surface to the intercept elevations. The uncertainty in the length estimates is about ± 200 ft (60 m) for each of the three drifts. The lengths of the drifts could be slightly less than the estimates provided in the following sections if the intercept locations occur as projected.

Each drift will be mined by the same techniques used for the main test level operations area described in Section 8.4.2.3.1. The exploratory drift layout is shown in Figure 8.4-10. The ribs and the back will be rock bolted and covered with wire mesh as required. Tests described in Section 8.4.2.5 will be conducted during the mining and site characterization periods.

8.4.2.4.1 Drift to the Ghost Dance fault

The drift to the Ghost Dance fault will examine features potentially important to the design and performance of a repository. First, the fault is a potential transmissive zone for movement of water from the surface to the water table. The drift will allow direct observation, collection of samples, and other measurements needed to model the hydrologic environment. Other information that can be obtained by this drift includes the nature of the fault zone and possibly the degree of fault offset.

To reach the Ghost Dance fault area, a drift approximately 1,200 ft (370 m) long heading northwest from the main test level operations area will be constructed by using the drill, blast, and muck technique previously

described. The tests to be performed during construction and site characterization are briefly described in Section 8.4.2.5.

8.4.2.4.2 Drift to the Drill Hole Wash structure

The drift to the Drill Hole Wash structure will examine characteristics potentially important to the construction and performance of the repository. There will be examination of structural features, such as faulting, that have been postulated based on surface mapping and drill holes. If the investigation shows little or no faulting, then the area of the formation that can potentially be used for a repository will be substantially increased.

The hydrologic character of the rock structures below Drill Hole Wash will also be studied from this drift. Because the wash tends to concentrate surface waters and channel them along a specific path, higher than average infiltration rates could occur in this area. Studying this area may resolve concerns about seasonal change and movement of water down a fracture zone.

To reach the Drill Hole Wash structure area, a drift heading northeast from the main test level operations area will be constructed by using the drill, blast, and muck technique previously described. The tests to be performed during construction and site characterization are briefly described in Section 8.4.2.5.

8.4.2.4.3 Drift to the imbricate normal fault zone

The drift to the imbricate normal fault zone is planned to study the width of the fault zone, the strike and dip of the faults, and the location of these faults at the proposed repository depth. These studies will aid in determining the eastern boundary and the total size of the repository. Hydrologic studies will also be performed to determine whether this fault zone is transmitting water.

A drift heading southeast from the main test level operations area will be constructed by using the drill, blast, and muck technique previously described. The tests to be performed during construction and site characterization are briefly described in Section 8.4.2.5.

8.4.2.5 Exploratory shaft facility testing

The various tests planned for the exploratory shaft facility (ESF) are designed to acquire data on geologic, hydrologic, geomechanical, geochemical, and waste package environment characteristics. Strictly speaking, all tests performed in the ESF will be done in situ. However, the DOE has classified those test activities that are initiated during construction of exploratory shaft 1 (ES-1) as construction phase tests. Tests initiated on the main test level after ES-1 and ES-2 are connected, or elsewhere in the ESF after the

shaft sinking subcontractor has departed the site, are termed in situ phase tests.

The construction phase and in situ phase tests are listed in Table 8.4-1 along with references to their discussion locations in Section 8.3. Section 8.3 provides the rationale for each test and information about how the resulting data will be used. The following sections provide a summary of how each test will be developed and implemented.

The extent of testing in the exploratory shafts and underground testing facilities possibly could change from tests described here. Most notably, the drifts or exploratory holes from the Calico Hills level to the Ghost Dance fault are not described here pending an analysis of possible impacts to the waste isolation capabilities of the site. Other tests described as contingency tests in Section 8.3 are likewise not discussed here. Decisions on whether to proceed with a contingency test will be based on criteria developed for each test. If it is decided to proceed with any test that is currently described as a contingency test, an analysis of the impacts of the test on waste isolation will be completed and available for review before proceeding with the test.

8.4.2.5.1 Exploratory shaft facility studies

The studies to be conducted in the ESF are outlined in the following subsections.

Activity: Geologic mapping of exploratory shaft and drifts (Section 8.3.1.4.2.2.4)

The activities that make up this task include cleaning the shaft or drift wall areas, surveying in reference points, and marking significant structural features. Geologists will map the exposed wall interval as described in Section 8.3 and make a permanent record of the exposed interval by using a camera 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.

Activity: Fracture mineralogy studies of exploratory shaft and drifts (Section 8.3.1.3.2.1.3)

In addition to mineralogic sampling in the shaft at the working face and in the drifts, samples will be collected on the surface from the muck resulting from each blast round. 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.

Table 8.4-1. Exploratory shaft facility tests and the sections in which they are discussed

Title	Section
EXPLORATORY SHAFT FACILITY TESTS	
Geologic mapping of the exploratory shaft and drifts	8.3.1.4.2.2.4
Fracture mineralogy studies of exploratory shaft and drifts	8.3.1.3.2.1.3
Seismic tomography and vertical seismic profiling	8.3.1.4.2.2.5
Shaft convergence	8.3.1.15.1.5.1
Demonstration breakout rooms	8.3.1.15.1.5.2
Sequential drift mining	8.3.1.15.1.5.3
Heater experiment in unit TSw1	8.3.1.15.1.6.1
Canister-scale heater experiment	8.3.1.15.1.6.2
Yucca Mountain heated block	8.3.1.15.1.6.3
Thermal stress measurements	8.3.1.15.1.6.4
Heated room experiment	8.3.1.15.1.6.5
Development and demonstration of required equipment	8.3.2.5.6
Plate loading tests	8.3.1.15.1.7.1
Rock-mass strength experiment	8.3.1.15.1.7.2
Overcore stress experiments in the exploratory shaft facility	8.3.1.15.2.1.2
Matrix hydrologic properties testing	8.3.1.2.2.3.1
Intact-fracture test in the exploratory shaft facility	8.3.1.2.2.4.1
Infiltration tests in the exploratory shaft facility	8.3.1.2.2.4.2

Table 8.4-1. Exploratory shaft facility tests and the section in which they are discussed (continued)

Title	Section
Bulk-permeability test in the exploratory shaft facility	8.3.1.2.2.4.3
Radial borehole tests in the exploratory shaft facility	8.3.1.2.2.4.4
Excavation effects test in the exploratory shaft facility	8.3.1.2.2.4.5
Calico Hills test in the exploratory shaft facility	8.3.1.2.2.4.6
Perched water test in the exploratory shaft facility	8.3.1.2.2.4.7
Hydrochemistry tests in the exploratory shaft facility	8.3.1.2.2.4.8
Diffusion tests in the exploratory shaft facility	8.3.1.2.2.5
Chloride and chlorine-36 measurements of percolation at Yucca Mountain	8.3.1.2.2.2.1
Repository horizon near-field hydrologic properties	8.3.4.2.4.4.1
Repository horizon rock-water interaction	8.3.4.2.4.4.2

LABORATORY TESTS USING SAMPLES OBTAINED
FROM THE EXPLORATORY SHAFT FACILITY

Density and porosity characterization	8.3.1.15.1.1.1
Volumetric heat capacity characterization	8.3.1.15.1.1.2
Thermal conductivity characterization	8.3.1.15.1.1.3
Thermal expansion characterization	8.3.1.15.1.2.1

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Table 8.4-1. Exploratory shaft facility tests and the section in which they are discussed (continued)

Title	Section
Compressive mechanical properties of intact rock at baseline experiment conditions	8.3.1.15.1.3.1
Effects of variable environmental conditions on compressive-mechanical properties	8.3.1.15.1.3.2
Tensile strength of unit TSw2 (portion of the welded Topopah Spring unit proposed for the repository)	8.3.1.15.1.3.3
Mechanical properties of fractures at baseline experiment conditions	8.3.1.15.1.4.1
Effects of variable environmental conditions on mechanical properties of fractures	8.3.1.15.1.4.2

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

When fracture domains are selected in the shaft or drifts as described in Section 8.3.1.4.2.2.5, short boreholes will be drilled for geophone or similar instrumentation installation. When the sensor arrays are in place, seismic stimuli will be initiated by using explosives or vibroseis techniques at locations to be selected by the investigators.

Activity: Shaft convergence (Section 8.3.1.15.1.5.1)

Using standard overcore techniques (Section 8.3.1.15.2.1.2), horizontal stress measurements will be made at each of three test locations as the exploratory shaft is being sunk. In the shaft wall, three radially arrayed multipoint borehole extensometers (MPBXs) will be installed in each location (Figure 8.4-17) to measure shaft wall convergence when mining resumes. Hydraulic pressure cells will be installed behind the shaft liner to monitor radial stress changes over time as shaft sinking continues below the test location. In addition to MPBX measurements, deformations will be measured with rod extensometers at each of the three levels.

Activity: Demonstration breakout rooms (Section 8.3.1.15.1.5.2)

At the upper demonstration breakout room (DBR) and the main test level, full-size repository openings will be mined. Optimum blasting methods in each DBR horizon and rock stabilization requirements will be determined.

MPBX = MULTIPLE POINT BOREHOLE EXTENSOMETER.

Figure 8.4-17. Measurement details of the shaft convergence test.

Rock mass response will also be measured in the DBR excavations by using extensometers and convergence anchors.

Activity: Sequential drift mining (Section 8.3.1.15.1.5.3)

At the main test level, an instrumentation drift will be mined. Instrumentation holes to monitor above, below, and adjacent to a second parallel drift as shown in Figures 8.4-18 and 8.4-19 will be drilled. Borehole sensors will be installed to monitor stress release, rock permeability changes, and deformation. Baseline data before mining will be obtained, and a parallel drift will be mined while the rock mass responses to mining are monitored. Air and water permeability in boreholes adjacent to the new drift opening (Figure 8.4-20) will be measured after mining. Stress changes around the mined opening will continue to be monitored.

Activity: Heater experiment in unit TS_{w1} (Section 8.3.1.15.1.6.1)

In the upper DBR, a heater emplacement hole will be drilled approximately into the wall (Figure 8.4-21). Several instrumentation holes parallel to the heater hole will be drilled and then heater and instruments (multipoint borehole extensometers (MPBX) and thermocouples) will be installed. In a borehole below 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.

Activity: Canister-scale heater experiment (Section 8.3.1.15.1.6.2)

At a location in the lower DBR or a location to be determined within the main test area, a hole will be drilled into the drift wall. Parallel small-diameter instrumentation holes (Figures 8.4-22 and 8.4-23) will be drilled. Baseline moisture data in neutron probe holes will be recorded. Heater and instrumentation (thermocouples, MPBXs, hole deformation gauges, and radon monitors) will be installed. Finally, cyclic heating steps will be initiated and thermal, thermomechanical, hydrothermal, and radon release rates at increasing heat loads will be monitored.

Activity: Yucca Mountain heated block (Section 8.3.1.15.1.6.3)

At a selected location on the main test level a 6 ft by 6 ft (2 m by 2 m) area of rock will be defined, baseline fracture permeabilities will be measured, reference survey pins will be established, and crosshole ultrasonics measurements will be made. Next, slots will be cut on each side of the block to a depth of approximately 6 ft (2 m) and flatjacks will be inserted. An array of heaters will be installed in holes on opposite sides of the block as shown in Figure 8.4-24. Other instrumentation holes will be drilled and instrumented with thermocouples, MPBXs, and deformation gauges. Finally, cyclic tests will be conducted at various stress loads (using flatjacks) and thermal load (heaters). The rock responses and permeability changes under induced conditions will be monitored.

BSM = BOREHOLE STRESS METER
 MPBX = MULTIPOINT BOREHOLE EXTENSOMETER

Figure 8.4-18. Sequential drift mining tests.

Figure 8.4-19. Instrumentation arrangements for sequential drift mining tests

Figure 8.4-20. Permeability testing scheme for sequential drift mining test.

MPBX - MULTIPOINT BOREHOLE EXTENSOMETER
TC - THERMOCOUPLE

NOT TO SCALE

Figure 8.4-21. Elevation view of heater experiment in TSu1 (lithophysal Topopah spring unit).

Figure 8.4-22. Canister-scale heater experiment showing heater and instrumentation holes.

TC - THERMOCOUPLE
 BDG - BOREHOLE DEFORMATION GAUGE
 MPBX - MULTIPOINT BOREHOLE EXTENSOMETER

Figure 8.4-23. Canister-scale heater experiment showing location of sections shown in Figure 8.4-22.

Figure 8.4-24. Conceptual layout for Yucca Mountain heated block experiment.

Activity: Thermal stress measurements (Section 8.3.1.15.1.6.4)

In the upper DBR and at a location in the main test level, 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 (Figure 8.4-25). 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 area will be monitored as thermal loading increases.

Activity: Heated room experiment (Section 8.3.1.15.1.6.5)

In the main test level or lower DBR, a drift representative of repository-size drifts will be excavated, and the rock around it will be heated. Either a preexisting drift will be used or a drift will be constructed 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, ground-support loading and deformation, and an estimate of the region in which the stress state is changed by elevation of temperature. The experiment may involve more than one opening so that temperatures around and between drifts more nearly represent those expected in the repository.

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

A development prototype boring machine (DPBM) is being investigated for use in underground demonstration 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) deep horizontal holes at the main test level or lower 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.

Activity: Plate loading tests (Section 8.3.1.15.1.7.1)

Plate loading experiments will be performed at numerous locations in the upper DBR and in the main test level. 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 modulus 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 (nonlithophysal Topopah Spring). 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.

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Activity: Rock-mass strength experiment (Section 8.3.1.15.1.7.2)

Experiments will be conducted in several areas of the ESF chosen to be representative of the range of geologic conditions expected in 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. If random jointing is encountered in the ESF, then another stage of the experiment will be performed in which a representative volume of randomly jointed rock will be loaded to failure. The final stage of this experiment will require a block of jointed rock 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.

Activity: Overcore stress experiments in the exploratory shaft facility (Section 8.3.1.15.2.1.2)

Soon after access is available at the upper DBR and the main test levels, small-diameter holes will be drilled to prescribed orientations and lengths (longer than three shaft or drift diameters). Stress sensors (dilatometers) will then be installed, and the instrumented center hole will be overcored in stages. Stress data will be taken as the core from each stage is retrieved. At the Calico Hills level, similar measurements will be made in packed-off boreholes to obtain verification stress data.

Activity: Matrix hydrologic properties testing (Section 8.3.1.2.2.3.1)

Bulk and core samples collected after selected blasting rounds during ES-1 and drift construction and from core holes will be collected, packaged, and labeled. The analyses will be performed in a laboratory.

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

Fracture-sampling locations will be selected at each breakout horizon (upper DBR, main test level, Calico Hills level) on the basis of detailed fracture maps. At about 12 locations (to be determined), a small pilot hole will be drilled across the 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.

Activity: Infiltration tests in the exploratory shaft facility (Section 8.3.1.2.2.4.2)

In a test alcove on the main test level (location to be determined), an elevated test bed will be constructed as shown conceptually in Section 8.3.1.2.2.4.2. A trickle system and sand bed will be installed after 4 vertical and 12 or more horizontal instrumentation holes have been air-cored, surveyed, tested for air permeability, and instrumented. The room will be lined with an impermeable (plastic) liner and sealed off from other test

areas. The infiltration test will involve trickling tracer-tagged water through the sand bed and monitoring flow rates and pathways over time in the underlying rock mass.

Activity: Bulk-permeability test in the exploratory shaft facility (Section 8.3.1.2.2.4.3)

A test location on the main test level will be selected on the basis of detailed fracture maps. A small-diameter pilot hole 100 to 200 ft (30 to 60 m) deep, parallel to but 12 ft (3 m) outside the wall of the proposed test room, will be air-cored and logged. Air permeability will be measured in packed-off intervals. If the rock is suitable for the test, two additional holes parallel to the first, but 4 ft (1.2 m) and 8 ft (2.4 m) outside the wall of the proposed test room, will be air-cored and then logged and tested as the pilot hole was. The test room will be excavated using controlled blasting and dry mining techniques (Section 8.3.1.2.2.4.3). The wall rock fractures will be mapped in detail. Up to nine holes parallel to principal permeability axes will be air-cored. Crosshole air permeability (injection) tests followed by crosshole water injection tests will be conducted. A double bulkhead to isolate the test room will be constructed. Pressure, temperature, and humidity sensors will be installed in the test room and adjacent boreholes. The room will then be pressurized, and the air movement outward to the borehole sensors will be monitored. The procedure will be repeated as required by using positive or negative pressure in the test room.

Activity: Radial borehole tests in the exploratory shaft facility (Section 8.3.1.2.2.4.4)

At approximately 12 locations in ES-1 (Section 8.3.1.2.2.4.4) two small-diameter holes will be air-cored diagonally from each other 30 ft (10 m) or more radially from the shaft. 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 shaft mining will be done when mining resumes. Long-term monitoring of matrix water potential, pressure, and temperature and periodic sampling of formation gases will be done.

Activity: Excavation effects test in the exploratory shaft facility (Section 8.3.1.2.2.4.5)

At the upper DBR and main test level stations, six vertical, small-diameter holes will be drilled parallel to the unexcavated shaft wall but set back 4, 8, and 12 ft (1.2, 2.4, and 3.5 m) from it. All holes will be logged and surveyed; three will be instrumented to monitor stress changes, and the other three will monitor permeability changes as the shaft is advanced. Pre-excavation (baseline) stress and permeability data will also be taken. Long-term permeability measurements will be made and temperature and moisture data collected. (Additional holes will be drilled to handle the instrumentation arrays if they are determined to be necessary during prototype testing.)

Activity: Calico Hills test in the exploratory shaft facility (Section 8.3.1.2.2.4.6)

At the Calico Hills station, a small drill room will be constructed to support the drilling of an approximately 250-ft (76-m) horizontal drillhole and a long (approximately 800-ft (250-m) drillhole out to Ghost Dance fault. All drillholes will be cored with air as the circulating fluid. Core samples will be collected, packaged, labeled, and analyzed for matrix, rock mass, and chemical parameters in a laboratory as described in Section 8.3.1.2.2.4.6. The holes will be logged and surveyed and then tested for permeability with gas-injection techniques in packed-off intervals. Air and water crosshole tests will be conducted in both drillholes at the stations and in holes drilled as part of the radial borehole tests (Section 8.3.1.2.2.4.4) above and below the Topopah Spring and Calico Hills contact.

Activity: Perched water test in the exploratory shaft facility (Section 8.3.1.2.2.4.7)

If perched water is encountered while mining ES-1, a small-diameter hole will be drilled to enhance drainage, facilitate collection of water samples, and allow flow measurements to be made. The holes will also be instrumented and sealed to obtain data on hydraulic pressure and water potential over time.

Activity: Hydrochemistry tests in the exploratory shaft facility (Section 8.3.1.2.2.4.8)

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

Study: Diffusion tests in the exploratory shaft facility (Section 8.3.1.2.2.5)

Four small-diameter holes will be air-drilled to a vertical (or horizontal) depth of 33 ft (10 m), a suitable nonsorbing tracer will be injected 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.

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

As the ES-1 shaft is 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.

Activities: Repository horizon near-field hydrologic properties (Section 8.3.4.2.4.4.1) and repository horizon rock-water interaction (Section 8.3.4.2.4.4.2)

These tests will provide thermal, hydrologic, mechanical, and limited chemical information during an abbreviated thermal cycle (of at least 1-yr duration) in the very near field emplacement environment. In test alcoves on the main test level, horizontal and vertical heater emplacement holes and small-diameter parallel and perpendicular instrumentation holes will be drilled as shown in Figures 8.4-26 and 8.4-27. Heater canisters and associated instrumentation packages will be inserted to monitor thermal, moisture, and stress and strain parameters during a thermal cycle 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.

In addition to the geomechanical and thermomechanical field tests planned in the ESF, a number of laboratory activities will use bulk rock and core samples collected in the ESF. These activities are listed in Table 8.4-1.

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. Study plans and the NNWSI Project Exploratory Shaft Test Plan will provide much more detailed information about all of the planned ESF tests. The study plans, which will be periodically updated with the site characterization plan, provide the official source of reference testing information.

8.4.2.5.2 Performance confirmation tests

At present, the NNWSI Project does not have a fully defined performance confirmation testing program. The overall approach to performance confirmation developed by the DOE is described in Section 8.3.5.16. The results of surface-based and ESF testing will help to define what testing will be needed as part of performance confirmation. The design of the ESF incorporates ample space and operational flexibility to support follow-on performance confirmation tests at full repository scales.

8.4.2.6 Potential impacts of exploratory shaft construction and testing on the waste isolation integrity of the site

The purpose of this section is to discuss whether the construction of the exploratory shaft facility (ESF) and operation of tests in the ESF could affect the waste isolation integrity of the site by providing a preferential pathway for radionuclide transport. Both the Nuclear Waste Policy Act and 10 CFR Part 60 request an analysis of characterization activities that could affect the waste isolation capabilities of the site. To determine whether

Figure 8.4-26. Typical layout for horizontal and vertical emplacement holes for the engineered barrier system field tests

Figure 8.4-27. Typical instrumentation array for the engineered barrier field test.

the construction of, or the testing in, the ESF could affect the waste isolation integrity of the site, it is first necessary to identify the elements of the system that are important to waste isolation. The DOE has defined items important to waste isolation to be "those barriers, structures, systems, and components which are relied on to meet 10 CFR 60, Subpart E postclosure performance objectives" (DOE, 1987c). Subpart E describes four postclosure performance objectives related to (1) total system performance assessment of release of radionuclides to the accessible environment, (2) containment requirements for the waste package, (3) engineered barrier system (EBS) release rate, and (4) pre-waste-emplacement ground-water travel time (GWTT). These performance objectives are addressed in Section 8.3.5.13, 8.3.5.9, 8.3.5.10, and 8.3.5.12, respectively, of this document. In addition to the general discussion here, the specific potential impacts of ESF construction and testing on each of these performance objectives are addressed in the subsections that follow.

Description of exploratory shaft facility

The ESF comprises a small fraction of the total repository area and is separate from potential waste emplacement panels (see Figures 8.4-8 and 8.4-10). The ESF is located in the northeastern portion of the potential repository, with ES-1 penetrating the unsaturated portion of the Calico Hills nonwelded unit and ES-2 extending only slightly below the repository level (Figure 8.4-12). Three long exploratory drifts are planned to allow access to the Ghost Dance fault, the Drill Hole Wash structure, and the imbricate normal fault zone (Figure 8.4-10). These drifts are permanent items that could be included as part of the underground facility. They will be constructed using the same methods that are expected to be used for drifts in the rest of the underground facility. Fluids in the testing area will drain away from these drifts.

The dedicated testing area occurs at the repository level and consists of an area dedicated for currently planned site-characterization testing and an area dedicated for performance-confirmation testing and other site-characterization testing that may be defined in the future. As shown in Figure 8.4-10, the ESF is physically separate from potential waste emplacement panels by a minimum of approximately 30 m of rock, with the area currently dedicated to site-characterization testing (Figure 8.4-11) generally separated from the panels by at least 60 m of rock. The ESF testing area is designed to drain any fluids that might enter the shafts or drifts toward ES-1 (see Figure 8.4-28) and away from the emplacement areas. Information on shaft and drift dimensions and penetration depths of the exploratory shafts is given in Section 8.4.2.

General approach to evaluation of potential impacts

Conceptual models of present hydrologic conditions are described in Chapter 3 and Section 8.3.1.2 of this document. Briefly, it is believed that within each unsaturated-zone rock unit, water will flow vertically downward and will travel mainly in the matrix of the rock units, with spatially averaged percolation flux not exceeding 0.5 mm/yr. Some lateral diversion of flux may occur at the interfaces between distinct hydrogeologic rock units. This diverted water may be directed down-dip along the interface (as matrix flow, given the present recharge rates) to the water table or to downward

Figure 8.4-28. Illustration of the planned drainage pattern towards exploratory shaft 1 in the exploratory shaft facility.

drainage points in the highly faulted zone southeast from the edge of the emplacement zone. Water reaching the water table will then flow in a roughly horizontal direction to the accessible environment boundary. As discussed in Section 8.3.5.13, the units of the unsaturated zone below the proposed repository level (especially the Calico Hills unit) and the saturated zone are expected to provide the primary barrier to radionuclide release to the accessible environment.

The conceptual model for the transport of gas (carbon-14 dioxide) through the partially saturated overburden has three principal features:

1. Gas-phase carbon-14 dioxide would move upward through air-filled pores and fractures of the unsaturated tuffs by molecular diffusion and by advection in a thermally driven air convection cell.
2. An isotopic equilibrium would exist between carbon dioxide in the gas phase, which is mobile, and dissolved bicarbonate, which is immobile.
3. Precipitation of calcite would irreversibly remove carbon-14 from the system. As discussed in Section 8.3.5.13, the engineered barrier system, especially the container, is expected to act as the primary barrier to gaseous radionuclide release to the accessible environment.

Given the above understanding of the hydrologic conditions at the site, ESF construction and testing could potentially impact the primary barriers and, therefore, the performance of the Yucca Mountain site through four primary mechanisms:

1. Create openings that remain after construction and potentially could furnish pathways for movement of liquids and gases.
2. Induce changes in the rock characteristics around these openings.
3. Introduce solid materials to the site.
4. Introduce fluids, both liquids and gases, to the site.

The potential impacts caused by these mechanisms are generally addressed in the paragraphs below. The potential impacts to each of the four postclosure performance objectives identified previously are specifically evaluated in the subsections that follow the general discussion.

Creation of openings. The openings and surrounding disturbed rock provide potential pathways for radionuclide travel in both the liquid and gaseous phases. These pathways include not only the shafts and drifts themselves but also the rock damage zone caused by excavation of openings. Fernandez et al. (1987) have analyzed the potential for both gaseous and liquid flow through a shaft and the damaged zone around a shaft and concluded that the presence of the shafts, damaged zone, and liner will not significantly impact the long-term isolation capability of the repository. The analysis results would be similar for the evaluation of potential performance impacts caused by the construction of the long exploratory drifts and the

testing area. Additionally, the shafts and drifts will be backfilled to reduce the potential for flow of gases and liquids through these openings. Fernandez et al. (1987) also described methods to remove the liner, to mitigate the damaged zone, and to emplace a seal in the event that future analyses suggest that these actions are necessary. Again, it should be pointed out that the ESF was designed to be physically separate from potential waste emplacement panels.

Induced changes to rock characteristics. Case and Kelsall (1987) examined the significance of construction-induced changes in the hydrologic characteristics of the rock mass surrounding an opening and found that significant changes to rock-mass permeability were limited to a few meters. As can be noted from Figure 8.4-29, the ESF comprises only an extremely small volume compared with the volume of rock mass over the entire repository. Therefore, the ESF induced changes in rock characteristics are not expected to significantly change the overall hydrologic flow characteristics at the site, especially near waste emplacement panels which are horizontally separated from the ESF. This is primarily because liquid water generally moves slowly vertically downward in the unsaturated zone at the site (see Section 3.9.3). Therefore, only localized effects on the flow patterns are expected.

Introduction of solid materials. Solid materials introduced to the site through the ESF include the shaft liner and those materials used for testing purposes. The chemical interactions of the shaft liner with the surrounding rock mass are expected to be limited in extent (a few meters) and are not likely to have any significant effect on performance. The current plans are for the liner to be removed below the waste emplacement level. Other materials (such as test instrumentation and cementitious materials) generally will be removed and, because all materials will be in regions separated by at least 30 m laterally from waste packages, are not expected to have any influence on the isolation integrity of the site. Potential chemical interactions of these materials with the site are now being evaluated, with preliminary results indicating no significant impacts on waste isolation.

Introduction of Fluids. A variety of fluids will be introduced to the site, both organic and inorganic. The fluids introduced in the largest quantities will be liquid water, introduced during ESF construction and testing, and air, primarily introduced through ventilation. The expected volume of water introduced by construction and testing is an order of magnitude smaller than the 20,000 m³ considered in scenarios by Fernandez et al. (1987). No significant impacts on performance were found in their analyses. The majority of water (approximately 80-90%) introduced is expected to be recovered, with the amount of water permanently lost to the rock mass at least one to two orders of magnitude larger than the amounts of other fluids lost. The other fluids are primarily small amounts of organics (such as lubricants and oils) lost by machinery. All water introduced will be tagged with a tracer to permit evaluation of the extent of the water movement.

The fluid injection pressures used in construction and testing are low, generally a few atmospheres or less, with the pressure applied only for a short time. Preliminary analyses indicate that water (or other liquids) will move only a short distance (several meters) into the rock mass because of the

SECTION THROUGH TUFF MAIN

Figure 8.4-29. Projection of exploratory shaft facility onto stratigraphic cross-section of the site along repository mains.

low injection pressures, the low matrix permeability, and the high capillary forces within the matrix. The analyses indicate that water movement in fractures under low pressure gradients will be significantly retarded by the high capillary forces in the adjacent rock matrix. The analyses also indicate that, at equilibrium with the rock mass, saturation of the rock mass will not change by significant amounts (only a few percent). Therefore, it is not expected that the flow field will be altered except in very localized areas around the water injection locations. Also, because water is expected to move slowly vertically downward, any liquid (organic or inorganic) entering the rock mass is expected to move vertically through the rock matrix after passing through the main test level. The ESF testing area is designed to drain any fluids that enter the shafts or drifts toward ES-1 and away from the emplacement areas (Figure 8.4-28). In addition, the physical separation of the ESF from potential waste emplacement locations, located at approximately the same elevation as the ESF testing area, suggests that fluids introduced into the ESF will not interact with the waste, nor will fluids that might contact the waste interact with the ESF fluids.

A significant amount of air will enter the ESF through ventilation. Analyses by Hopkins et al. (1987) indicate that a volume of water comparable to that estimated to be lost during ESF construction and testing can potentially be removed from the rock mass in 3-4 years of ventilation. The analyses suggest that more water would be removed by ventilation than introduced by ESF construction and testing and, hence, the rock-mass saturation could actually be reduced. The analyses indicate that the ventilation effect occurs only within a few meters of the exposed rock surfaces. These factors, combined with the considerations noted above, indicate that the fluids introduced into the ESF during construction and testing will not significantly impact the waste isolation integrity of the site. The investigation of fluid movement at the site is an integral part of the planned site characterization activities, and future data and analyses will be evaluated to determine the validity of this conclusion.

Summary. In summary, potential impacts of ESF construction and testing on performance are not expected to be significant because 1) the exploratory shafts will be located where water is not likely to enter, 2) any water entering the shafts will drain from the sump of ES-1, 3) liquid movement is expected to be vertically downward, 4) the drainage pattern in the ESF is away from waste-emplacement panels, 5) damage to the rock mass surrounding openings is limited to a few meters, 6) liquids introduced by construction and testing are expected to move only a short distance (several meters) into the rock, 7) the ESF is laterally separated from waste-emplacement panels by at least 30 m, 8) a significant volume of water will be removed by ventilation, 9) air and water flow through the shaft can be controlled effectively by the emplacement of a shaft fill, and 10) deposition of solids from chemical interactions of the shaft liner with ground water will be a localized phenomena and should not decrease the drainage capacity of the rock at the base of the shaft. These findings are based on current knowledge of the site and preliminary results of some ongoing studies. These findings are used in the following subsections to evaluate the potential impacts of ESF construction and testing on the performance of the site.

8.4.2.6.1 Potential impacts on the pre-waste-emplacement ground-water travel time postclosure performance objective

Summary of issue resolution strategy

One of the postclosure performance objectives described in 10 CFR 60, Subpart E addresses pre-waste-emplacement ground-water travel time (GWTT) and places a minimum criterion of 1,000 yr for ground-water travel time from the disturbed zone to the accessible environment along the fastest path of likely radionuclide travel. The draft generic position paper on GWTT issued by the Nuclear Regulatory Commission (NRC) (NRC, 1986) states that "Pre-waste-emplacement pertains to conditions at the site prior to any significant disturbance of the hydrological or geological setting such as construction activities or the effects of radioactive wastes." The position paper also states that the GWTT objective should be viewed as a conceptually simple measure of the overall quality of the geologic setting.

Section 8.3.5.12 (Issue 1.6) describes the Issue Resolution Strategy (IRS) proposed for determining if the site meets the performance objective for GWTT as required by 10 CFR 60.113(a)(2). The IRS considers liquid water movement along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment. The flow path will include portions of both the unsaturated zone and the saturated zone at the site. The strategy for demonstrating compliance with the GWTT performance objectives is to rely on each hydrogeologic unit from the disturbed zone to the accessible environment as a barrier to flow, with the primary barrier designated as the unsaturated Calico Hills nonwelded unit. Current understanding of flow in the unsaturated zone is that, under present conditions, water moves predominantly vertically downward and through pores in the rock matrix, with the possibility of lateral water movement along hydrogeologic unit interfaces (see Section 3.9.3). The flow path through the saturated zone is generally horizontal and through the fractures. Preliminary estimates of GWTT through the unsaturated zone, based on an upper-bound estimate of flux (see Section 3.9), indicate travel times of tens of thousands of years (Sinnock et al., 1986). The travel time through the unsaturated Calico Hills nonwelded unit alone was estimated to be over 10,000 yr. These preliminary estimates suggest that the pre-waste-emplacement GWTT objective can be met with reasonable assurance at the Yucca Mountain site.

Evaluation of potential impacts

None of the four potential impacts of ESF construction or testing on the waste isolation integrity of the site listed previously have been identified as significant, with respect to the GWTT performance objective. The GWTT performance objective addresses performance of the site under pre-waste-emplacement conditions. Therefore, the impacts of ESF construction and testing are relevant to this performance objective only in how the boundary of the disturbed zone might be altered (i.e., how the hydrologic characteristics and performance of the site might be significantly changed by ESF construction or testing).

The creation of openings or the introduction of materials are not expected to alter the dimensions of the disturbed zone discussed below. Openings are explicitly a part of the disturbed zone, excluding shafts,

boreholes, and their seals. The introduction of materials is not likely to impact the current conservatively assumed boundary of the disturbed zone of 50 m below the repository midplane. Therefore, these two potential impacts are not expected to affect the GWTT performance objective.

As part of the IRS of Section 8.3.5.12 and the GWTT estimates by Sinnock et al. (1986), a preliminary definition for the boundary of the disturbed zone was conservatively assumed to be a plane 50 m below the repository midplane. This assumption is in accordance with the recommendations made in the NRC draft technical position paper on the disturbed zone (June 1986), where significant construction-induced changes to rock-mass hydrologic characteristics were estimated to extend no more than 50 m from any underground opening.

Construction-induced modification of rock-mass permeability could impact the definition of the boundary of the disturbed zone. Case and Kelsall (1987) examined the significance of construction-induced changes to the hydrologic characteristics in the rock mass surrounding an opening (such as the exploratory shaft) and found significant changes to rock-mass permeability to be limited to much less than 50 m. Thus, not only are the exploratory shafts not part of the disturbed zone by definition, the potential modification of hydrologic characteristics of the rock around the shafts and drifts is of limited extent and within the assumption made in estimates of GWTT. As stated above, these estimates indicate that the construction of the ESF is unlikely to impact the ability of the site to comply with the GWTT performance objective.

The introduction of fluids by ESF construction and testing could change the rock-mass saturation, hydrologic properties, and flow paths; thereby impacting the definition of the boundary of the disturbed zone. The ESF testing area is designed to drain any fluids that enter the shafts or drifts toward ES-1 and away from the emplacement areas (Figure 8.4-28). The previous section suggests that introduction of fluids into the rock mass will be limited to much less than 50 m of the ESF because of the low fluid pressures used and the hydrologic properties of the rock, and therefore would not alter the current conservatively assumed value for the boundary of the disturbed zone. Moreover, ventilation through the facility will remove, in a few years, a volume of water comparable to the amount lost in the rock by construction and testing. Finally, the ESF is separated by a minimum of approximately 30 m from the waste emplacement drifts (see Figure 8.4-9). Because fluids introduced into the facility are expected to move vertically downward, the fluids will not interact with the flow paths that are directly below the waste emplacement areas. Therefore, even if some fluids could move more than 50 m vertically from the ESF, the fluids will not affect likely paths of radionuclide travel and will not affect performance relative to the GWTT performance objective. Because of these factors, current knowledge supports the conclusion that no significant impacts on the GWTT performance objective are expected to result from exploratory shaft construction or testing.

The basis for this conclusion is the current design of the ESF and test program. Although not currently a part of the ESF design, a long, lateral drift in the unsaturated Calico Hills unit has been proposed and described in Section 8.3.1.2.2.4.1 (Calico Hills test in the ESF). The current under-

standing, based on the intent of the GWTT performance objective to be a conceptually simple measure of performance, is that this drift would be excluded in defining the boundary of the disturbed zone. Moreover, the NNWSI Project believes that activities described in Section 8.3.5.12.5 will justify a definition for the disturbed zone as a boundary 10 m or less below any underground opening, which would still provide almost 85 m of unsaturated rock to the water table. This thickness of Calico Hills rock would be more than the minimum expected at other locations below the repository. Based on preliminary GWTT estimates by Sinnock et al. (1986), 85 m of unsaturated Calico Hills rock would still yield travel times well in excess of the 1,000-yr criterion specified by 10 CFR 60.113.

8.4.2.6.2 Potential impacts on container lifetime

Summary of issue resolution strategy

This section discusses containment requirements for the waste package and the impact of the construction of and testing in the ESF on the waste package. Issue 1.4 (Section 8.3.5.9) addresses the performance of the waste package as required by 10 CFR 60.113. The performance objective for containment is as follows: "The engineered barrier system shall be designed, assuming anticipated processes and events, so that containment of high-level waste (HLW) within the waste package will be substantially complete for a period to be determined by the Commission, taking into account factors specified in 60.113(b) provided that such a period shall not be less than 300 yr nor more than 1,000 yr after permanent closure of the geologic repository."

A precise interpretation of the regulatory term "substantially complete containment" depends in large part on the level of waste-package performance needed at the site. Therefore, a specific interpretation of the general requirements cannot be made until additional information regarding site condition and the characteristics of alternative materials and waste package design subject to these conditions is available. To guide testing and design programs to obtain the information needed to assess the performance of the set of waste packages, three quantitative design objectives have been set. These objectives state that (1) 80 percent or more of the waste packages will retain all their radioactivity for a containment period of 1,000 yr after permanent closure, (2) at any time during the containment period, at least 99 percent of the radioactivity resulting from original waste emplaced in the underground facility will be retained within the set of waste packages, and (3) releases from the EBS in any one year during this period should not exceed one part in 100,000 of the total inventory of the radionuclide activity present in the geologic repository system in that year.

The NNWSI Project has chosen to use the components of the waste package, together with the near-field environment as altered through engineering design, as a basis for the strategy to demonstrate that the containment performance objective has been met. The system elements relied upon are (1) the postemplacement environment of the waste package, as altered by the engineered aspects of the waste package, (2) the waste container and its properties under those conditions, and (3) the waste form and its properties

under those environmental conditions. Section 8.3.5.9 provides a detailed discussion of the regulatory basis and resolution strategy for Issue 1.4.

Evaluation of potential impacts

The container can be breached by two mechanisms: mechanical damage to the container or corrosion of the container through contact with water. With respect to the potential impacts listed in the introduction, the creation of openings and rock-induced damage are the only impacts that could result in mechanical damage. Mechanical damage to a container as a result of ESF construction and operation is not a credible scenario because of the separation of the ESF from waste emplacement areas and because the excavation of the ESF will meet the same general standards as the rest of the underground facility (SCP-CDR, 1987). A significant failure of the drifts in the ESF during the containment period is highly unlikely because of the planned methods of mining and methods of supporting the drifts (SCP-CDR Section 3.3). However, even if a failure were assumed to occur, any deformation in those drifts would be isolated from the waste-emplacement areas by a minimum of 30 m (Figure 8.4-8 and Figure 8.4-10). This is well beyond the range of significant effects of deformation.

During construction of and testing in the ESF, materials such as experiment instrumentation, concrete, and other construction materials will be introduced into the host rock. A large portion of these materials will be retrieved. For those materials not expected to be removed, it is expected that they will have no impact on the performance of the repository. Any movement of the solids away from the shaft would be by dissolution in the ground water and subsequent ground-water flow through the rock. Since, as discussed above, the water is expected to flow predominantly vertically, the water and dissolved solids are not expected to contact the waste packages.

Water introduced during ESF construction and testing is not expected to significantly impact performance with respect to container lifetime. The basic strategy for limiting the potential for corrosion of the container is to limit the liquid water that can contact the container and limit any changes in water chemistry. Construction and operation of the ESF will not significantly change the hydrology and geochemistry of waste emplacement areas. During construction of the ESF, water will be used for dust control, drilling and mining, and testing. Most of this water will be removed to the surface by mucking operations. Preliminary estimates indicate that only a small fraction of the water used in the ESF during construction will be retained in the host rock. This water will be retained in the rock mass around the shaft and drifts. Retained water may flow into fractures and move away from exposed rock surfaces or be retained in the rock matrix near the surfaces.

If water flows in the vertically oriented fractures, it would increase the distance that the water moved (generally several meters); however, the effect on the equilibrium saturation level in the rock mass would be quite small (a few percent). If the water moved primarily into the matrix, there would be a somewhat larger local effect on the saturation level, but the distance of the effect from the surface would be short (generally tens of centimeters or less). As water moves away from the walls of the shafts and

drifts, its effect on the equilibrium saturation level is decreased simply because there is an increase in the volume of rock containing the fixed volume of water.

Since the injection pressure of the water used during construction will be low, retained water is expected to be a local effect near shafts and drifts. Since flow in the potential repository unit is expected to be essentially vertical (see Section 3.9.3), water from ESF construction and testing is not expected to flow laterally through the 30 m or more of rock that separates the ESF from a waste package and reach emplacement boreholes and the waste package. A modified permeability zone (MPZ) around an exploratory shaft, due to excavation of the shaft, was calculated by Case and Kelsall (1987). The MPZ was estimated to have a radius twice the radius of the shaft and considered as a preferential pathway for radionuclide travel by Fernandez et al. (1987). The permeability in the MPZ was estimated to be substantially larger than the undisturbed rock permeability. This increase in permeability will allow easier movement of fluids into that limited region but the fluids would still be retained near the shaft wall. Fernandez et al. (1987) have analyzed the potential for both gaseous and liquid radionuclide transport through the exploratory shaft and damaged zone around the shaft and concluded that the presence of the shafts, damaged zone, and liner will not significantly impact the isolation capability of the repository. The analysis results would be similar in the evaluation of potential performance impacts caused by the construction of the long exploratory drifts and in the testing area.

As an additional measure, the ventilation system will remove water from the exposed walls in the ESF during construction and testing. Hopkins et al. (1987) have performed analyses that show that ventilation will reduce the saturation level several meters into the wall. Specifically, the ventilation system will remove, in a few years, a volume of water comparable to that retained from construction and testing before emplacement of waste, thereby reducing the potential for construction water reaching a waste package.

Further, drainage in the ESF is designed for water to flow toward ES-1 (see Figure 8.4-10 and 8.4-28) reducing the potential for water to reach a waste package. If surface water were to enter the exploratory shafts, this water is also expected to drain vertically and not flow horizontally for the 100 m or more necessary to reach waste packages. Fernandez et al. (1987) have performed analyses that indicate that if a large quantity of water, estimated to be an order of magnitude or more larger than the water retained during construction, entered the exploratory shaft, this water would be contained within the shaft sump and subsequently drain.

Therefore, the conclusion is that potential impacts of ESF construction and testing on the containment capability of the packages will not be significant. Water and other materials will be introduced into the host rock during construction and testing of the ESF. However, injection pressure for construction water is so low and the quantity is so small that the change in the saturation level at equilibrium will be small. The quantity of the other materials that will remain in the ESF is also small. Because of the relatively small amount of water and materials that will remain in the ESF, the relatively short distance into the rock mass that they will penetrate, the horizontal distance separating the ESF from the emplaced waste packages,

and the expected predominant vertical flow of water, the fluids and materials introduced into the ESF and the construction-induced changes to the rock-mass permeability in the few meters surrounding the shafts and drifts are not expected to contact and affect performance of the waste packages.

8.4.2.6.3 Potential impacts on releases from the engineered barrier system (EBS)

Summary of issue resolution strategy

This section discusses the postclosure performance objective related to the engineered barrier system (EBS) release rate and the impact of the construction and testing in the ESF on the releases from the EBS. Issue 1.5 (Section 8.3.5.10) addresses the performance of the EBS as required by 10 CFR 60.113(a)(1)(ii), which states in part that the EBS shall be designed, assuming anticipated processes and events, so that: "(B) the release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided that this requirement does not apply to any radionuclide which is released at a rate less than 0.1 percent of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay."

The strategy for resolution of Issue 1.5 is based on present knowledge of the repository emplacement environment, data gathered on waste form performance in environments that can be related to the projected repository environment, and the use of models to assess the performance of various system elements. The system elements relied upon to limit releases are (1) the engineered environment that limits the quantity and quality of water that can contact the containers and (2) the waste form that controls the release rate from inside failed containers. Strategies are developed for the expected case of no liquid water contacting waste packages and for a bounding case that allows all containers to experience the maximum water flux, even though this latter case is not expected to occur.

Current data (see Section 7.4) indicate that it is very likely that the performance objective for control of the release rate from the EBS can be met by the waste form in an unprotected condition, i.e., without relying upon the presence of a container. The unprotected conditions that will be assumed will be different for the two basic waste forms because of intrinsic differences. The glass waste form will be assumed to be in its pour canister, with the canister degraded to the point that water can flow freely into and out of the canister. The spent fuel waste form will be assumed to consist of bare fuel pellets that have been exposed because of cladding rupture. For both waste forms, the container will be assumed to be substantially intact, thereby providing a means to accumulate water in contact with the waste form. Section 8.3.5.10 provides a detailed discussion of the regulatory basis and resolution strategy for Issue 1.5.

Evaluation of potential impacts

No significant impacts of ESF construction and testing on the waste isolation integrity of the site, with respect to container lifetime, were identified in Section 8.4.2.6.2. The system elements relied upon for container lifetime include two of the same elements that are relied upon to limit releases from the EBS: the engineered environment and the waste form. Therefore, the discussion presented in Section 8.4.2.6.2 is applicable to the impact on the EBS releases and will not be totally repeated in this section.

As discussed in Section 8.4.2.6.2, a significant failure of drifts in the ESF is highly unlikely. Furthermore, even in the event of a failure, the waste-emplacement areas are beyond the range of significant effects of deformation.

Transport of small amounts of other materials retained from construction and testing will be primarily by ground-water flow. Since the water is expected to flow predominantly vertically, these materials should also neither contact waste packages or affect releases from the EBS.

As described in Section 8.4.2.6.2, the amount of water retained in the walls and ceilings of the ESF will be small since the injection pressure of water used during construction will be low. It is expected that retained water will be a local effect near the shafts and drifts will probably drain vertically down through rock of the unsaturated zone. The ventilation system will remove some of water retained during construction and testing before emplacement of waste, further reducing the potential for construction water to affect the performance of the EBS. As explained in Section 8.4.2.6, the drifts are designed so that fluids in the drifts will drain toward ES-1. Therefore, fluids that enter the host rock during construction and testing are expected to remain well within 30 m of the ESF and not move laterally into the vicinity of the waste package.

Water and other materials will be introduced into the host rock during construction of and testing in the ESF. Because of the small amount of water and materials that will remain in the ESF, the relatively short distance into the rock mass that they will penetrate, the relatively long horizontal distance from the ESF to the waste packages, and the expected predominant vertical flow of the water in the unsaturated zone; the fluids and materials introduced into the ESF and the construction-induced changes in permeability of the rock mass surrounding the shafts and drifts are not expected to affect releases from the EBS.

8.4.2.6.4 Potential impacts on release to accessible environment

Summary of issue resolution strategy

This section discusses the postclosure performance objective related to the assessment of total system releases to the accessible environment. Issue 1.1 (Section 8.3.5.13) addresses the performance of the total system as required by 10 CFR 60.112 and 10 CFR 60.115. These regulations specify

cumulative release limits for radionuclides to the accessible environment from all significant processes and events that may affect the geologic repository for 10,000 years following permanent closure.

The strategy for the resolution of Issue 1.1 is to determine the contribution to total radionuclide releases to the accessible environment during the next 10,000 yr of all scenarios involving processes and events which are sufficiently credible to warrant consideration and to construct a complementary cumulative distribution function (CCDF) for the cumulative radioactivity (in curies) released to the accessible environment in the 10,000-yr period following closure. Generic lists of processes and events that could affect a repository system are evaluated together with site-specific information to identify the significant process and events. Significant processes and events are those that could have a significant impact on the characteristics of the system important to waste isolation and that are sufficiently credible to warrant consideration. Scenarios, based on the set of significant process and events, are then developed for both undisturbed and disturbed conditions. Undisturbed conditions are the natural processes and events that are likely to occur given the modifications that result from the repository construction and waste emplacement. Disturbed conditions are the natural processes and conditions and human activities that are considered unlikely yet sufficiently credible to warrant consideration. Mathematical models for each scenario class are constructed to calculate the cumulative normalized releases from the occurrence of each scenario. The release values are then used to construct the CCDF as advocated by the regulations.

Because of the variety of scenarios that must be addressed, various barriers are relied upon. In general, the primary barriers to be relied upon for release scenarios involving liquid-water transport include the unsaturated zone beneath the repository (primarily the Calico Hills nonwelded unit), with the saturated zone used as a backup. For release scenarios involving gaseous transport, the EBS is the primary barrier, with the overburden as a backup.

Evaluation of potential impacts

Construction and operations of the ESF are not expected to alter the physical characteristics of the natural geologic setting so as to have a significant effect on releases to the accessible environment. As discussed in the introduction, the primary potential impacts to performance of the total system are the creation of openings and the associated disturbed zone, thereby creating potential pathways for water and air flow after construction, and the introduction of solid materials and fluids during ESF construction and testing.

Fernandez et al. (1987) have analyzed the potential for both gaseous and liquid flow through the exploratory shafts and the construction-induced zone of modified rock characteristics surrounding the openings. The potential impacts of drifts in the testing area of the ESF and the long exploratory drifts are expected to be similar, but not greater, than the impacts caused by the exploratory shafts. Therefore, much of the following discussion focuses on the exploratory shafts. The features of the exploratory shaft that should be considered during the postclosure phase are the shaft fill,

the shaft liner, and the zone of increased rock permeability around the shaft (the Modified Permeability Zone, MPZ) is discussed in Case and Kelsall (1987). Determinations of both expected and maximum increases in permeability.

Fernandez et al. (1987) address the potential for the exploratory shafts to create preferential pathways for water and air flow. Scenarios have been considered in which water enters the top of the exploratory shafts and migrates downward through the shaft backfill and the MPZ to a sump at the base of ES-1. Water entering the ESF will drain away from the waste emplacement areas and toward the ES-1 (Figure 8.4-28) and flow from there to the sump at the base of ES-1. The long exploratory drifts that will be mined within the ESF are a special case and will be designed to meet permanent repository standards. These drifts will be graded to control any water entering them (see Figure 8.4-9) and hydraulically isolate the ESF from the rest of the underground facility (see Figure 8.4-10). Fernandez et al. (1987) show that, for the majority of scenarios analyzed, no water enters the ESF test area or drifts because the water can be effectively drained at the base of the shafts. Water was able to enter the ESF drifts and test area for only two of the scenarios analyzed, and the flow was computed to be low and easily contained within the ESF, not reaching any waste. It was assumed by Fernandez et al. (1987) that the saturated hydraulic conductivity of the shaft fill is 10^{-2} m/s and the shaft liner below the repository station would be removed. Hence, analysis suggests that the exploratory shafts, as currently designed, will not affect releases to the accessible environment by allowing surface water to enter repository areas.

The worse-case scenario considered by Fernandez et al. (1987) assumes that all water from a probable maximum flooding event is restricted in an alluvial basin adjacent to the shaft allowing water to drain into the shaft. Because water entering the shaft is contained within the shaft sump and the ESF, water does not enter the emplacement panels. Therefore, it is concluded that the exploratory shafts do not affect the repository performance by allowing surface water to enter repository areas. This worst-case scenario is considered highly unlikely since the currently planned exploratory shaft locations are well above flood levels for a probable maximum flooding event and are not located in alluvium. These considerations further reduce the likelihood that the ESF will have any effect on repository performance.

Convective air transport of gases through drifts and shaft was also evaluated in Fernandez et al (1987). Gaseous transport may be induced by either thermal energy differences within the repository or barometric pressure variations.

The first convective air flow analysis modeled the temperature variation within the repository and determined that air would rise up the exploratory shaft and be drawn in through peripheral ramps and shafts. The analyses also considered flow through rock above the waste disposal area. For several combinations of host rock air conductivity above the repository, the fraction of the flow through the shaft fill and the MPZ to the total flow through the rock mass above the waste disposal areas, as well as through the shaft fill and the MPZ, was determined. It was concluded from the analysis that shafts and ramps, in general, and the exploratory shafts in particular, are not preferential pathways for gaseous radionuclide release if air conductivity of

the shaft fill is less than 3×10^{-4} m/min or an equivalent hydraulic conductivity of 10^{-2} cm/s. This condition is expected to be met.

The second air flow analysis considered barometric pressure changes and modeled air flow both in and out of the repository in response to these changes. Possible flow paths included all shafts and ramps in addition to the host rock. As before, conductivities were varied to determine the magnitude of the air flow as well as the ratio of air flow through the shafts and MPZ to the total flow. Because of the total volume of air mass and the cyclic nature of barometric pressure changes, it was concluded that this mechanism contributes negligibly to any airborne radioactive release.

The primary impact of solid materials introduced to the site is expected to be from chemical interactions of the shaft liner with ground water. There exists a potential to form precipitates in the MPZ and the shaft fill. This precipitation is a consequence of water chemistry changes as alkali is leached from the concrete liner. Analyses presented in Fernandez et al. (1987) indicate that these precipitates will be deposited very near to the point of their nucleation so that these effects will be very localized. Additionally, the deposited precipitates will tend to reduce the hydraulic conductivity of both the MPZ and the shaft backfill, to further reduce air flow and water entry into the ES. As discussed in Section 8.4.6.2, transport of small amounts of other materials retained from construction and testing will be primarily by ground-water flow. Since the water is expected to flow predominantly vertically, these materials also should neither contact waste packages nor affect releases from the EBS.

It is expected that fluids introduced by ESF construction and testing will have no significant impact on the performance of the total system, for reasons similar to those presented in section 8.4.2.6.2. As described in that section, the amount of water retained in the walls and ceilings of the ESF will be small since the injection pressure of water used during construction will be low. It is expected that retained water will be a local effect near the shafts and drifts and will probably drain vertically down through the unsaturated zone. The ventilation system will remove some of the water retained during construction and testing before emplacement of waste, further reducing the potential for construction water to affect the performance of the EBS. Also, the drifts are designed so that fluids in the drifts will drain toward ES-1. Fluids that enter the host rock during construction and testing are expected to remain well within 30 m of the ESF, not move laterally into the vicinity of the waste package, and not affect releases from the total system.

In summary, potential impacts of ESF construction and testing on performance are not expected to be significant because (1) the exploratory shafts will be located where water is not likely to enter, (2) any water entering the shafts will drain from the sump of ES-1, (3) liquid movement is expected to be vertically downward, (4) the drainage pattern in the ESF is away from waste-emplacement panels, (5) damage to the rock mass surrounding openings is limited to a few meters, (6) liquids introduced by construction and testing are expected to move only a short distance (several meters) into the rock, (7) the ESF is laterally separated from waste-emplacement panels by at least 30 m, (8) a significant volume of water will be removed by ventilation, (9) air and water flow through the shaft can be controlled

effectively by the emplacement of a shaft fill, and (10) deposition of solids from chemical interactions of the shaft liner with ground water will be a localized phenomena and should not decrease the drainage capacity of the rock at the base of the shaft.

8.4.2.7 Relationship of the exploratory shaft facility and the conceptual repository design

If the Yucca Mountain site is shown to be suitable and is selected for the waste repository, the exploratory shaft facility (ESF) will be incorporated into the repository. The relationship between the ESF and the repository is shown in Figure 8.4-30. It is likely that both shafts will be used as a source of intake air for the Phase I repository operations. It is currently envisioned that exploratory shaft 1 (ES-1) will be used as the primary source of intake air for the waste-emplacement operations. For this provision, all ES-1 internals would be removed before these operations, leaving only the concrete liner and provisions for shaft and liner inspection conveyances. Likewise, exploratory shaft 2 (ES-2) would be used as a source of intake air during repository operations to ventilate the repository shop facilities supporting waste-emplacement operations. However, since the volume of air required to ventilate these areas from ES-2 would be minimal, the internal features and the hoist hardware could be left in place without hindering the ventilation function during repository operations. Both shafts would continue to have scheduled inspections. Additionally, if the shaft internals for ES-2 are left in place, the shaft could continue to be used as an emergency exit.

8.4.2.8 Exploratory shaft facility construction and testing summary schedule

A logic diagram which shows the relative duration and sequencing of major exploratory shaft construction- and testing-related activities is provided in Section 8.5.1.2. The summary schedule is provided to show approximately when each of the ESF tests will begin relative to the construction operations. The sequencing of tests on the main test level is still under evaluation and is based on complex construction operations, scientific considerations, and probable test durations.

Figure 8.4-30. Relationship of exploratory shaft facility and the conceptual repository design. Dashed line shows the conceptual layout of the repository.

Chapter 8

Nuclear Waste Policy Act
(Section 113)

Section 8.5

*Consultation Draft*MILESTONES,
DECISION POINTS
AND SCHEDULE

Site Characterization Plan

*Yucca Mountain Site, Nevada Research
and Development Area, Nevada*

Volume VII

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*U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585*

8.5 MILESTONES, DECISION POINTS, AND SCHEDULE

This section presents the milestones, decision points, and summary schedule information established for the site characterization program for the Yucca Mountain site through the submittal of the license application to the Nuclear Regulatory Commission (NRC). This information represents a summary of the schedule information provided in Section 8.3, which includes the sequencing, interrelationships, and relative durations of the studies and activities described in each site investigation and performance assessment or design information need. Specific durations, and start and finish dates for the studies and activities are being developed as part of ongoing planning efforts, and improved information should be available at the time the SCP is issued. Schedule information will then be updated, as appropriate, in subsequent semiannual progress reports. No specific dates or absolute timelines have been specified in this section except in Table 8.5-1 in Section 8.5.6.

Section 8.5.1 presents summary schedule and milestone information related to the site programs described in Section 8.3.1 and includes an exploratory shaft logic diagram showing the relative duration and sequencing of construction- and testing-related activities. Section 8.5.2 presents summary schedule and milestone information for preclosure and postclosure performance assessment issues. Summary schedule information for both preclosure and postclosure repository design issues and for the seal design issue are presented in Section 8.5.3. Section 8.5.4 presents summary schedule information associated with waste package design issues while Section 8.5.5 provides a list of the major decision points and presents a simplified flow diagram showing the interfaces among these decision points. Section 8.5.6 presents a summary schedule for the program elements covered in Sections 8.5.1 through 8.5.4.

The points shown on the timelines presented in Sections 8.5.1 through 8.5.4 represent major events or important summary milestones associated with the investigations or information needs presented in Section 8.3. The milestones selected for presentation in Section 8.5.6 are the major integration products from the activities presented in Sections 8.5.1 through 8.5.4. Regulatory and institutional milestones have been added, as appropriate, to complete the schedule.

The information provided in this section should be viewed as a snapshot in time with regard to planned site characterization activities and the schedule for those activities. The site characterization program will undergo a series of refinements, beginning with changes resulting from review of the consultative draft of the SCP by the State, Tribes, and the NRC. The opportunity to preliminarily review and comment on the SCP and interact with the Department of Energy (DOE) on substantive technical issues prior to final production of the SCP may result in the need for some revision in the scope of activities and the schedule for these activities. Revisions required as a result of consultations with the State, Tribes, and the NRC would be considered in the ongoing planning efforts, and would be reflected, as appropriate, in the SCP at the time of issuance. Further revisions to the scope of activities and schedules may be required as a consequence of the NRC

and State review of the document to evaluate the data to be obtained and to assess the adequacy of the planned activities. These revisions would be presented in the semiannual SCP progress reports.

8.5.1 SITE CHARACTERIZATION ACTIVITIES AND MILESTONES

The site programs described in Section 8.3.1 do not directly tie to regulatory requirements in the manner that the performance and design issues do. Instead, site programs have been structured to address acquisition of data on present and expected site characteristics, processes, and events needed to develop site descriptions and to support the resolution of design and performance issues. The performance and design issues were derived from the regulations, thus providing an indirect tie from the site programs to the regulations. The issue resolution strategies presented in Section 8.2 and discussed in greater detail in Sections 8.3.2 through 8.3.5 identified the site data required to support the resolution of the design and performance issues that are tied directly to the NRC (10 CFR Part 60) and other regulatory requirements. This includes data required to support the higher level findings on the DOE general siting guidelines (10 CFR Part 960). On the basis of these strategies, the site testing program has been designed to obtain sufficient data to satisfy these requirements.

The following section, 8.5.1.1, provides summary schedule information associated with the site program. A logic diagram showing the relative duration and sequencing of major exploratory shaft construction- and testing-related activities is provided in Section 8.5.1.2. Section 8.5.1.3 presents the list of site characterization study plans. Study plans will contain schedule and milestone information to supplement that presented in the SCP.

8.5.1.1 Site programs

Summary schedule information for each site program described in Section 8.3.1 is provided in this section in the form of timelines. The schedule information presented in the figures that follow has been grouped by site program as follows:

1. Geohydrology program
2. Geochemistry program
3. Rock characteristics program
4. Climatology program
5. Erosion program
6. Postclosure tectonics program
7. Human interference program
8. Meteorology program
9. Offsite installations program
10. Surface characteristics program
11. Thermal and mechanical rock properties program
12. Preclosure hydrology program
13. Preclosure tectonics program

Each investigation within a site program is represented by a timeline. The length of the timeline representing the investigation is proportional to the investigation duration. Points shown on the timelines represent major events or important milestones associated with the investigation. Solid lines represent investigation durations and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.

GEOHYDROLOGY PROGRAM (SECTION 8.3.1.2)

Results of the studies under this program will be used in the resolution of Issues 1.1 and 1.6 (total system performance and pre-waste-emplacement ground-water travel time, respectively). The activities in this investigation will progress in parallel with the activities necessary to resolve performance and design issues.

The points on the timelines and the data input and output are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone Z491. Report available on the refinement of the three-dimensional ground-water flow model.
2	Three-dimensional ground-water flow model will be used in the studies of Investigations 8.3.1.5.2 and 8.3.1.8.3 to test the impacts of possible future ground-water developments, tectonic activity, and climatic changes on the saturated hydrologic system.

CONSULTATION DRAFT

- 3 Milestone Q044. Report available on the characterization of the Yucca Mountain regional hydrologic system.

<u>Point number</u>	<u>Description</u>
4	Meteorological and runoff data input to infiltration study.
5	Milestone Z483. Issue report on the preliminary hydrologic description of the unsaturated zone at Yucca Mountain.
6	Analyses as part of the unsaturated zone flow and transport modeling study and system analysis and integration study will be used toward the resolution of Issues 1.1 (total system performance) through 1.6 (ground-water travel time).
7	Milestone M391. Issue report on the hydrologic description of the unsaturated zone at Yucca Mountain.
8	Milestone P897. Issue report on the preliminary hydrologic description of the saturated zone for input to the draft environmental impact statement.
9	Milestone M389. Issue report on the description of the site saturated zone hydrology at Yucca Mountain.

GEOCHEMISTRY PROGRAM (SECTION 8.3.1.3)

The results of studies under this program will be used in the resolution of Issue 1.1 (total system performance). The geochemical retardation that can be relied upon in the rock units between the repository and the accessible environment is one component of the strategy for meeting the release limits specified in the regulations. The activities in this investigation will progress in parallel with activities supporting resolution of the performance and design issues.

INVESTIGATION

8.3.1.3.1
Water
chemistry

8.3.1.3.2
Mineralogy,
petrology and rock
chemistry

8.3.1.3.3
Minerals/glass
stability

8.3.1.3.4
Radionuclide
retardation –
sorption
processes

8.3.1.3.5
Radionuclide
retardation –
precipitation
processes

8.3.1.3.6
Radion. retard. –
dispersion, diffu-
sive, and advective
transp. processes

8.3.1.3.7
Radionuclide
retardation –
all processes

8.3.1.3.8
Gaseous
radionuclide
retardation

Start exploratory shaft

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone M374. Final report available on ground-water chemistry model.
2	Milestone Q030. Summary report available on alteration history.
3	Milestone Q001. Report available on the summary results defining the geochemical characteristics (mineralogy-petrology, mineral stability, and water chemistry) at Yucca Mountain.
4	Milestone R360. Final report available on conceptual model of mineral evolution at Yucca Mountain.
5	Milestone R385. Sorption model complete.
6	Milestone M376. Final sorption report available.
7	Data input on radionuclide retardation by precipitation processes from Investigation 8.3.1.3.5 to Investigations 8.3.1.3.4 and 8.3.1.3.6 for the interpretation of batch sorption and column tests, respectively.
8	Milestone Z224. Final report available on colloid stability and characterization.
9	Milestone M377. Final report available on the solubility of radionuclides in Yucca Mountain water.
10	Data input on dispersion and diffusion from Investigation 8.3.1.3.6 to Investigation 8.3.1.3.7 for geochemical-geophysical model development.
11	Milestone R340. Final report available on unsaturated flow column experiments.
12	Milestone Q038. Summary report available on radionuclide retardation by diffusive, dispersive, and advective processes.
13	Milestone M390. Final geochemical-geophysical model complete.
14	Milestone P381. Final integrated transport calculations available.
15	Milestone Q002. Report available on the summary of results defining radionuclide retardation at Yucca Mountain.

Point
number

Description

16	Complete assessment as to whether calculated gas transport rates with their associated uncertainties are adequate to assess gaseous radionuclide releases for performance assessment calculations; results of this assessment will determine whether experimental measurements of radionuclide transport rates and retardation processes are needed to verify calculational models.
17	Report available on the results of experimental measurements of gaseous transport and retardation rates to verify calculational models (assuming the experimental measurements are necessary).

ROCK CHARACTERISTICS PROGRAM
(SECTION 8.3.1.4)

Results of studies in this program will be used to develop an integrated drilling program for the Yucca Mountain site, to better define the geologic framework of the site, and to produce a three-dimensional rock characteristics model for the site. This information will be useful in the resolution of a number of performance and design issues, including Issues 1.1 (total system performance), 1.6 (pre-waste-emplacement ground-water travel time), and 1.11 (configuration of underground facilities).

CONSULTATION DRAFT

The points on the timeline and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone Q085. Produce integrated drilling plan for the first year of site characterization.
2	Results of integrated drilling plan for second year of site characterization available to Investigation 8.3.1.4.3.
3	Milestone Q120. Complete all borehole construction and testing for licensing application.
4	Milestone Q121. Issue final report on integration of site characterization borehole construction.
5	Milestone P780. Issue final geologic map of Yucca Mountain.
6	Milestone R757. Complete alteration and fracture mineralogy studies.
7	Milestone Z263. Complete vertical seismic profiling studies.
8	Milestone Q117. Complete drilling of geologic holes.
9	Milestone M384. Complete final 3-D geologic model of the site area.
10	Milestone Q101. Complete Phase I of performance assessment drilling program.
11	Milestone Q118. Complete Phase II of performance assessment drilling (representative sampling) program.
12	Milestone Q006. Complete final reference model for 3-D rock characteristics of Yucca Mountain.

CLIMATE PROGRAM (SECTION 8.3.1.5)

Results of studies in this program will be used to support the resolution of Issue 1.1 (total system performance). Expected changes in climatic conditions over the next 10,000 yr are important for predicting if releases of radionuclides to the accessible environment are likely to comply with the regulatory limits.

CONSULTATION DRAFT

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Data input from meteorology program (Section 8.3.1.12) and geohydrology program (Section 8.3.1.2).
2	Milestone P101. Report available on characterization of the present regional climate and environment.
3	Input from climate information relevant to Quaternary faulting in the site area to Investigation 8.3.1.17.4 (preclosure tectonics data collection and analysis).
4	Milestone M366. Define Quaternary climate of Yucca Mountain.
5	Conceptual model of calcite-silica deposits available for Issue 1.1 (total system performance, Section 8.3.5.13) and for the postclosure tectonics program (Section 8.3.1.8).
6	Milestone P104. Report available on future climate as predicted from models based on the nature and rates of change in climatic conditions.
7	Final input regarding future climate as predicted from models is available for use in Investigation 8.3.1.5.2.
8	Milestone Q162. Report available on potential effects of future climate conditions on hydrologic characteristics at Yucca Mountain.
9	Final input to Issue 1.1 (total system performance) on effects of future climatic change on the hydrologic system.

CONSULTATION DRAFT

EROSION PROGRAM (SECTION 8.3.1.6)

Studies in this program will document the predicted impacts of erosion on the performance of a repository at Yucca Mountain. A series of topical reports are planned to demonstrate that the overall impacts of erosion at the Yucca Mountain site are likely to be insignificant.

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone Z286. Complete development of geomorphic map of Yucca Mountain.
2	Information received from climate investigations 8.3.1.5.1 and 8.3.1.5.2.
3	Milestone Z290. Issue topical report on the evaluation of the impact of future climatic conditions on locations and rates of erosion.

- 4 Information received from postclosure tectonics (Investigation 8.3.1.8.2).
- 5 Milestone Z292. Issue topical report on the evaluation of the impact of future uplift/subsidence and faulting on erosion at Yucca Mountain and vicinity.
- 6 Information received from the geohydrology, geochemistry, and rock characteristics programs (Sections 8.3.1.2, 8.3.1.3, and 8.3.1.4).
- 7 Milestone Z294. Issue topical report on the evaluation of future erosion on baseline conditions at Yucca Mountain and vicinity.
- 8 Milestone Z498. Issue topical report on the effects of erosion on postclosure containment and isolation at Yucca Mountain.

POSTCLOSURE TECTONICS PROGRAM (SECTION 8.3.1.8)

Results of the studies in this program will be used to support the resolution of a number of performance and design issues, including Issues 1.1 (total system performance), 1.8 (NRC siting criteria), 1.11 (configuration of the underground facilities), and Issue 4.4 (preclosure design and technical feasibility). Scenarios resulting from tectonic processes and events will be considered in the evaluation of the cumulative radionuclide releases over 10,000 yr in Issue 1.1.

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone Z378. Summary report available on effects of igneous and volcanic effects.
2	Probability calculations for risk assessment as well as other results of the investigation input to Issue 1.1 (total system performance).
3	Milestones Z379, Z380, and Z382. A series of reports to be available for use by Issue 1.11 (configuration of underground facilities (postclosure)) assessing the effects of faulting, folding, deformation, and igneous intrusive processes on the waste packages, and on expected repository ground motions during the postclosure period (Milestone Z381).

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
4	Milestones Z384, Z383, and Z393. A series of reports is available for use by Issue 1.1 assessing the effects of volcanism, faulting, folding, uplift, and subsidence on flux rates.
5	Milestones Z385, Z386, and Z388. A series of reports is available for use by Issue 1.1 assessing the effects of igneous intrusions, strain changes, faulting, folding, uplift and subsidence on water-table elevations.
6	Milestones Z389, Z390, Z391. A series of reports is available for use by Issue 1.1 assessing the effects of igneous intrusions, faulting, and stress and strain changes on local fracture permeability and effective porosity.
7	Milestones Q149, Z397, Z398, and Z399. A series of reports is available for use by Issue 1.1 assessing the effects of igneous intrusions, faulting, or tectonically induced changes in water-table elevation on rock geochemical properties along likely travel pathways.
8	Milestone Z302. Report available on evaluation of folds in Neogene rocks of the region.
9	Milestone Z409. Report available on geochemical cycles of basalt fields of the Great Basin.

HUMAN INTERFERENCE PROGRAM (SECTION 8.3.1.9)

Results of studies in this program will be used to establish that markers and monuments will remain effective for the time specified in the regulations. The likelihood of human interference related to natural resources will be considered in the calculation of total releases to the accessible environment over 10,000 yr as required for the resolution of Issue 1.1 (total system performance).

The points on the timeline and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Data input from investigations examining volcanic eruption, repository igneous intrusion, waste package rupture due to tectonic processes and events, and modern regional climate (8.3.1.8.1, 8.3.1.8.2, 8.3.1.8.5 and 8.3.1.5.1) for activities examining tectonic activity and erosion and future climate and erosion (8.3.1.6.3.1.1 and 8.3.1.6.2.1.1).
2	Milestone Z472. Issue report synthesizing the natural processes that could affect marker survivability.
3	Milestone T082. Issue final report on the evaluation of natural resources at Yucca Mountain and vicinity.
4	Milestone R676. Issue report on factors contributing to the likelihood of human interference and intrusion events at Yucca Mountain.
5	Milestones Z473 and Z474. Issue reports on potential effects of exploiting ground water and the assessment of unlikely events of human interference.

METEOROLOGICAL PROGRAM (SECTION 8.3.1.12)

Results of the studies and monitoring performed in this program will be used to support issue resolution of a number of preclosure issues concerned with radiological safety, including Issues 2.1 (public radiological exposures--normal conditions), 2.2 (worker radiological safety--normal conditions), 2.3 (accidental radiological releases), and 2.7 (repository design criteria for radiological safety). The activities in this program will proceed in parallel with the performance and design activities.

The points on the timelines are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone Q032. Issue report on regional meteorological conditions.
2	Milestone M393. Issue five-year summary report on meteorological conditions.
3	Milestone Q033. Issue report on extreme weather phenomena and expected recurrence intervals at Yucca Mountain.

CONSULTATION DRAFT

OFFSITE INSTALLATIONS PROGRAM (SECTION 8.3.1.13)

Results of the activities of this program will be used to support the resolution of a number of preclosure issues concerned with radiological safety requirements, including Issues 2.1 (public radiological exposures--normal conditions), 2.2 (worker radiological safety--normal conditions), 2.3 (accidental radiological releases), 2.5 (higher level findings--preclosure radiological safety), and 2.7 (repository design criteria for radiological safety). The activities in this program will proceed in parallel with the performance and design activities.

The points on the timelines are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Data collection for the identification of near-site activities is complete.
2	Complete data collection for the identification of all nuclear facilities.
3	Issue report on alternative rail access spur screening.
4	Issue final report on U.S. Air Force overflight impacts.
5	Select rail access route to repository.
6	Milestone N338. Issue report on the characterization of the existing radiological environment.

SURFACE CHARACTERISTICS PROGRAM
(SECTION 8.3.1.14)

Results of the studies in this program will be used in the design and siting of surface repository facilities at the Yucca Mountain site. The principle issue concerned with surface-facility design is Issue 4.4 (preclosure design and technical feasibility). This program will proceed in parallel with the activities supporting resolution of the performance and design issues.

The points on the timeline and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone Z413. Issue report on the results of the geotechnical exploration program for surface-facility advanced conceptual design (ACD) at Yucca Mountain.
2	Milestone Z415. Issue report on the results of geotechnical field tests and characterization measurements for surface-facility ACD at Yucca Mountain.
3	Material property and geophysical field measurement data available to Investigation 8.3.1.17.3 (vibratory ground motion).
4	Milestone Z417. Issue update report on the results of geotechnical laboratory tests and material property measurements for surface-facility ACD at Yucca Mountain.
5	Milestone Q150. Issue summary report on rock and soil properties at the reference conceptual site.

CONSULTATION DRAFT

THERMAL AND MECHANICAL ROCK PROPERTIES PROGRAM (SECTION 8.3.1.15)

Results of the studies in this program will be used in the design of the underground repository facilities. Issue 1.11 (configuration of underground facilities) will use the stratigraphic data, the information on geologic structure, and information on thermal and mechanical rock properties to develop appropriate layouts for the underground repository facilities.

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Input of Phase I performance assessment drilling results from Investigation 8.3.1.4.3 (development of 3-D models of rock characteristics at the repository site).
2	Milestone M058. Issue final report on the thermal, thermo-mechanical, and mechanical properties of material from shaft construction.
3	Milestone M445. Update document on thermomechanical properties for license application.
4	Milestone M691. Issue report on the results of the canister-scale heater experiments in the ESF.

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
5	Milestone M687. Issue report on overcore stress experiments.
6	Issue summary report on the results of in situ studies in the site vicinity.

PRECLOSURE HYDROLOGY PROGRAM (SECTION 8.3.1.16)

Results of studies in this program will be used to support resolution of Issue 4.4 (preclosure design and technical feasibility). Potential flooding hazards will be considered in the design and placement of surface facilities. This program will provide input to the plans being developed for obtaining the water necessary to support repository-related activities.

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Data input from Sections 8.3.1.2 (geohydrology program), 8.3.1.5 (climate program), 8.3.1.12 (meteorology program), and 8.3.1.14 (surface characteristics program).

CONSULTATION DRAFT

- 2 Milestone P923. Issue report summarizing prehistoric flooding at Yucca Mountain.
- 3 Milestone P935. Issue report summarizing modern flooding events and debris transport.
- 4 Milestone P787. Issue report on predictions of future flooding and debris movement due to climate changes.
- 5 Milestone Z494. Issue report on characterization of runoff and streamflow for Yucca Mountain and vicinity.
- 6 Milestone Z246. Issue report on repository-related water supply alternatives.
- 7 Data input from Section 8.3.1.2 (geohydrology program) and advanced conceptual design.
- 8 Milestone T040. Issue final report on the potential effects of water withdrawals on the local flow system.
- 9 Data input from Section 8.3.1.2 (geohydrology program).
- 10 Milestone Q124. Issue report on ground-water conditions within and above the potential host rock.

PRECLOSURE TECTONICS PROGRAM (SECTION 8.3.1.17)

Results of the studies in this program will be used to support the resolution of Issue 4.4 (preclosure design and technical feasibility). Designs of the surface and underground facilities will account for all aspects of the seismic hazards recognized at the Yucca Mountain site. Hazards due to volcanic activity and to both vibratory ground motion and surface faulting will be identified through activities in this program. Repository design activities will continue in parallel with the studies in this program.

CONSULTATION DRAFT

The points on the timelines and the data input and output at the interfaces are shown in the following table:

Point number	Description
1	Milestone Q144. Report on volcanic ash-fall potential at the site. This information will be considered in both the advanced conceptual and license application designs of the surface and underground ventilation systems.
2	Initiation of investigation requires: information from Investigation 8.3.1.17.4 (data collection and analysis); preliminary results from trenching in Midway Valley; preliminary interpretation of tectonic interrelationships between local faults; preliminary information on fault-zone widths and recurrence of movement on potentially significant faults within 5 km of proposed sites for surface facilities that are potentially important to safety; preliminary identification of faults in or near the repository block with 1 m offset of Quaternary materials, 100 m offset of Tertiary rocks, or Quaternary slip rates ≥ 0.005 mm/yr; preliminary information on the regional spacing and rate of Quaternary faulting; and tectonic relationships between local faults.

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
3	Milestone Q147. Final report on the assessment of the potential for faulting at the sites of prospective surface facilities.
4	Milestone Q148. Final report on the assessment of the potential for displacement on faults that intersect underground facilities.
5	Input to license application design on assessment of the potential for displacement on faults that intersect underground facilities.
6	Description available of strong ground motion to be considered in the advanced conceptual design of a high-level nuclear waste repository at Yucca Mountain.
7	Milestone Q165. Final report available on earthquake ground motion (attenuation) models appropriate for the Yucca Mountain site.
8	Milestone Q167. Final report available on probabilistic seismic hazard analysis of the Yucca Mountain site.
9	Milestone Q169. Report available on the description of strong ground motion to be considered in the license application design of a high-level nuclear waste repository at Yucca Mountain.
10	Milestone P701. Complete preliminary regional tectonic model.
11	Milestone P880. Issue report on Quaternary geology and faults of Yucca Mountain.
12	Milestone P879. Issue summary report on detachment faults at or proximal to Yucca Mountain.
13	Report available on historical and current lateral crustal movement in the Yucca Mountain region.
14	Milestone M383. Issue report on the final tectonic model.

8.5.1.2 Exploratory shaft

The following table presents a list of milestones related to the construction of, and testing in, the exploratory shaft (ES). A logic diagram for these activities is presented in Figure 8.5-1. The diagram has been included to illustrate the sequence of activities planned and the relationships of the various activities to the construction schedule and to each

Figure 8.5-1. Logic diagram for the exploratory shaft.

other. It should be recognized that certain in situ tests will be continued for confirmatory purposes after the license application has been submitted.

Milestone number	Related SCP section	Milestone description
CONSTRUCTION-RELATED ACTIVITIES AND MILESTONES		
M642	NA ^a	Issue revised surface Title II design
M645	8.4.1	Start exploratory shaft (ES) site preparation
M652	8.4.2.1	Start ES-1 shaft construction
R013	8.4.1	Start construction of surface facilities
M647	8.4.2.2	Start ES-2 shaft construction
M089	8.4.2.1	Complete ES-1 upper break-out room (600-ft level)
M646	8.4.1	Complete surface facility construction
M093	8.4.2.2	Complete ES-2 1,055-ft level breakout room
T153	8.4.2.1	Complete ES-1 excavation to 1,020-ft breakout level
M643	8.4.2.2	Complete ES-2 shaft construction
M095	8.4.2.1	Complete ES-1 drillroom 1,360-ft level
M654	8.4.2.1	Complete ES-1 shaft liner and internals
R569	8.4.2.2.2	Complete connection of ES-1 to ES-2
R572	NA	Test bed cables terminated
M656	8.4.2.4	Complete geologic drifting
M655	8.4.2.2	Complete ES-2 1,055-ft level testbed excavation
P750	NA	Complete ESF Title III design

TESTING-RELATED ACTIVITIES AND MILESTONES

M612	NA	Start ES construction phase testing
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CONSULTATION DRAFT

Milestone number	Related SCP section	Milestone description
TESTING-RELATED ACTIVITIES AND MILESTONES (continued)		
P751	NA	Complete construction phase testing
R570	NA	Start in situ phase testing
M688	8.3.1.15.1.5.2	Begin demonstration breakout room testing
M609	8.3.1.15.1.5.2	Complete report on demonstration breakout room testing
M686	8.3.1.15.1.5.1	Begin shaft convergence test
M620	8.3.1.15.1.5.1	Complete shaft convergence testing data report
M602	8.3.1.15.2.1.2	Begin overcore stress experiments
M687	8.3.1.15.2.1.2	Complete report on overcore stress experiments
M689	8.3.1.15.1.5.3	Begin sequential drift mining evaluations
M627	8.3.1.15.1.5.3	Complete sequential drift mining evaluations report
M675	8.3.1.4.2.2.4	Begin shaft wall mapping
M619	8.3.1.4.2.2.4	Complete shaft wall mapping report
M693	8.3.1.2.2.2.1	Begin chlorine-36 dating pore water test
M623	8.3.1.2.2.2.1	Complete chlorine-36 analysis report
N601	8.3.1.15.1.6.1	Begin small scale heater experiment
N602	8.3.1.15.1.6.1	Complete final report on small scale heater experiment results
M674	8.3.1.15.1.7.1	Begin plate loading testing
M697	8.3.1.15.1.7.1	Complete final report on plate loading testing
M882	8.3.1.2.2.4.5	Begin excavation effects test
T081	8.3.1.2.2.4.5	Complete report on the results of the excavations effects test
M604	8.3.1.2.2.4.7	Begin perched-water test

Milestone number	Related SCP section	Milestone description
TESTING-RELATED ACTIVITIES AND MILESTONES (continued)		
M694	8.3.1.2.2.4.7	Complete report on the results of the perched-water test
M698	8.3.1.15.1.7.2	Begin slot strength testing
N600	8.3.1.15.1.7.2	Complete final report on slot strength testing
M690	8.3.1.15.1.6.3	Begin Yucca Mountain heated block experiment
M631	8.3.1.15.1.6.3	Complete report on the results of the Yucca Mountain heated block experiment
M680	8.3.1.2.2.4.8	Begin hydrochemistry tests
M617	8.3.1.2.2.4.8	Complete final report on the results of hydrochemistry tests
M648	NA	Preliminary in situ test data available for draft environmental impact statement (DEIS)
M603	8.3.1.15.1.6.2	Begin canister scale heater experiments
M691	8.3.1.15.1.6.2	Complete report on the results of canister scale heater experiments
M696	8.3.1.2.2.5.1	Begin diffusion test
M633	8.3.1.2.2.5.1	Complete final report on the results of diffusion tests
M681	8.3.1.2.2.4.4	Begin radial borehole tests
M640	8.3.1.2.2.4.4	Complete report on the results of the radial borehole tests
M657	NA	ESF testing complete
M682	8.3.1.2.2.4.1	Begin intact fracture tests
M625	8.3.1.2.2.4.1	Complete report on the results of intact fracture tests
M683	8.3.1.2.2.4.3	Begin bulk-permeability tests

CONSULTATION DRAFT

Milestone number	Related SCP section	Milestone description
TESTING-RELATED ACTIVITIES AND MILESTONES (continued)		
M626	8.3.1.2.2.4.3	Complete report on the results of the bulk-permeability test
M685	8.3.1.2.2.4.6	Start hydrologic testing of the Calico Hills
M635	8.3.1.2.2.4.6	Complete report on the hydrologic testing of the Calico Hills
M699	8.3.4.2.4.4	Begin waste package system test
M650	8.3.4.2.4.4	Complete final report on the results of the waste package system test
M684	8.3.1.2.2.4.2	Begin infiltration test
M639	8.3.1.2.2.4.2	Complete report on the results of the infiltration test
M658	NA	Complete documentation of ES test results for license application (LA)

^aNA = not applicable

8.5.1.3 Site characterization study plans

The following table provides a list of site characterization study plans which will present details of site-related studies, tests, and analyses and the schedule for those activities as a supplement to the information in this document. Preparation and review of study plans will be staggered depending on when the studies are to commence. The availability of new or updated study plans will be reported in the semiannual SCP progress reports.

Study plans are being prepared to be consistent with agreements between the DOE and the NRC. Detailed technical and compliance reviews will be completed by the DOE. Following these reviews, study plans will then be submitted to the NRC for review and comment and to the State and affected Indian tribes for their information.

Study plan
number^a

Study plan title^b

GEOHYDROLOGY PROGRAM

8.3.1.2.1.1	Characterization of Meteorology for Regional Hydrology
8.3.1.2.1.2	Characterization of Runoff and Streamflow
8.3.1.2.1.3	Characterization of the Regional Ground-Water Flow System
8.3.1.2.1.4	Regional Hydrologic System Synthesis and Modeling
8.3.1.2.2.1	Characterization of Unsaturated Zone Infiltration
8.3.1.2.2.2	Water Movement Tracer Tests Using Chloride and Chlorine-36 Measurements of Infiltration at Yucca Mountain
8.3.1.2.2.3	Characterization of Percolation in the Unsaturated Zone - Surface-Based Study
8.3.1.2.2.4	Characterization of Yucca Mountain Percolation in the Unsaturated Zone - Exploratory Shaft Facility Investigations
8.3.1.2.2.5	Diffusion Tests in the Exploratory Shaft Facility
8.3.1.2.2.6	Characterization of Flux within the Paintbrush Nonwelded Unit in the vicinity of the Ghost Dance Fault
8.3.1.2.2.7	Characterization of Gaseous-Phase Movement in the Unsaturated Zone
8.3.1.2.2.8	Hydrochemical Characterization of the Unsaturated Zone
8.3.1.2.2.9	Unsaturated Zone Flow and Transport Modeling
8.3.1.2.2.10	Unsaturated Zone System Analysis and Integration
8.3.1.2.3.1	Characterization of the Site Saturated Zone Ground-Water Flow System
8.3.1.2.3.2	Characterization of the Site Saturated Zone Hydrochemistry
8.3.1.2.3.3	Saturated Zone Hydrologic System Synthesis and Modeling

GEOCHEMISTRY PROGRAM

8.3.1.3.1.1	Ground-Water Chemistry Model

CONSULTATION DRAFT

Study plan
number^a

Study plan title^b

GEOCHEMISTRY PROGRAM (continued)

8.3.1.3.2.1	Three-Dimensional Mineral Distribution at Yucca Mountain
8.3.1.3.2.2	History of Mineralogic and Geochemical Alteration of Yucca Mountain
8.3.1.3.3.1	Natural Analog of Hydrothermal Systems in Tuff
8.3.1.3.3.2	Kinetics and Thermodynamics of Mineral Evolution
8.3.1.3.3.3	Conceptual Model of Mineral Evolution
8.3.1.3.4.1	Batch Sorption Studies
8.3.1.3.4.2	Biological Sorption and Transport
8.3.1.3.4.3	Development of Sorption Models (Isotherms)
8.3.1.3.5.1	Dissolved Species Concentration Limits
8.3.1.3.5.2	Colloid Behavior
8.3.1.3.6.1	Dynamic Transport Column Experiments
8.3.1.3.6.2	Diffusion
8.3.1.3.7.1	Retardation Sensitivity Analysis
8.3.1.3.7.2	Demonstration of Applicability of Laboratory Data to Repository Transport Calculations
8.3.1.3.8.1	Gaseous Radionuclide Transport Calculations and Measurements

ROCK CHARACTERISTICS PROGRAM (POSTCLOSURE)

8.3.1.4.2.1	Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area
8.3.1.4.2.2	Characterization of the Structural features within the Site Area
8.3.1.4.2.3	Three-Dimensional Geologic Model
8.3.1.4.3.1	Systematic Acquisition of Site-Specific Subsurface Information

Study plan
number^a

Study plan title^b

ROCK CHARACTERISTICS PROGRAM (POSTCLOSURE) PROGRAM (continued)

8.3.1.4.3.2 Three-Dimensional Rock Characteristics Models

CLIMATE PROGRAM

8.3.1.5.1.1 Characterization of Modern Regional Climate

8.3.1.5.1.2 Paleoclimate Study: Lake, Playa, Marsh Deposits

8.3.1.5.1.3 Climate Implications of Terrestrial Paleoecology

8.3.1.5.1.4 Analysis of the Paleoenvironmental History of the Yucca Mountain Region

8.3.1.5.1.5 Paleoclimate-Paleoenvironment Synthesis

8.3.1.5.1.6 Characterization of the Future Regional Climate and Environments

8.3.1.5.2.1 Characterization of the Quaternary Regional Hydrology

8.3.1.5.2.2 Characterization of the Future Regional Hydrology due to Climate Changes

EROSION PROGRAM

8.3.1.6.1.1 Distribution and Characteristics of Present and Past Erosion

8.3.1.6.2.1 Influence of Future Climatic Conditions on Locations and Rates of Erosion

8.3.1.6.3.1 Evaluation of the Effects of Future Tectonic Activity on Erosion at Yucca Mountain

8.3.1.6.4.1 Development of a Topical Report to Address the Effects of Erosion on the Hydrologic, Geochemical, and Rock Characteristics at Yucca Mountain

TECTONICS PROGRAM (POSTCLOSURE)

8.3.1.8.1.1 Probability of a Volcanic Eruption Penetrating the Repository

CONSULTATION DRAFT

Study plan number ^a	Study plan title ^b
TECTONICS PROGRAM (POSTCLOSURE) (continued)	
8.3.1.8.1.2	Effects of Volcanic Eruption Penetrating the Repository
8.3.1.8.2.1	Analysis of Waste Package Rupture due to Tectonic Processes and Events
8.3.1.8.3.1	Analysis of the Effects of Tectonic Processes and Events on Average Percolation Flux Rates Over the Repository
8.3.1.8.3.2	Analysis of the Effects of Tectonic Processes and Events on Changes in Water-table Altitude
8.3.1.8.3.3	Analysis of the Effects of Tectonic Processes and Events on Local Fracture Permeability and Effective Porosity
8.3.1.8.4.1	Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties
8.3.1.8.5.1	Characterization of Volcanic Features
8.3.1.8.5.2	Characterization of Igneous Intrusive Features
8.3.1.8.5.3	Investigation of Folds in Miocene and Younger Rocks of the Region
HUMAN INTERFERENCE PROGRAM	
8.3.1.9.1.1	An Evaluation of Natural Processes That Could Affect the Long-Term Survivability of the Surface Marker System at Yucca Mountain
8.3.1.9.2.1	Natural Resource Assessment of Yucca Mountain, Nevada
8.3.1.9.2.2	Water Resource Assessment of Yucca Mountain, Nevada
8.3.1.9.3.1	Evaluation of Data Needed to Support an Assessment of the Likelihood of Future Inadvertent Human Intrusion at Yucca Mountain as a Result of Exploration and/or Extraction of Natural Resources
8.3.1.9.3.2	An Evaluation of the Potential Effects of Exploiting Natural Resources on the Hydrologic Characteristics at Yucca Mountain

Study plan
number^a

Study plan title^b

METEOROLOGICAL PROGRAM

8.3.1.12.2.1 Meteorological Data Collection at the Yucca Mountain Site

SURFACE CHARACTERISTICS PROGRAM

8.3.1.14.2.1 Exploration Program

8.3.1.14.2.2 Laboratory Tests and Material Property Measurements

8.3.1.14.2.3 Field Tests and Characterization Measurements

ROCK CHARACTERISTICS PROGRAM (PRECLOSURE)

8.3.1.15.1.1 Laboratory Thermal Properties

8.3.1.15.1.2 Laboratory Thermal Expansion Testing

8.3.1.15.1.3 Laboratory Determination of Mechanical Properties of
Intact Rock

8.3.1.15.1.4 Laboratory Determination of the Mechanical Properties of
Fractures

8.3.1.15.1.5 Excavation Investigations

8.3.1.15.1.6 In Situ Thermomechanical Properties

8.3.1.15.1.7 In Situ Mechanical Properties

8.3.1.15.1.8 In Situ Design Verification

8.3.1.15.2.1 Characterization of the Site Ambient Stress Conditions

8.3.1.15.2.2 Characterization of the Site Ambient Thermal Conditions

PRECLOSURE HYDROLOGY PROGRAM

8.3.1.16.1.1 Characterization of Flood Potential of the Yucca Mountain
Site

8.3.1.16.2.1 Location of Adequate Water Supply for Construction,
Operation, Closure, and Decommissioning of a Mined
Geologic Disposal System at Yucca Mountain, Nevada

CONSULTATION DRAFT

Study plan number ^a	Study plan title ^b
	PRECLOSURE HYDROLOGY PROGRAM (continued)
8.3.1.16.3.1	Determination of Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada
	TECTONICS PROGRAM (PRECLOSURE)
8.3.1.17.1.1	Potential for Ash Fall at the Site
8.3.1.17.2.1	Faulting Potential at the Repository
8.3.1.17.3.1	Relevant Earthquake Sources
8.3.1.17.3.2	Underground Nuclear Explosion Sources
8.3.1.17.3.3	Ground Motion from Regional Earthquakes and Underground Nuclear Explosions
8.3.1.17.3.4	Effects of Local Site Geology on Surface and Subsurface Motions
8.3.1.17.3.5	Ground Motion at the Site from Controlling Seismic Events
8.3.1.17.3.6	Probabilistic Seismic Hazards Analyses
8.3.1.17.4.1	Historical and Current Seismicity
8.3.1.17.4.2	Location and Recency of Faulting Near Prospective Surface Facilities
8.3.1.17.4.3	Quaternary Faulting within 100 km of Yucca Mountain, Including the Walker Lane
8.3.1.17.4.4	Quaternary Faulting proximal to Site within Northeast-Trending Fault Zones
8.3.1.17.4.5	Detachment Faults at or proximal to Yucca Mountain
8.3.1.17.4.6	Quaternary Faulting within the Site Area
8.3.1.17.4.7	Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain
8.3.1.17.4.8	Stress Field within and proximal to the Site Area
8.3.1.17.4.9	Tectonic Geomorphology of the Yucca Mountain Region

Study plan
number^a

Study plan title^b

TECTONICS PROGRAM (PRECLOSURE) (continued)

- 8.3.1.17.4.10 Geodetic Leveling
- 8.3.1.17.4.11 Characterization of Regional Lateral Crustal Movement
- 8.3.1.17.4.12 Tectonic Models and Synthesis

SHAFT AND BOREHOLE SEAL CHARACTERISTICS

- 8.3.3.2.2.1 Seal Material Properties Development

WASTE PACKAGE CHARACTERISTICS

- 8.3.4.2.4.1 Characterize Chemical and Mineralogic Changes in the Postemplacement Environment
- 8.3.4.2.4.2 Hydrologic Properties of Waste Package Environment
- 8.3.4.2.4.3 Thermal and Mechanical Attributes of the Waste Package Environment
- 8.3.4.2.4.4 Engineered Barrier System Field Tests

^aStudy plan number corresponds to the SCP section number under which a discussion of the study is provided.

^bStudy plan title corresponds to the appropriate SCP section title.

8.5.2 PERFORMANCE ASSESSMENT ACTIVITIES AND MILESTONES

The elements of performance assessment for a high-level radioactive waste repository can be categorized into calculations covering two distinctly different time periods. The first time period, referred to as the preclosure period, covers the period during repository operation, closure and decommissioning. Calculations must demonstrate compliance with the radiation exposure and radioactive material release limits for the unrestricted area and the exposure limits for repository workers during the period of waste emplacement and until final closure and decommissioning of the repository. The preclosure radiological safety requirements are summarized in Section 8.3.5.1.

The second time period covered by performance assessment calculations is termed the postclosure period which represents the time following

permanent closure of the repository. Calculated releases from the repository must meet the limits specified by the NRC in 10 CFR Part 60. The postclosure performance requirements are summarized in Section 8.3.5.8. Performance requirements apply to the overall geologic repository, the engineered barrier system, the geologic setting (natural barriers), and the waste package.

The following sections provide summary schedule information associated with the performance assessment issues presented in Section 8.3.5. Preclosure and postclosure performance assessment schedule information is treated separately in Sections 8.5.2.1 and 8.5.2.2, respectively.

8.5.2.1 Preclosure performance assessment

Preclosure performance assessment activities and milestones address the requirements for determination of radiation exposures and release of radioactive material. Radiation exposure and airborne concentration limits for workers and the public are established by 10 CFR Part 20. Repository preclosure activities must also comply with certain EPA standards according to 10 CFR Part 60.

Summary schedule information, in the form of timelines, for each preclosure performance assessment issue described in Sections 8.3.5.2 through 8.3.5.5 is given in this section. Information needs within an issue are presented as appropriate. The length of the timeline representing the information need is proportional to the duration of the activities described in the information need. Points shown on the timelines represent major events or important milestones associated with the investigation. Solid lines represent information need activity durations and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.

WASTE RETRIEVABILITY (ISSUE 2.4, SECTION 8.3.5.2)

The activities described in this issue are those addressing the requirement that the repository design, construction, operation, and maintenance must ensure that any or all of the emplaced waste can be retrieved starting at any time up to 50 yr after waste emplacement operations have begun. Activities planned to support resolution of this issue include design analyses and documentation of retrieval conditions for access to waste emplacement boreholes, access to waste containers, borehole access for waste removal, and for transport of retrieved waste to the surface facilities. As with all preclosure design issues, Issue 4.4 (preclosure design and technical feasibility) integrates the requirements for maintaining the retrieval option from Issue 2.4 with other constraints on repository design addressed in other issues to produce reference designs.

PERFORMANCE
ASSESSMENT
INFORMATION
NEED2.4.1
Information
needed2.4.2
Access to
emplacement
boreholes2.4.3
Access to waste
packages2.4.4
Removal of waste
from boreholes2.4.5
Waste transport
and delivery2.4.6
Retrieval
requirements

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Receive and compile requests for input items and information for information needs within this issue (2.4).
2	Milestone Z153. Preliminary report compiling retrieval conditions and performance goals.

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
3	Milestone Z122. Receive design requirements list for license application design (LAD) from Issue 4.4 (technical feasibility).
4	Milestone Z154. Final report compiling retrieval conditions.
5	Milestone Z441. Compile final request for input items from Issue 4.4.
6	Receive final input items on borehole access from Information Needs 4.4.5 (reference preclosure repository design), 4.4.7 (design analyses), and 4.4.9 (underground facility technology).
7	Milestone Z126. Final report on retrieval conditions for access to waste emplacement boreholes.
8	List of final input items related to access to waste emplacement boreholes is available.
9	Receive preliminary input items for compliance analysis from Information Needs 4.4.5, 4.4.7, and 4.4.9.
10	Milestone Z128. Input completed for final report on compliance analysis for retrieval requirements.
11	Receive input items on access to waste containers from Information Needs 4.4.5, 4.4.7, and 4.4.9.
12	Receive advanced conceptual design (ACD) requirements for access to waste containers.
13	Milestone Z134. Input to preliminary report on compliance analysis for retrieval requirements.
14	Receive LAD requirements for access to waste containers.
15	Milestone Z133. Final report on retrieval conditions for access to waste containers.
16	List of final input items related to access to waste containers available for LAD.
17	Milestone Z135. Input to final report on compliance analysis for retrieval requirements.
18	Receive final input on borehole access for waste removal from Information Needs 4.4.5, 4.4.7, and 4.4.9.
19	Milestone Z141. Provide input to preliminary report on compliance analysis for retrieval requirements.

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
20	Milestone Z140. Final report on retrieval conditions for waste removal from emplacement boreholes.
21	List of final input items relative to access for waste removal from emplacement boreholes available.
22	Milestone Z142. Provide input to final report on compliance analysis for retrieval requirements.
23	Receive final input items on retrieved waste transport from Information Needs 4.4.5, 4.4.7, and 4.4.9.
24	Milestone Z148. Input to preliminary report on compliance analysis for retrieval requirements.
25	Milestone Z147. Final report on retrieval conditions for transport of waste to surface facilities.
26	List of final input items related to transport of retrieved waste to surface facilities available.
27	Milestone Z149. Input to final report on compliance analysis for retrieval requirements available.
28	Milestone Z157. Retrievability strategy report.
29	Milestone Z160. Compile LAD requirements for retrievability using reasonably available technology.
30	Receive input items related to reasonably available technology from Information Needs 4.4.3 (plans for repository operation) and 4.4.5 through 4.4.9.
31	List of final items related to retrievability using reasonably available technologies is available.
32	Milestone Z156. Final report on compliance analysis for retrieval requirements available.

PUBLIC RADIOLOGICAL EXPOSURES - NORMAL CONDITIONS (ISSUE 2.1, SECTION 8.3.5.3)

The activities planned to support resolution of this issue address the requirements that radiation exposure to the general public associated with normal conditions during operation, closure, and decommissioning of the repository meet the exposure limits in 10 CFR Part 20 and 40 CFR 191, Subpart A. The activities performed under this issue involve repetitive examination of an evolving design to ensure that the final design meets the established criteria.

CONSULTATION DRAFT

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Input from Milestone P159. Radiological safety analysis for normal repository conditions--advanced conceptual design (ACD) guidance from Issues 2.1 and 2.2.
2	Milestone N464. List of normal conditions, accident scenarios, and source terms for preclosure safety analysis.
3	Input information from site programs 8.3.1.3 (geochemistry), 8.3.1.10 (population density), 8.3.1.12 (meteorology), 8.3.1.13 (offsite installations), and 8.3.1.15 (thermal and mechanical rock properties).
4	Input data/information from preclosure risk assessment methodology: lists of required parameters for preclosure safety analysis.
5	Milestone R784. ACD preclosure safety analysis report.
6	Milestone Z458. Complete development of activities for assessing public radiological safety for license application design.
7	Milestone Z496. Provide preliminary preclosure performance assessment input (radiological safety) in support of the draft environmental impact statement (DEIS).
8	Output radiological safety information to the DEIS.
9	Milestone R780. Issue updated report on radiological safety assessment report to support the final environmental impact statement and license application (includes update of design evaluation if necessary).

WORKER RADIOLOGICAL SAFETY - NORMAL CONDITIONS
(ISSUE 2.2, SECTION 8.3.5.4)

The activities planned to support resolution of this issue include those necessary to demonstrate that the radiological safety of workers during normal operations is guaranteed. The activities performed under this issue will show that the mined geologic disposal system will limit the normal radiation doses to workers during construction, operation, closure, and decommissioning of the repository to less than the limits specified in 10 CFR Part 20.

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Input from Milestone P159. Radiological safety analysis for normal repository conditions. Advanced conceptual design (ACD) guidance from Issues 2.1 and 2.2.
2	Milestone N464. List of normal conditions, accident scenarios, and source terms for preclosure safety analysis.
3	Receive input data/information from site programs 8.3.1.3 (geochemistry), 8.3.1.10 (population density), 8.3.1.12 (meteorology), 8.3.1.13 (offsite installations), and 8.3.1.15 (rock characteristics).
4	Provide radiological safety analysis for normal conditions to Issue 2.7 (repository design criteria for radiological safety).

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<u>Point number</u>	<u>Description</u>
5	ACD preclosure safety analysis report completed (Milestone R784).
6	Provide information/data on safety analysis report to Issue 2.7 (repository design criteria for radiological safety).
7	Milestone Z496. Preliminary preclosure performance assessment input (radiological safety) available in support of the draft environmental impact statement (DEIS).
8	Provide information/data on radiological safety assessment to the DEIS.
9	Milestone R780. Update report on radiological safety assessment to support the final environmental impact statement (FEIS) and license application (includes update of design evaluation, if necessary).
10	Input information from preclosure risk assessment methodology: lists of required parameters for analyses.
11	Milestone Z458. Complete development of activities for assessing public radiological safety for license application design.

ACCIDENTAL RADIOLOGICAL RELEASES (ISSUE 2.3, SECTION 8.3.5.5)

The activities planned to support resolution of this issue include those necessary to show that radiation exposure to the general public and repository workers under credible accident conditions during construction, operation, closure and decommissioning will be kept at safe levels. The activities to be conducted will show that the structures, systems, and components of the repository provide for prevention of accidents and mitigation of consequences. The three approaches that will be used to protect the health and safety of the general public and repository workers are to provide locations that assist in limiting potential radiation exposure from accidents; provide prevention, containment, and mitigation of accident consequences; and provide assurance that repository workers are safe from the effects of offsite accidents.

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The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Radiological safety analysis for accident conditions available (Milestone P160).
2	Milestone N464. List of normal conditions, accident scenarios, and source terms for use in preclosure safety analysis.
3	Receive data/information from site programs 8.3.1.12 (meteorology), 8.3.1.13 (offsite installations), and 8.3.1.16 (preclosure hydrology).
4	Milestone Z478. List of credible accidents completed.
5	Provide list of credible accidents to Issue 2.7 (radiological design criteria).
6	Advanced conceptual design (ACD) preclosure safety analysis report available (Milestone R784).
7	Provide safety analysis information/data to Issue 2.7 (radiological design criteria).
8	Milestone R777. Update preclosure performance assessment input (radiological safety).
9	Provide updated information/data on preclosure performance assessment to FEIS and license application.

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<u>Point number</u>	<u>Description</u>
10	Milestone R780. Issue updated report on radiological safety assessment to support the final environmental impact statement (FEIS) and license application (includes update of design evaluation, if necessary).
11	Provide information/data on radiological safety analysis (a), sensitivity and importance analysis (b), advanced conceptual design (ACD) safety analysis (c), credible and design basis accidents (d), consequence analyses of event trees (d), and preclosure performance assessment (c) to Issue 2.7.
12	Milestone Z461. Issue report on results of consequence analysis of event trees for preliminary ACD.
13	Milestone Z479. Issue report on results of preliminary ACD sensitivity and importance analysis.
14	Receive data/information from site programs 8.3.1.12 (meteorology), 8.3.1.13 (offsite installations), 8.3.1.14 (surface characteristics), 8.3.1.16 (preclosure hydrology) and 8.3.1.17 (preclosure tectonics), and Information Need 4.2.1.
15	Milestone R784. ACD preclosure safety analysis report.
16	Milestone Z482. License application design (LAD) event trees for credible accidents and design basis accidents.
17	Milestone Z462. Issue report on results of consequence analysis of event trees for LAD.
18	Milestone Z480. Issue report on results of LAD sensitivity and importance analysis.
19	Milestone M068. Preclosure performance assessment input for enclosure in license application.

8.5.2.2 Postclosure performance assessment

This section presents summary schedule information for each postclosure performance assessment issue described in Sections 8.3.5.9 through 8.3.5.15. The information presented has been grouped by the principal elements of postclosure performance assessment: overall system performance of the geologic repository, performance of the engineered barrier system and the waste packages, and performance of the geologic setting (natural barriers). These elements represent the primary barriers for which the NRC established performance objectives in 10 CFR 60.112 and 60.113.

Overall geologic repository system performance

The requirement for performance of the overall geologic repository system after permanent closure is established in 10 CFR 60.112. This requirement states that the geologic setting shall be selected and the engineered barrier system and the shafts, boreholes, and their seals shall be designed to ensure that releases of radioactive materials to the accessible environment conform to environmental standards for radioactive material release established by the EPA. The EPA has specified limits for total cumulative release of radionuclides over 10,000 yr. Performance assessment calculations will be used to show that releases resulting from both expected (undisturbed) conditions and processes and from potentially disruptive conditions and processes will be within the allowable limits.

Engineered barrier system and waste package performance

The engineered barrier system (EBS) is to be designed so that releases of radionuclides are gradual, resulting in small fractional releases to the geologic setting over long periods of time. The release rate is specified to be not greater than one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 yr after permanent closure of the repository. The EBS is also to be designed so that containment of high level waste will be substantially complete during the period when radiation and thermal conditions are dominated by fission product decay. The waste package is to be designed to provide substantially complete containment of the high level waste for 300 to 1,000 yr after permanent closure of the geologic repository. The product milestones associated with the EBS and waste package performance issues (Sections 8.3.5.9 and 8.3.5.10) represent the results of evaluations of releases from various components of the EBS, and reports that document the performance of the waste package in compliance with the requirements previously specified.

Performance of the geologic setting

The performance requirements specified by the NRC in 10 CFR 60.113(a)(ii)(B)(2) for the geologic setting state that the geologic repository should be located so that pre-waste-emplacement ground-water travel time (GWTT) along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment will be at least 1,000 yr. Although this regulation addresses the pre-waste-emplacement ground-water travel time, the calculations for ground-water flow (Section 8.3.5.12) are the same ones used to predict radionuclide migration in the total system performance assessment (Section 8.3.5.13). Therefore, the activities and milestones completed for this component of the performance assessment program serve a dual role although they are more focused toward the assessment of ground-water travel times.

The schedule information for the issues associated with the principal elements of postclosure performance assessment is given in this section in the form of timelines. Information needs within an issue are represented as appropriate. The length of the timeline representing the information need is proportional to the duration of the activities described in the information need. Points shown on the timeline represent major events or important milestones associated with the issue. Solid lines represent information need

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durations and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.

CONTAINMENT BY WASTE PACKAGE (ISSUE 1.4, SECTION 8.3.5.9)

The activities planned to support resolution of this issue include those necessary to show that the set of waste packages meet the NRC requirement for substantially complete containment for 300 to 1,000 yr. These activities will produce information that allows prediction of both the degree of containment and the duration of containment. The results derived from activities in this issue provide important input to Issue 1.5 (engineered barrier system release rates) and Issue 1.1 (total system performance).

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The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Barrier material selection, model development, and performance assessment are ongoing, parallel efforts.
2	Milestone P265. Complete feasibility evaluation of ceramic-lined waste package as an alternative design approach.
3	Milestone M265. Metal barrier material selected.
4	Milestone P259. Issue test plan for metal barrier data acquisition in support of license application.
5	Milestone P260. Initiate license application testing for metal barriers.
6	Milestone Z036. Issue final data base for container material performance in license application.
7	Milestone P261. Complete data acquisition to support the draft environmental impact statement (DEIS) performance calculations.
8	Milestone P262. Provide input on metal barrier to waste package performance assessment to support the DEIS.
9	Milestone P268. Provide input on other materials to waste package performance assessment to support the DEIS.
10	Milestone P200. Complete documentation of the results of other materials testing to support the DEIS.
11	Milestone P040. Issue final report on oxidation/corrosion performance of selected container material.
12	Milestone T075. Complete and document waste package performance analysis codes.
13	Milestone M260. Issue report on preliminary long-term waste package performance assessments for waste package conceptual design.
14	Milestone M263. Complete waste package performance assessment for advanced conceptual design.
15	Milestone Z489. Initiate waste package performance assessment to support the DEIS.
16	Milestone M268. Complete waste package performance assessment for license application design.

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Point
number

Description

- 17 Milestone M273. Issue final report on license application design waste package performance assessment, regulatory performance of aggregate of waste packages, and reliability in meeting regulatory requirements, and waste package radionuclide source term.

ENGINEERED BARRIER SYSTEM RELEASE RATES (ISSUE 1.5, SECTION 8.3.5.10)

The activities conducted under this issue will support demonstrations of compliance with the requirements of the Nuclear Regulatory Commission that the engineered barrier system should limit the release rate of any radionuclide after the containment period so that no greater than one part in 100,000 of the 1,000 yr inventory of that nuclide shall be released per year. The activities that will be performed under this issue include waste form testing, waste package performance assessment, and scenario analysis to provide near-field radionuclide source terms to Issue 1.1 (total system performance).

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The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone M269. Complete spent fuel waste form testing for design.
2	Milestone Z066. Complete studies of alteration of glass.
3	Milestone Z069. Complete confirmatory testing of spent fuel waste forms.
4	Complete documentation of waste form testing results for license application.
5	Input received from Information Need 1.4.5 (substantially complete containment of waste) on time of container failure.
6	Scenarios supplied from total system calculations by Information Need 1.1.2.
7	Milestone P334. Issue final EQ3/6 data base.
8	Milestone M012. Complete modeling of expected long-term performance of spent fuel waste forms under repository conditions to support the draft environmental impact statement (DEIS).
9	Complete modeling of expected long-term performance of glass waste forms under repository conditions to support the DEIS.
10	Milestone T065. Complete and document waste package performance analysis codes.
11	Milestone T076. Complete waste package performance assessment code verification and validation.
12	Report on preliminary long-term waste package performance assessment for waste package conceptual designs is available.
13	Milestone M263. Complete waste package performance assessments for advanced conceptual design (ACD).
14	Milestone M268. Complete waste package performance assessments for license application design.
15	Output release calculations to Issue 1.4 (containment by waste package), Information Need 1.5.5 (radionuclides leaving near-field of waste package), and Issue 1.1 for total system release calculations.

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
16	Milestone M273. Issue final report on license application design waste package performance assessment, regulatory performance of aggregate of waste packages, and reliability in meeting repository requirements and waste package radionuclide source term.
17	Milestone IR02. Preliminary issue resolution report addressing the performance objective for controlled radionuclide release by the engineered barrier system.
18	Milestone W260. Complete local flow and transport model.
19	Provide input to unsaturated flow studies in Information Need 1.10.4 (Section 8.3.4.2.4).
20	Output preliminary information on source term to Information Need 1.5.3 and to Issue 1.1 for total system release calculations.
21	Milestone P204. Issue final report on near-field radionuclide source term.

GROUND-WATER TRAVEL TIME (ISSUE 1.6, SECTION 8.3.5.12)

The activities planned to support resolution of this issue are those required to demonstrate that the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment will be at least 1,000 yr. Because the repository at the Yucca Mountain site would be situated in the unsaturated zone, many of the activities are focused on understanding the dynamics and mechanisms of flow under unsaturated conditions. The NRC regulation responsible for this issue requires that the travel time be calculated along the fastest path of likely radionuclide travel, resulting in some activities to identify the fastest path. This issue also requires a definition of the starting point for the travel-time calculation, i.e., the disturbed zone. Activities necessary to identify the disturbed zone are also included under this issue.

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone R073. Development of verification and validation strategies.
2	Milestone P650. Issue report on concepts of flow in partially saturated tuff.
3	Update of conceptual, mathematical, and numerical models (codes) for use in identification of fastest flow path (Information Need 1.6.3) and calculation of ground-water travel time (GWTT) (Information Need 1.6.4). Activity to be reported in Milestone M183, Information Need 1.6.4.
4	Final codes and models developed and selected for use in calculations of GWTT for the DEIS and license application. Activity to be reported in Milestone P652, Information Need 1.6.4.

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
5	Milestone P227. Verification of codes and validation of models used for identification of fastest path and calculation of GWTT for the draft environmental impact statement (DEIS) and license application.
6	Identification of the fastest path of likely radionuclide travel for use in preliminary calculation of pre-waste emplacement GWTT. Activity to be reported in Milestone M181, Information Need 1.6.4.
7	Update of identification of fastest path of likely radionuclide travel for use in interim calculation of GWTT. Activity to be reported in Milestone M183, Information Need 1.6.4.
8	Identification of fastest path of likely radionuclide travel for use in calculation of GWTT for DEIS and license application. Activity to be reported in Milestone P652, Information Need 1.6.4.
9	Milestone M183. Issue report on GWTT based on interim site characterization data.
10	Milestone P652. Calculation of pre-waste-emplacement GWTT in support of the DEIS and calculation of post-emplacement ground-water travel time (Activity 1.6.5.1).
11	Update of GWTT calculations for the final environmental impact statement (FEIS) and license application.
12	Milestone M107. Issue report on the preliminary definition of the disturbed zone.
13	Milestone M188. Issue report on the detailed analysis of the effect of heat and excavation on water flow in the vicinity of the waste package.
14	Milestone Z090. Issue report on the definition of the disturbed zone.

TOTAL SYSTEM PERFORMANCE (ISSUE 1.1, SECTION 8.3.5.13)

The activities planned to support resolution of this issue are those necessary to show that total repository system releases over 10,000 yr will comply with the cumulative release limits specified in 40 CFR Part 191. The contribution to total radionuclide releases to the accessible environment for the scenarios that are likely to occur, as well as those scenarios that are unlikely, yet sufficiently credible, will be determined. This issue relies on Issue 1.6 (pre-waste-emplacement ground-water travel time) for transport

models, and on Issue 1.5 (engineered barrier system releases) for radionuclide source terms. It also draws information from a variety of site programs, such as the climate program (Section 8.3.1.5) and the postclosure tectonics program (Section 8.3.1.8) to establish the range of expected conditions and processes over the next 10,000 yr at the Yucca Mountain site.

The points on the timelines and the data input and output at the interfaces are shown in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone M126. Report on the NNWSI Project data priority study.
2	Milestone P654. Report on the description of preliminary scenario classes to be screened against consequences.
3	Input refined scenario classes to Information Need 1.1.4.
4	Milestone M125. Report on preliminary models of releases through volcanism and human intrusion.
5	Milestone P655. Report on preliminary models of gas-phase releases.

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<u>Point number</u>	<u>Description</u>
6	Milestone P086. Report on preliminary systems models of releases through water pathways.
7	Milestone M193. Report on a refined source term model using exploratory shaft and waste package advanced conceptual design information.
8	Complete validation of models and verification of codes in support of the draft environmental impact statement (DEIS).
9	Milestones Z043 and Z075. Reports on the results of screening scenario class models.
10	Milestone Z077. Report on final computationally efficient models to be used in the total system simulator.
11	Milestone Z078. Report on structure of the total system simulator.
12	Milestone Z079. Report on joint probability distributions used in the total system simulator.
13	Milestone N121. Complete interim probability analysis of performance of the total system for input into the DEIS.
14	Output of performance assessment calculations in support of the DEIS.
15	Update of DEIS performance assessment calculations in support of the final environmental impact statement (FEIS) and license application.

INDIVIDUAL PROTECTION (ISSUE 1.2, SECTION 8.3.5.14)

The activities planned to support resolution of this issue address the EPA requirements limiting the annual dose equivalent from the repository system to any member of the public in the accessible environment following permanent closure. Two transport mechanisms must be considered at the Yucca Mountain site: ground-water transport and gas-phase transport. The activities planned under this issue will determine if any exposure to the public will occur during the 1,000-yr period following permanent closure.

PERFORMANCE
ASSESSMENT
INFORMATION
NEED

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Information received from Issue 1.6 (ground-water travel time, Section 8.3.5.12) and the geochemistry program (Section 8.3.1.3).
2	Milestone Z456. Issue report on the determination of doses to the public in the accessible environment through the ground-water pathways.
3	Information received from Issue 1.5 (engineered barrier system release rates, Section 8.3.5.10), Issue 1.1 (total system performance, Section 8.3.5.13), and the meteorology program (Section 8.3.5.12).
4	Initial calculation of gaseous transport time of carbon-14 dioxide through overburden complete. If the confidence levels are adequate, prepare report on gaseous transport time (Milestone Z457). If the confidence levels are not adequate, initiate next activity to evaluate upper-bound internal and external doses.
5	Milestone Z457. Issue report on the determination of doses to the public in the accessible environment through gas-phase transport.

GROUND-WATER PROTECTION
(ISSUE 1.3, SECTION 8.3.5.15)

The activities planned to support resolution of this issue are those necessary to demonstrate that concentrations of radioactive waste products in special sources of ground water will meet the limits specified in 40 CFR 191.16. To comply with this requirement, the first approach to be used is to demonstrate that no special sources of ground water exist in the vicinity of the site. If special sources of ground water are found to be present, the second approach is to show that concentrations of radionuclides in any ground-water sources during the first 1,000 yr after disposal will not exceed the limits.

**PERFORMANCE
ASSESSMENT
INFORMATION
NEED**

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Analysis begins with information received from Investigations 8.3.1.2.1 (regional hydrology system), 8.3.1.2.3 (site saturated zone hydrologic system), and 8.3.1.9.2 (value of resources).
2	Milestone Z454. Issue report on evaluation of the potential for special sources of ground water at Yucca Mountain.

Point
numberDescription

3	Milestone Z360. Complete evaluation of the potential for special sources of ground water at Yucca Mountain.
4	Analysis begins with decision that analysis is needed based on results of evaluation of the potential for special sources of ground water from 8.3.5.1.5.1.1; information is also passed from Investigation 8.3.1.2.3 (site saturated hydrologic system) and Section 8.3.5.13 (total system performance).
5	Milestone Z455. Issue report on the calculations to determine concentration of waste products in special source aquifers over the first 1,000 yr after disposal.

8.5.3 REPOSITORY DESIGN ACTIVITIES AND MILESTONES

The repository design must address regulatory requirements for both the preclosure and postclosure periods. The design must ensure radiological safety, as described in Section 8.5.2.1. For the preclosure period, 10 CFR 60.131-133 specify general design criteria for the geologic repository operations area and additional design criteria for the surface and underground facilities. A DOE requirement (10 CFR Part 960) also specifies that the designs should be feasible on the basis of reasonably available technology. For postclosure, a general criterion for the underground facility requires that the orientation, geometry, layout and depth of the facility, and the design of engineered barriers should contribute to the containment and isolation of radionuclides (10 CFR 60.133(a)(1)). The engineered barriers are also to be designed to assist the geologic setting in meeting the performance objectives. Other postclosure requirements on the repository design specify that it must allow the performance objectives to be met under the predicted postclosure conditions (10 CFR 60.133(h)). Another postclosure requirement placed on the geologic repository operations area, and combined with the repository design milestones for purposes of this section, is the requirement for the development of seals for shafts and boreholes (10 CFR 60.134).

Summary schedule information, in the form of timelines, for each preclosure and postclosure repository design issue presented in Sections 8.3.2.2 through 8.3.2.5 and the seal design issue presented in Section 8.3.3.2 is given in this section. Each information need is represented as appropriate. The length of the timeline representing the information need is proportional to the activity durations. Points shown on the timelines represent major events or important milestones associated with the information need. Solid lines represent the information need activity durations and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.

CONFIGURATION OF UNDERGROUND FACILITIES (POSTCLOSURE)
(ISSUE 1.11, SECTION 8.3.2.2)

The activities planned to support resolution of this issue are those related to aspects of the underground facility design that have implications for the postclosure behavior of the repository. The requirements addressed by the issue state that the underground facility and the engineered barrier system shall contribute to the containment and isolation of radionuclides, incorporate sufficient flexibility to accommodate site specific conditions, and assist the geologic setting in meeting the postclosure performance objectives. Major considerations in addressing the requirements covered by this issue include the potential excavation effects on performance, the rock response to the thermal loads induced by the emplaced waste, and the availability of adequate usable host rock for the underground facility. Data from site programs are required for resolution of this issue, including information on stratigraphy and structure and on the thermal and mechanical properties of the host rock.

The points on the timelines and the data input and output at the interfaces are described in the following table:

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<u>Point number</u>	<u>Description</u>
1	Milestone M444. Report available updating reference thermo-mechanical properties for advanced conceptual design (ACD).
2	Initial report available describing the three-dimensional thermal and mechanical stratigraphy of Yucca Mountain.
3	Milestone M445. Report available updating reference thermo-mechanical properties for license application design (LAD).
4	Milestone Z094. Complete the determination of the adequacy of existing data needed for postclosure repository design.
5	Input waste package data required to resolve this issue from Issue 1.10.
6	Milestone Z097. Complete determination and compilation of waste package information required for design of the underground facility.
7	Milestone Z103. Complete evaluation of usable area and flexibility for ACD.
8	Milestone M466. Vertical or horizontal emplacement option selected.
9	Milestone P584. Report available on usable area and flexibility for LAD.
10	Milestone P588. Underground facility contingency plan available.
11	Data/information on usable area and flexibility to Issue 4.4 (preclosure design and technical feasibility) and Information Need 1.11.1 (site characteristics needed for design).
12	Milestone Z098. Report available on the potential effects of construction materials on geochemistry.
13	Milestone P586. Water usage criteria report available.
14	Output water usage criteria to information needs on significant release scenarios, repository design, and equipment development (Information Needs 1.1.2, 4.4.4, and 4.4.6).
15	Milestone P587. Underground facility material inventory criteria.
16	Output underground facility material inventory criteria to information needs on release estimates, waste package design, repository design, and equipment development (Information Needs 1.1.5, 1.10.4, 4.4.4, and 4.4.6, respectively).

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
17	Milestone P585. Complete definition of underground facility excavation methods criteria.
18	Output excavations criteria to Information Needs 1.11.6 (thermal loading and thermomechanical rock response) and 4.4.4 (repository design requirements).
19	Milestone Z023. Issue long-term subsidence control strategy report.
20	Output long-term subsidence control information to Information Needs 1.11.6, 1.11.7 (reference postclosure underground designs), and 4.4.7 (design analyses).
21	Milestone P573. Complete strategy for underground facility ACD considerations to enhance containment.
22	Milestones P576 and P577. Complete ACD far-field and near-field reference design analysis calculations.
23	Milestone P583. Complete determination of allowable far-field areal power density for LAD.
24	Output information on far-field areal power density to Information Needs 1.1.2 (potentially significant release scenario classes) and 4.4.7 (design analyses).
25	Milestone Z106. Complete strategy for underground facility LAD considerations to enhance containment.
26	Milestone Z107. Complete LAD reference design calculations.
27	Output near-field sensitivity information to Information Need 4.4.7 (design analyses); reference design calculations to Information Needs 1.1.3 (models for release scenarios), 1.6.5 (disturbed zone boundary), and 1.10.4 (near-field environment).
28	Milestone P581. Complete reference postclosure design for ACD.
29	Output reference conceptual design to Information Need 1.1.2 (potentially significant release scenario classes).
30	Input information on potentially significant scenario classes (Information Need 1.1.2) and design analyses (Information Need 4.4.7).
31	Milestone M063. Issue design analysis report to support license application.

CONSULTATION DRAFT

Point
number

Description

- 32 Milestone Z439. Complete reference postclosure design confirmation for the LAD.

REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY (ISSUE 2.7, SECTION 8.3.2.3)

The activities performed under this issue will provide radiological safety design analyses to support resolution of Issue 4.4 (preclosure design and technical feasibility). Data from a variety of site programs, such as Meteorology (Section 8.3.1.12) and Preclosure tectonics (8.3.1.17) will be used to determine the site-specific conditions that must be considered in designing a repository facility that will protect the health and safety of repository workers and the public.

The points on the timelines and the data input and output at the interfaces are described in the following table:

Point
number

Description

- 1 Receive site characterization data from site programs 8.3.1.3 (geochemistry), 8.3.1.12 (meteorology), 8.3.1.13 (offsite installations), 8.3.1.14 (surface characteristics), 8.3.1.15 (rock properties), 8.3.1.16 (preclosure hydrology), and 8.3.1.17 (preclosure tectonics), and data/information from Information Need 2.3.1 (credible accident sequences, Section 8.3.5.5.1).
- 2 Receive site characterization data from site Investigations 8.3.1.3, 8.3.1.12, 8.3.1.13, 8.3.1.14, 8.3.1.15, 8.3.1.16, and 8.3.1.17 and data/information from Information Need 2.3.1. (See point 1 description for investigation names.)

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
3	Milestone R784. Advanced conceptual design (ACD) preclosure safety analysis report.
4	Output radiological safety design analyses to Issue 4.4 (preclosure design and technical feasibility).
5	Milestone M068. Preclosure performance assessment input for enclosure in license application.
6	Milestone R777. Update preclosure performance assessment report in support of draft environmental impact statement (DEIS) preparation.
7	Output preclosure performance assessment information/data to DEIS.
8	Milestone R780. Update preclosure performance assessment report in support of final environmental impact statement (FEIS) and license application.
9	Output preclosure radiological safety assessment to FEIS and license application.

NONRADIOLOGICAL HEALTH AND SAFETY (ISSUE 4.2, SECTION 8.3.2.4)

The activities planned to support resolution of this issue are those necessary to demonstrate that repository designs and operating procedures will protect the nonradiological health and safety of repository workers. General areas of concern for nonradiological health and safety include stability of drifts and boreholes, adequate ventilation, and temperatures in the underground facility.

CONSULTATION DRAFT

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Input reference designs and design analyses from Information Needs 4.4.5 (reference preclosure repository design) and 4.4.7 (design analyses).
2	Milestone Z161. Advanced conceptual design (ACD) and analyses of repository accesses and drifts.
3	Milestone Z163. ACD and analysis of repository ventilation system.
4	Input reference designs and design analyses from Information Needs 4.4.5 and 4.4.7.
5	Output design and analyses to support worker nonradiological safety to ACD report.
6	Milestone Z162. License application design (LAD) and analysis of repository accesses and drifts.
7	Milestone Z164. LAD and analysis of repository ventilation system.
8	Output information/data on design and analysis of repository accesses and drifts to LAD report.

PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY (ISSUE 4.4, SECTION 8.3.2.5)

The activities supporting resolution of this issue are those necessary to demonstrate that the repository can be designed, constructed, operated, and closed using reasonably available or proven technology. This issue is also the focus for repository design requirements addressed under other issues. Because of this role, the activities performed under this issue must address a variety of design requirements, such as the ability to retrieve the waste, the quantities and types of waste to be emplaced, the waste package designs, the waste handling and emplacement systems, the stability of boreholes, the seismic design of surface facilities, and the mine ventilation systems. Activities under this issue will provide updated designs that meet design criteria, taking into account the various requirements placed on the preclosure repository facilities.

The points on the timelines and the data input and output interfaces are described in the following table:

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
1	Input technical feasibility information for pre-ACD studies from Information Needs 4.4.8, 4.4.9, and 4.4.10.
2	Milestone Z444. Issue updated set of reference values of geotechnical properties to support repository ACD.
3	Milestone R770. Repository advanced conceptual design (ACD) design freeze.
4	Output design information for completion of reports on conformance with ACD requirements (Milestone Q140) in waste retrievability (Section 8.3.5.2).
5	Milestone P007. Complete ACD of surface waste handling facilities.
6	Milestone Z445. Issue updated set of reference values of geotechnical properties to support repository license application design (LAD).
7	Milestone T120. Repository LAD configuration freeze.
8	Milestone M459. Issue repository LAD report.
9	Output design information for completion of final reports on conformance with requirements (Milestone Q141) in waste retrievability (Section 8.3.5.2).
10	Milestone Z165. Issue report on waste types, quantities, and characteristics for repository ACD.
11	Output information on waste quantities and characteristics to other design-related information needs, specifically 1.10.2, 1.10.3, 1.10.4, 1.11.2, 1.11.6, 1.11.7, 2.2.2, 2.3.2, 2.3.3, 2.3.4, 2.4.4, 2.6.3, 2.7.2, 2.7.6, 4.4.5, 4.4.6, and 4.5.1.
12	Output preliminary waste package design information to other design-related information needs, specifically 1.10.2, 1.10.3, 1.10.4, 1.11.2, 1.11.6, 1.11.7, 2.2.2, 2.3.2, 2.3.3, 2.3.4, 2.4.4, 2.6.3, 2.7.2, 2.7.6, 4.4.5, 4.4.6, and 4.5.1.
13	Milestone Z169. Obtain preliminary waste package design information needed for ACD.
14	Milestone Z171. Issue report on preliminary design basis for waste handling and emplacement systems in repository ACD.
15	Output information on waste handling and emplacement systems to other design-related information needs, specifically 1.10.2, 1.10.3, 1.10.4, 1.11.2, 1.11.6, 1.11.7, 2.2.2, 2.3.2, 2.3.3, 2.3.4, 2.4.4, 2.6.3, 2.7.2, 2.7.6, 4.4.5, 4.4.6, and 4.5.1.

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
16	Milestone Z172. Issue report on final design basis for waste handling and emplacement systems in repository LAD.
17	Output final design for waste handling and emplacement systems to other design-related information needs, specifically 1.10.2, 1.10.3, 1.10.4, 1.11.2, 1.11.6, 1.11.7, 2.2.2, 2.3.2, 2.3.3, 2.3.4, 2.4.4, 2.6.3, 2.7.2, 2.7.6, 4.4.5, 4.4.6, and 4.5.1.
18	Milestone Z166. Issue report on waste types, quantities, and characteristics for repository LAD.
19	Milestone Z170. Obtain final waste package design information needed for LAD.
20	Output information on waste quantities and characteristics to other design-related information needs, specifically 1.10.2, 1.10.3, 1.10.4, 1.11.2, 1.11.6, 1.11.7, 2.2.2, 2.3.2, 2.3.3, 2.3.4, 2.4.4, 2.6.3, 2.7.2, 2.7.6, 4.4.5, 4.4.6, and 4.5.1.
21	Output final waste package design information to other design-related information needs, specifically 1.10.2, 1.10.3, 1.10.4, 1.11.2, 1.11.6, 1.11.7, 2.2.2, 2.3.2, 2.3.3, 2.3.4, 2.4.4, 2.6.3, 2.7.2, 2.7.6, 4.4.5, 4.4.6, and 4.5.1.
22	Milestone N242. Issue pre-ACD operations plan.
23	Input information from other design-related information needs, specifically 1.11.4, 1.11.5, 1.11.7, 1.12.3, 2.7.5, 2.7.6, 2.7.8, and 4.4.5.
24	Milestone Z006. Issue repository ACD operations plan.
25	Output operations planning information to other design-related information needs, specifically 1.1.5, 2.1.2, 2.2.2, 2.3.1, 2.7.3, 2.7.4, 3.2.2, 3.2.4, 3.2.6, 3.2.7, 3.2.8, 3.2.9, 3.2.10, 3.3.1, 3.3.3, 3.3.4, 3.7.1, 3.8.4, 3.8.5, 4.2.2, and 4.4.5.
26	Input planning-related information from Information Needs 1.11.4, 1.11.5, 1.11.7, 1.12.3, 2.7.5, 2.7.6, 2.7.8, 4.4.2, 4.4.4, and 4.4.5.
27	Milestone Z173. Issue repository LAD operations plan.
28	Output operations planning information to other design-related information needs, specifically 1.1.5, 2.1.2, 2.2.2, 2.3.1, 2.7.3, 2.7.4, 3.2.2, 3.2.4, 3.2.6, 3.2.7, 3.2.8, 3.2.9, 3.2.10, 3.3.1, 3.3.3, 3.3.4, 3.7.1, 3.8.4, 3.8.5, 4.2.2, and 4.4.5.

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
29	Input information related to planning from Information Needs 1.11.4, 1.11.5, 1.11.7, 1.12.3, 2.7.5, 2.7.6, 2.7.8, 4.4.2, 4.4.4, and 4.4.5.
30	Milestone Z174. Final procurement and construction design (FP&CD) operations plan.
31	Output final operations planning information to Information Needs 1.1.5, 2.1.2, 2.2.2, 2.3.1, 2.7.3, 2.7.4, 3.2.2, 3.2.4, 3.2.6, 3.2.7, 3.2.8, 3.2.9, 3.2.10, 3.3.1, 3.3.3, 3.3.4, 3.7.1, 3.8.4, 3.8.5, 4.2.2, and 4.4.5.
32	Milestone N546. Issue preliminary report on preliminary design requirements document.
33	Milestone M456. Issue updated repository design requirements document with changes resulting from ACD review.
34	Input information on design requirements from other design-related information needs, specifically 1.11.4, 1.11.5, 1.11.6, 1.12.2, 1.12.3, 2.6.1, 2.6.2, 2.6.3, 2.7.6, 2.7.7, 2.7.8, 2.10.2, 2.10.4, 4.2.3, and 4.4.2.
35	Milestone M042. Complete repository design requirements document for LAD.
36	Input information on design requirements from other design-related information needs, specifically 1.11.4, 1.11.5, 1.11.6, 1.12.2, 1.12.3, 2.6.1, 2.6.2, 2.6.3, 2.7.6, 2.7.7, 2.7.8, 2.10.2, 2.10.4, 4.2.3, and 4.4.2.
37	Milestone R781. Update subsystem design requirements for the final procurement and construction design.
38	Input information from the rock characteristics (8.3.1.4), surface characteristics (8.3.1.14), thermal and mechanical properties (8.3.1.15), and preclosure tectonics (8.3.1.17) programs; other design-related documents; and repository operations plans (Information Need 4.4.3).
39	Input updated information from the rock characteristics (8.3.1.4), surface characteristics (8.3.1.14), thermal and mechanical properties (8.3.1.15), and preclosure tectonics (8.3.1.17) programs; other design-related documents; and repository operations plans (Information Need 4.4.3).
40	Milestone M468. Issue repository ACD report.

CONSULTATION DRAFT

<u>Point number</u>	<u>Description</u>
41	Output ACD to other design-related information needs, specifically 1.11.3, 2.1.1, 2.2.2, 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.4.2, 2.4.3, 2.4.4, 2.4.5, 2.7.3, 2.7.4, 2.7.5, 2.7.6, 2.7.7, 2.7.8, 4.4.7, 4.4.8, 4.4.9, 4.4.10, and 4.5.2.
42	Output LAD to other design-related information needs, specifically 1.11.3, 2.1.1, 2.2.2, 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.4.2, 2.4.3, 2.4.4, 2.4.5, 2.7.3, 2.7.4, 2.7.5, 2.7.6, 2.7.7, 2.7.8, 4.4.7, 4.4.8, 4.4.9, 4.4.10, and 4.5.2.
43	Milestone Z175. Complete repository equipment list.
44	Milestone R269. Issue report on detailed design of emplacement and retrieval equipment.
45	Milestone R271. Complete fabrication of emplacement and retrieval equipment for demonstration.
46	Milestone R273. Complete demonstration of emplacement and retrieval equipment.
47	Milestone R274. Complete documentation of emplacement results for support of the license application.
48	Input site characterization data from the surface characteristics (8.3.1.14), thermal and mechanical properties (8.3.1.15), preclosure hydrology (8.3.1.16), and preclosure tectonics (8.3.1.17) programs.
49	Issue report on Benchmarking I, preliminary verification analyses of thermal and mechanical models.
50	Milestone Z176. Issue report on repository access analysis for incorporation into ACD report.
51	Milestone Z177. Issue report on repository opening analysis for incorporation into ACD report.
52	Milestone Z178. Issue report on borehole analysis for incorporation into ACD report.
53	Milestone Z180. Issue report on mine ventilation design for incorporation into ACD report.
54	Milestone Z448. Issue report on surface facility design analysis for incorporation into ACD report.
55	Milestone Z449. Issue report on seismic design of surface facilities for incorporation into ACD report.

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<u>Point number</u>	<u>Description</u>
56	Milestone Z450. Report on design of surface facilities for wind, tornados, and flooding for ACD report.
57	Output design analysis information to information needs associated with waste retrievability, nonradiological safety, and technical feasibility, specifically 2.4.2, 2.4.3, 2.4.4, 2.4.5, 4.2.3, 4.4.4, and 4.4.5.
58	Input site characterization data from the surface characteristics (8.3.1.14), thermal and mechanical properties (8.3.1.15), preclosure hydrology (8.3.1.16), and preclosure tectonics (8.3.1.17) programs.
59	Milestone Q156. Issue report on repository access analysis report for incorporation into LAD report.
60	Milestone Q157. Issue report on repository opening analysis for incorporation into LAD report.
61	Milestone Q154. Issue report on borehole analysis for incorporation into LAD report.
62	Milestone Q155. Issue report on mine ventilation design for incorporation into LAD report.
63	Milestone Z181. Issue report on surface facility design analysis for LAD report.
64	Milestone Z182. Issue report on seismic design of surface facilities for incorporation into LAD report.
65	Milestone Z183. Report on design of surface facilities for wind, tornados, and flooding for LAD report.
66	Milestone Z451. Issue report on technology requirements for repository surface facilities and systems for incorporation into ACD.
67	Output technology requirements for surface facilities to Information Need 4.5.3 (plans for repository operation).
68	Milestone Z184. Issue report on technology requirements for repository surface facilities and systems for incorporation into LAD.
69	Output technology requirements for surface facilities to Information Need 4.5.3 (plans for repository operation).

<u>Point number</u>	<u>Description</u>
70	Milestone Z452. Issue report on technology requirements for repository underground facilities and systems for incorporation into ACD.
71	Output requirements for underground facilities to Information Need 4.5.3 (plans for repository operation).
72	Milestone Z185. Issue report on technology requirements for repository underground facilities and systems for incorporation into LAD.
73	Output requirements for underground facilities to Information Need 4.5.3 (plans for repository operation).
74	Milestone Z453. Issue report on technology requirements for seal design, material, and emplacement for incorporation into ACD.
75	Output seals technology requirements to Information Need 4.5.3 (plans for repository operation).
76	Milestone Z186. Issue report on technology requirements for seal design, material, and emplacement for incorporation into LAD.
77	Output seals technology requirements to Information Need 4.5.3 (plans for repository operation).

SEAL CHARACTERISTICS (ISSUE 1.12, SECTION 8.3.3.2)

The activities planned to support resolution of this issue include those necessary to develop designs and evaluate performance of seals to be placed in the shafts, ramps, and boreholes associated with the development and closure of the repository. Data from a number of site programs, such as geohydrology (Section 8.3.1.2) and rock properties (Section 8.3.1.15), will be used to ensure that shafts and boreholes are adequately sealed so that after closure, they do not become pathways that compromise the ability of the geologic repository to meet the postclosure performance objectives.

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone Z108. List of information needed for seal design completed.
2	Milestone R280. Issue detailed test plan for longevity testing.
3	Issue report on development of a degradation model for cementitious sealing materials.
4	Milestone R283. Complete Phase I testing associated with longevity testing.
5	Milestone R281. Issue report on the results of pipe restraint tests.
6	Milestones R282 and R286. Issue reports on the results of crushed tuff properties test and Phase II seal materials longevity testing.

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<u>Point number</u>	<u>Description</u>
7	Input site characterization data from site programs 8.3.1.2 (geohydrology), 8.3.1.3 (geochemistry), 8.3.1.5 (climate), 8.3.1.6 (erosion), 8.3.1.8 (postclosure tectonics), 8.3.1.14 (surface characteristics), 8.3.1.15 (rock properties), 8.3.1.16 (preclosure hydrology), and 8.3.1.17 (preclosure tectonics); input data/information from Information Needs 1.11.6 (thermal loading), 1.12.2 (seal characteristics), and 4.4.7 (design analyses).
8	Milestone M461. Sealing conceptual design for incorporation into advanced conceptual design (ACD) report.
9	Output sealing conceptual designs information/data to Information Need 4.4.7 (design analyses).
10	Milestone R276. Recommendations for materials for LAD and performance assessment studies.
11	Output information/data on seal material recommendations to Design Activity 1.12.4.2 (development of LAD for sealing) and Information Needs 1.11.7 (reference postclosure repository design), 4.4.5 (reference preclosure repository design) and 4.4.10 (seal technology).
12	Milestone M492. License application design (LAD) sealing criteria incorporated into repository design requirements.
13	Output information/data on sealing criteria to Information Need 4.4.3 (repository operations plan).
14	Milestone M449. Report on sealing subsystem performance assessment.
15	Output information/data on seal performance assessment to Information Need 1.1.6 (estimates of total system releases).
16	Milestone Z186. Issue report on technology requirements for seal design, materials, and emplacement for repository LAD.

8.5.4 WASTE PACKAGE DESIGN ACTIVITIES AND MILESTONES

The waste package design requirements address the preclosure and post-closure time periods in a manner similar to the repository design requirements covered by the milestones presented in Section 8.5.3. Detailed discussions of the waste package preclosure and postclosure design requirements are provided in Section 8.3.4. The primary requirements placed on the waste package for the preclosure time period cover such concerns as control

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of criticality, limits on reactive materials and free liquids, and the availability of production technologies for fabrication, closure, and inspection of the waste package.

For the postclosure time period, the waste package requirements address the need for considerations of potential interactions between the waste package and its environment that could compromise the function of the packages or the performance of the underground facility or the geologic setting.

Summary schedule information, in the form of timelines, for design-oriented waste package issues presented in Sections 8.3.4.2 through 8.3.4.4 is given in this section. Summary schedule information related to waste package performance assessment issues was presented in Section 8.5.2. Each information need is represented as appropriate. The length of the timeline representing the information need is proportional to the duration of the activities in the information need. Points shown on the timelines represent major events or important milestones associated with the information need. Solid lines represent the information need durations and dashed lines show interfaces. The data input and output at the interfaces are shown by circles.

WASTE PACKAGE CHARACTERISTICS (POSTCLOSURE) (ISSUE 1.10, SECTION 8.3.4.2)

The activities planned to support resolution of this issue are those required to demonstrate that interactions of the waste package with the emplacement environment do not compromise the function of the package or the performance of the underground facility or the geologic setting. The principal characteristics of high-level waste that must be considered are the high levels of radiation and the heat generated within the waste form. To understand the effects of the waste package on the emplacement environment, it is necessary, first, to understand ambient conditions at the repository horizon and the way those conditions will be altered by repository construction and operation. The activities displayed in this section are those necessary to show that the waste package design will meet the requirements addressed by this issue.

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Data input from Information Need 1.10.4 (near-field environment).
2	Milestone M264. Complete development of models for integrated testing of waste forms with ground water and container material.
3	Milestone IR21. Issue preliminary report on waste package design criteria considering its interaction with the environment.
4	Milestone T073. Complete waste package design requirements document for advanced conceptual design (ACD).
5	Milestone P267. Final waste package environment definition provided to waste package performance assessment.
6	Output to repository license application design (LAD).

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<u>Point number</u>	<u>Description</u>
7	Output to Issues 1.4 and 1.5, (containment by waste package and engineered barrier system release rates, respectively).
8	Milestone M274. Issue waste package LAD report.
9	Milestone M468. Issue repository ACD report.
10	Milestone M459. Issue repository LAD report.
11	Input results of prototype testing.
12	Milestone M007. Issue report on effects of grout on ground-water chemistry and grout-affected water on waste form dissolution.
13	Data output to Issue 1.5, waste form dissolution.
14	Milestone Z464. Issue report on characterization of potential chemical and mineralogical changes in the post-emplacement environment.
15	Milestone P204. Issue final report on radionuclide source term.
16	Milestone Z466. Issue report summarizing the thermal and mechanical attributes of the waste package environment.
17	Milestone M650. Complete final report on the results of the waste package system test.
18	Data output to Issues 1.4 and 1.5 (containment by waste package and engineered barrier system release rates, Sections 8.3.5.9 and 8.3.5.10, respectively) and Information Need 1.10.1 (waste package design information, Section 8.3.4.2.1).

WASTE PACKAGE CHARACTERISTICS (PRECLOSURE) (ISSUE 2.6, SECTION 8.3.4.3)

The activities planned to support resolution of this issue are related to development of the waste package designs and the integration of the designs into the repository system. Requirements and constraints are placed on the waste form, the container, and the waste package assembly during the preclosure period. It is also important that the waste form and container are not subjected to conditions that could impact their performance during the postclosure period. The requirements derived through this issue are combined with those from the postclosure waste package design issue (Issue 1.10, Section 8.3.4.2) to develop a consolidated design.

CONSULTATION DRAFT

The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone M259. Issue waste package advanced conceptual design report.
2	Data output to Issues 2.1 through 2.4 (Sections 8.3.5.2 through 8.3.5.5).
3	Milestone M274. Issue waste package license application design report.
4	Milestone Z468. Issue report on the comparison of waste form acceptance specifications with regulatory criteria.
5	Milestone P258. Complete documentation of the results of waste form testing to support the draft environmental impact statement.

WASTE PACKAGE PRODUCTION TECHNOLOGIES (ISSUE 4.3, SECTION 8.3.4.4)

The activities planned to support resolution of this issue are those related to the DOE requirements that the repository operations shall be demonstrated to be feasible on the basis of reasonably available technology. Rather than differentiate among various aspects of the production process, all production-related requirements are addressed in this issue. Activities to be performed under this issue include process criteria definition, process identification, process testing and evaluation, and prototype fabrication and testing.

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The points on the timelines and the data input and output at the interfaces are described in the following table:

<u>Point number</u>	<u>Description</u>
1	Milestone Z054. Issue report on prototype closure joints and closure process for license application design.
2	Milestone P203. Document prototype waste package testing results.

8.5.5 MAJOR DECISION POINTS FOR THE NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS (NNWSI) PROJECT

This section presents the major decision points currently recognized by the NNWSI Project. A logic diagram, shown in Figure 8.5-2, illustrates the interfaces among the major program elements affected by the decisions.

The timing of some of the highest level decision points is closely tied to critical milestones in the Mission Plan for the Civilian Radioactive Waste Management Program. Decision points for the NNWSI Project are generally related to the provision of site information required by the performance and design elements of the Project to address licensing and other regulatory requirements. This information consists of the technical data bases and supporting information that will allow an evaluation of compliance with regulatory requirements. Preliminary design and performance assessment analyses and calculations, such as those presented in the environmental assessment (DOE, 1986b), were completed on the basis of limited site information. If new site information collected during site characterization raises questions about earlier models and hypotheses, then certain design or performance strategies and approaches may require revision. If, at any time, new site data present evidence that a disqualifying condition exists or that a qualifying condition of any system or technical guideline cannot be met, 10 CFR 960.3-1-5 requires that the site be disqualified. Revised design or

Figure 8.5-2. General logic diagram for major decision points in site characterization program.

performance strategies may also result in the need for additional site information.

Some of the major decision points covered in this section do not rely on site information. Decision points may be determined by the activities of other Federal agencies, such as the publication of the Site Characterization Analyses by the NRC. Other decision points will be reached by the systematic progress of design activities from preliminary conceptual to advanced conceptual design (ACD), and ultimately to the final design suitable for inclusion in the license application. The expected dates presented here for the actions resulting from each decision point are the best estimates available at this time. It should be recognized that factors beyond the DOE's control may impact these dates.

The following table lists major decision points, describes their likely outcome, and provides expected dates for the outcomes.

Decision point	Likely outcome
Is the SCP acceptable for public release?	Release SCP for NRC, State, and public review
Have all prerequisites been met to start ACD? ^a	Conduct waste package and repository ACD
Is Project prepared to initiate surface-based activities? ^b	Complete readiness review and begin surface-based activities
Is the Project ready for exploratory shaft (ES) construction and ES construction-phase testing? ^c	Complete readiness review and start ES construction and ES construction-phase testing
Can the metal barrier be selected for the waste package?	Primary emphases placed on selected materials
Can the decision be made to use or not use a ceramic liner for waste packages?	Continue or terminate liner design and production
Is the ACD adequate and complete?	Conduct final design review for ACD; complete all required design documents; start license application design (LAD)
Is the Project prepared to conduct ES in situ testing? ^d	Complete readiness review and start in situ test phase
Can the decision be made on horizontal versus vertical waste emplacement?	Stop all design and analyses of emplacement mode not selected; continue ACD

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Decision point	Likely outcome
Can the repository horizon be selected?	Stop consideration of alternative horizons and continue LAD
Can the decision on final areal power density be made?	Incorporate final areal power density into LAD
Is the lateral extent sufficient and are the characteristics of repository horizon acceptable?	Stop consideration of extension areas; continue LAD
Can the reference sealing material for LAD be selected?	Stop consideration of alternative materials; continue LAD
Is the Project prepared to conduct the demonstration of waste emplacement and retrieval technologies?	Demonstrate the technologies and incorporate into LAD
Are site information and the technical data base for sufficient for waste package and repository design?	Freeze input to ACD; continue data collection for LAD or Freeze input to LAD
Is the Project ready to hold the final LAD design review for waste package?	Conduct the final LAD design review and activities for waste package design
Is the Project ready to hold the final LAD design review for repository?	Conduct the final LAD design review and terminate LAD activities for repository design
Are performance assessment model development and code validation and verification complete?	Complete performance assessment calculations for draft environmental impact statement (DEIS), final environmental impact statement (FEIS) or license application (LA)
Are site information and the technical data base sufficient for performance assessment calculations?	Complete performance assessment calculations for DEIS, FEIS, or LA
Is all technical information adequate to issue DEIS?	Issue DEIS
Is all technical information sufficient to support higher level findings on DOE siting guidelines?	DOE/HQ begins process of selecting first repository site

Decision point	Likely outcome
Is all technical information sufficient for LA?	Issue final SCP progress report supporting LA; complete LA; start NRC licensing process

^aPrerequisites for ACD

- systems requirements document published
- repository design requirements document published
- waste package design requirements document published
- reference information base data available
- Waste package postclosure compliance strategy developed

^bRequirements for readiness review prior to initiation of surface-based activities:

- land access agreements in place
- environmental permits obtained
- appropriate study plans reviewed by NRC
- test procedures and quality assurance (QA) level assignments completed and approved

^cRequirements for ES construction and ES construction-phase testing readiness review:

- environmental permits obtained
- construction-phase study plans reviewed by NRC
- test procedures and QA level assignments completed and approved

^dRequirements for ES in situ testing readiness review:

- in situ phase study plans reviewed by NRC
- test procedures and QA level assignments completed and approved

8.5.6 SUMMARY SCHEDULE

The following sections provide information useful for developing an overall understanding of the structure of the site characterization program, together with the repository and waste package design and the performance assessment programs. The summary schedule presented in Section 8.5.6.1 portrays the evolution of the major elements of the program from the present time through the license application to the Nuclear Regulatory Commission (NRC). Table 8.5-1 provides a list of the major NNWSI Project Mission Plan Amendment milestones and the scheduled completion date for each milestone. A schematic figure, presented in Section 8.5.6.2, and the text describing preliminary plans for regulatory and institutional activities and milestones provide an overview of the general approach that will be used to document the results of site characterization and important design and performance assessment products.

8.5.6.1 Presentation of summary schedule for the Yucca Mountain site

Figure 8.5-3 provides a summary schedule for the site characterization program planned at the Yucca Mountain site. The schedule should be viewed as an aid to understanding the overall structure of the site characterization program. A list of the major NNWSI Project Mission Plan Amendment milestones and the scheduled completion date for these milestones is provided in Table 8.5-1. These milestones are a subset of the milestones shown on the summary schedule. All milestones shown on the summary schedule in Figure 8.5-3 are listed in the following table.

The major program elements represented include regulatory and institutional, performance assessment, repository and waste package design, site investigations, and exploratory shaft.

Table 8.5-1 Major NNWSI Project Mission Plan Amendment milestones

Milestone	Current Schedule
Start Exploratory Shaft Construction	Fourth quarter
Start Waste Package ACD	10/89
Start Repository ACD	10/89
Complete Exploratory Shaft Connection	Second quarter
Complete Waste Package ACD	1/92
Complete Repository ACD	1/92
Start Waste Package LAD	1/92
Start Repository LAD	1/92
Complete Waste Package LAD	1/94
Issue DEIS	10/93
Complete Repository LAD	7/94
Issue FEIS	10/94
Issue Site Selection Report	11/94
Issue Record of Decision	11/94
Submit LA	1/95

CONSULTATION DRAFT

NNWSI PROJECT SCHEDULE

Figure 8.5-3. Summary schedule for the site characterization program at Yucca Mountain.

Milestone number	Related SCP section	Milestone description
REGULATORY AND INSTITUTIONAL MILESTONES		
M522	NA ^a	DOE/HQ issues SCP to public
5200	NA	Begin environmental impact statement (EIS) scoping hearings
Z497	NA	Complete documentation of site characterization program results to support the draft environmental impact statement (DEIS)
M509	NA	Issue DEIS
X512	NA	Issue final environmental impact statement (FEIS)
X513	NA	Issue site selection report to President
X514	NA	President recommends first repository site
X516	NA	Submit license application to the NRC
IR37	2.1 & 2.2; 8.3.5.3, 8.3.5.4; 10 CFR 60.111; 2.3 & 2.7; 8.3.5.5, 8.3.2.3; 10 CFR 60.131, 60.132, 60.133	Preliminary issue resolution report addressing the performance objective for protection against radiation exposures and releases of radioactive materials
IR06	2.4; 8.3.5.2; 10 CFR 60.111(b)	Preliminary issue resolution report addressing the performance objective for preserving the option of waste retrievability
IR01	1.4; 8.3.5.9; 10 CFR 60.113	Preliminary issue resolution report for the performance objective for substantially complete containment by the waste package

Milestone number	Related SCP section	Milestone description
IR02	1.5; 8.3.5.10; 10 CFR 60.113	Preliminary issue resolution report addressing the performance objective for controlled radionuclide release by the engineered barrier system
IR04	1.6; 8.3.5.12; 10 CFR 60.113	Preliminary issue resolution report addressing the performance objective for pre-waste-emplacement ground-water travel time
IR03	1.1; 8.3.5.13; 10 CFR 60.112	Preliminary issue resolution report addressing the performance objective for overall system performance

PERFORMANCE ASSESSMENT

Z154	8.3.5.2	Complete final report on retrieval conditions
Z496	8.3.2.3 8.3.5.3 8.3.5.4 8.3.5.5	Provide preliminary preclosure performance assessment input (radiological safety) in support of the DEIS
Z156	8.3.5.2	Issue final report on compliance analysis for retrieval requirements
R780	8.3.2.3 8.3.5.3 8.3.5.4 8.3.5.5	Issue update report on preclosure radiological safety assessment to support the FEIS and license application
0001	8.3.5.13	Complete validation of models and verification of performance assessment codes for DEIS
P652	8.3.5.12.4	Complete calculations of pre-waste-emplacement ground-water travel time for DEIS
0002	8.3.5.13	Complete performance assessment calculations for DEIS
M273	8.3.5.9 8.3.5.10	Issue final report on waste package license application design (LAD) performance assessment
Z488	8.3.5.16	Complete baseline phase and begin confirmation phase of performance confirmation

Milestone number	Related SCP section	Milestone description
REPOSITORY AND WASTE PACKAGE DESIGN		
M233	8.3.4.2 8.3.4.3	Start waste package advanced conceptual design (ACD)
P274	8.3.4.2 8.3.4.3	Complete waste package ACD
Q043	8.3.4.2 8.3.4.3	Start waste package license application design (LAD)
M275	8.3.4.2 8.3.4.3	Complete waste package LAD drawings and specifications
N430	8.3.2.2 8.3.2.5	Start repository ACD
R773	8.3.2.2 8.3.2.5	Complete repository ACD
M458	8.3.2.2 8.3.2.5	Start repository LAD
P566	8.3.2.2 8.3.2.5	Complete repository LAD
M459	8.3.2.2 8.3.2.5	Issue repository LAD report
SITE		
Q147	8.3.1.17.2	Issue report on the assessment of the potential for faulting at the sites of prospective surface facilities
T082	8.3.1.9.2	Issue final report on evaluation of natural resources at Yucca Mountain and vicinity
Z493	8.3.1.4.2	Complete final three-dimensional geologic model of the site area
M383	8.3.1.17.4	Issue report on final tectonic model
M390	8.3.1.3.7	Complete final geochemical-geophysical model

CONSULTATION DRAFT

Milestone number	Related SCP section	Milestone description
SITE (continued)		
Q001	8.3.1.3.1 8.3.1.3.2 8.3.1.3.3 8.3.1.3.4	Issue report on the summary of results defining the geochemical characteristics (mineralogy-petrology, mineral stability, and water chemistry) at Yucca Mountain
Q002	8.3.1.3.4 8.3.1.3.5 8.3.1.3.6 8.3.1.3.7	Issue report on the summary of results defining radionuclide retardation at Yucca Mountain
M389	8.3.1.2.3	Issue report on the description of the site saturated zone hydrology at Yucca Mountain
M391	8.3.1.2.2	Issue report on the hydrologic description of the unsaturated zone at Yucca Mountain
M393	8.3.1.12.2	Issue five-year summary report on meteorological conditions at Yucca Mountain
P104	8.3.1.5.1	Issue report on future climate as predicted from models based on the nature and rates of change in climatic conditions
Q162	8.3.1.5.2	Issue report on potential effects of future climate conditions on hydrologic characteristics at Yucca Mountain and vicinity
EXPLORATORY SHAFT ^a		
M645	8.4.1	Start exploratory shaft (ES) site preparation
M652	8.4.2.1	Start ES-1 shaft construction
R569	8.4.2.2.2	Complete connection of ES-1 to ES-2
M655	8.4.2.2	Complete ES-2 1,055-ft level testbed excavation
P750	NA ^b	Complete exploratory shaft facility Title III design
M612	NA	Start ES construction phase testing

Milestone number	Related SCP section	Milestone description
EXPLORATORY SHAFT ^a (continued)		
R570	NA	Start in situ phase testing
M657	NA	Preliminary in situ test data available for license application
M658	NA	Complete documentation of ES test results for license application

^aSee Section 8.5.1.2

^bNot applicable

8.5.6.2 Regulatory and institutional activities and milestones

As shown in Figure 8.5-3, the principal milestones for regulatory and institutional activities include issuance of the SCP and the semiannual progress reports, as well as those documents and activities that support the site selection process eventually leading to issuance of the environmental impact statement, repository site recommendation, and submittal of the license application.

Because regulatory and institutional milestones were not included in Sections 8.5.1 through 8.5.4, a brief discussion of the preliminary planning basis for regulatory and institutional activities is provided here. The manner in which site information will be utilized in performance and design activities and, finally, in the preparation of regulatory documents is schematically displayed in Figure 8.5-4. Throughout the site characterization program, a series of reports will be prepared to document the DOE position on regulatory requirements and technical issues, as shown in the figure. For purposes of this document, two different types of reports have been defined. Topical reports will be developed by assimilation and compilation of information from published reports documenting the results of site program activities and analyses, performance assessment activities, and the design of the waste package and repository. Many of the reports shown on the timelines in Sections 8.5.1 through 8.5.4, including some reports published by DOE contractors, will be used as input to topical reports or may be directly used as topical reports. Some topical reports may also be used as one component of a larger compiled topical report. This is especially true in the case of those reports that document implementation of the issue resolution strategies for performance and design issues, called issue resolution (IR) reports in this document. Preliminary milestones for the IR reports identified to date are presented below. The need for additional

Figure 8.5-4. Schematic diagram showing utilization of site data by performance assessment and design, and for preparation of regulatory documents.

topical and IR reports is likely to be recognized during site characterization. Titles of new reports will be provided in the semiannual progress reports.

Specific plans have not yet been developed for the process through which the DOE and NRC will reach concurrence on technical issues and regulatory requirements. However, it is expected that some of the topical and IR reports may be used as the basis for interaction with the NRC.

Issue resolution reports

Issue resolution (IR) reports are intended to provide preliminary documentation of the implementation of the issue resolution strategies defined for performance and design issues in Sections 8.3.2 through 8.3.5. These reports may also be used to present preliminary DOE positions on other technical issues of concern to the NRC, State, or public, such as an assessment of the seismic hazards at the Yucca Mountain site or the significance of calcite-silica deposits in faults near the site.

Three of the earliest IR reports to be issued will be related to the higher level findings required by the DOE general siting guidelines (10 CFR 960, Appendix III) at the time of selection of the first repository.

Topical reports

Topical reports will be used to document the DOE's developing positions on regulatory requirements and technical issues (Figure 8.5-4). As new design, performance, and site information becomes available, the DOE will incorporate this information into topical reports. Topical reports will serve as a vehicle through which the DOE establishes and communicates its developing technical information base. Specific plans have not yet been developed for the process through which the DOE and the NRC will reach concurrence on technical issues and requirements for regulatory compliance. However, preliminary plans are to use topical reports as the basis for interactions between the DOE and NRC, allowing the NRC to have early input into the DOE's developing positions. Some reports published by DOE contractors may be directly usable by the DOE as topical reports, while others will be used as one component of a larger compiled topical report. As various site models are tested and revised, and design and performance analyses proceed to a mature stage, the topical reports will provide the record of the development of DOE positions on the technical issues and regulatory requirements.

The timelines presented in Sections 8.5.1 through 8.5.4 include associated milestones, some of which are reports that will serve as topical reports or input to topical reports. The need for additional topical reports is likely to be recognized during site characterization, and titles of new reports will be provided in SCP progress reports.

The following table provides a list of preliminary issue resolution reports, the corresponding issue and regulatory requirement addressed by the IR report, and the corresponding SCP section number.

CONSULTATION DRAFT

Report number	Corresponding issue, SCP section, and regulation	Report description
ISSUE RESOLUTION REPORT DESCRIPTIONS		
IR11	1.3; 8.3.5.15; 40 CFR 191.16	Preliminary issue resolution report addressing the requirement for protection of special sources of ground water
IR23	1.12; 8.3.3.2; 10 CFR 60.134	Preliminary issue resolution report addressing the design criteria for the shaft and borehole seals
IR25	2.7; 8.3.2.3; 10 CFR 60.131	Preliminary issue resolution report addressing the general design criteria for the geologic repository operations area
IR26	2.7; 8.3.2.3; 10 CFR 60.132	Preliminary issue resolution report addressing the additional design criteria for surface facilities in the geologic repository operations area
IR27	2.7; 8.3.2.3; 10 CFR 60.133	Preliminary issue resolution report addressing the additional design criteria for the underground facility
IR28	4.2; 8.3.2.4; 10 CFR 60.131	Preliminary issue resolution report for the nonradiological health and safety requirements for repository workers
IR29	4.3; 8.3.4.4; 10 CFR 60.135	Preliminary issue resolution report addressing final production technologies for fabrication, closure, and inspection of the waste package
IR30	4.4; 8.3.2.5; 10 CFR 960.5-1	Preliminary issue resolution report addressing reasonable availability of technologies for repository construction, operation, closure and decommissioning
IR31	4.5; 8.2.2.3; 10 CFR 960.5-1	Preliminary issue resolution report addressing estimated life-cycle costs of the reference and alternate total system designs and analysis of cost effectiveness of reference and alternate total system designs
IR14	2.3; 8.3.5.5; 10 CFR 960.5-1	Preliminary issue resolution report addressing radiation exposure, radiation levels, and releases of radioactive material to the repository workers and the public under accidental conditions

Report number	Corresponding issue, SCP section, and regulation	Report description
ISSUE RESOLUTION REPORT DESCRIPTIONS (continued)		
IR24	2.6; 8.3.4.3; 10 CFR 60.135	Preliminary issue resolution report addressing the design criteria for the waste package and its components
IR22	1.11; 8.3.2.2; 10 CFR 60.133	Preliminary issue resolution report addressing the additional design criteria for the underground facility
IR36	1.2; 8.3.5.14; 40 CFR 191.15	Preliminary issue resolution report addressing the requirement for limiting individual doses in the accessible environment
IR37	2.1 & 2.2; 8.3.5.3 & 8.3.5.4; 10 CFR 60.111; 2.3 & 2.7; 8.3.5.5 & 8.3.2.3; 10 CFR 60.131, 60.132, 60.133	Preliminary issue resolution report addressing the performance objective for protection against radiation exposures and releases of radioactive materials
IR12	2.1; 8.3.5.3; 10 CFR 60.111	Preliminary issue resolution report addressing radiation exposures, radiation levels, and releases of radioactive material to the public under normal conditions
IR13	2.2; 8.3.5.4 10 CFR 960.5-1	Preliminary issue resolution report addressing radiation exposures, radiation levels, and releases of radioactive material to repository workers under normal conditions
IR06	2.4; 8.3.5.2; 10 CFR 60.111(b)	Preliminary issue resolution report addressing the performance objective for preserving the option of waste retrievability
IR15	1.8; 8.3.5.17; 10 CFR 60.122	Preliminary issue resolution report for the evaluation of the Yucca Mountain site against the favorable and potentially adverse conditions of 10 CFR 60.122
IR05	1.8; 8.3.5.17; 10 CFR 60.122	Preliminary issue resolution report for the NRC Siting Criteria

CONSULTATION DRAFT

Report number	Corresponding issue, SCP section, and regulation	Report description
ISSUE RESOLUTION REPORT DESCRIPTIONS (continued)		
IR21	1.10; 8.3.4.2; 10 CFR 60.135	Preliminary issue resolution report addressing the design criteria for the waste package considering its interactions with the emplacement environment
IR01	1.4; 8.3.5.9; 10 CFR 60.113	Preliminary issue resolution report for the performance objective for substantially complete containment by the waste package
IR02	1.5; 8.3.5.10; 10 CFR 60.113	Preliminary issue resolution report addressing the performance objective for controlled radionuclide release by the engineered barrier system
IR04	1.6; 8.3.5.12; 10 CFR 60.113	Preliminary issue resolution report addressing the performance objective for pre-waste-emplacement ground-water travel time
IR03	1.1; 8.3.5.13; 10 CFR 60.112	Preliminary issue resolution report addressing the performance objective for overall system performance
IR16	1.9; 8.3.5.18; 10 CFR 960.3	Preliminary issue resolution report documenting higher level findings on the qualifying and disqualifying conditions for the postclosure system and technical guidelines
IR17	1.9; 8.3.5.18; 10 CFR 960.3	Preliminary issue resolution report for the prediction of cumulative radionuclide releases over 100,000 years
IR18	2.5; 8.3.5.6; 10 CFR 960.5	Preliminary issue resolution report documenting higher level findings on the qualifying and disqualifying conditions for the preclosure radiological safety system and technical guidelines
IR19	4.1; 8.3.5.7; 10 CFR 960.5	Preliminary issue resolution report documenting higher level findings on the qualifying and disqualifying conditions for the preclosure system and technical guidelines on ease and cost of siting, construction, operation, and closure

Report number	Corresponding issue, SCP section, and regulation	Report description
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ISSUE RESOLUTION REPORT DESCRIPTIONS (continued)

IR20	1.7; 8.3.5.16; 10 CFR 60.137	Preliminary issue resolution report for the requirements for performance confirmation
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ISSUE RESOLUTION OR TOPICAL REPORT DESCRIPTIONS
ADDRESSING BROADER TECHNICAL AND REGULATORY ISSUES

IR09	NA ^a	Evaluation of potential hazards at the Yucca Mountain site resulting from underground nuclear explosions at the Nevada Test Site
IR35	NA	Mode of origin of calcite-silica deposits and the potential effects on repository performance
IR34	NA	Final assessment of volcanic hazards at the site
IR08	NA	Assessment of potential hazards at the site due to faulting and vibratory ground motion
IR33	NA	Evaluation of potential impacts at the site due to natural resource extraction
IR32	NA	Potential for coupling of tectonic and hydrologic processes and events

^aNA = not applicable.

The following table lists other major regulatory and institutional milestones included on the summary schedules in Figure 8.5-3.

Milestone number	Related SCP section	Milestone description
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OTHER REGULATORY AND INSTITUTIONAL MILESTONES

M522	NA ^a	DOE/HQ issues SCP to public
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CONSULTATION DRAFT

Milestone number	Related SCP section	Milestone description
OTHER REGULATORY AND INSTITUTIONAL MILESTONES (continued)		
5200	NA	Begin environmental impact statement (EIS) scoping hearings
Z497	NA	Complete documentation of site characterization program results to support the draft environmental impact statement (DEIS)
M509	NA	Issue DEIS
X512	NA	Issue final environmental impact statement
X513	NA	Issue site selection report to President
X514	NA	President recommends first repository site
X516	NA	Submit license application to NRC

^aNA = not applicable.

Nuclear Waste Policy Act
(Section 113)

Section 8.6

Consultation Draft

**QUALITY ASSURANCE
PROGRAM**

Site Characterization Plan

***Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

Volume VII

January 1988

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

8.6 QUALITY ASSURANCE PROGRAM

This section briefly summarizes the Quality Assurance (QA) Program for the Nevada Nuclear Waste Storage Investigations (NNWSI) Project, including reference to the regulatory requirements applicable to the NNWSI Project and the QA administrative and technical procedures developed by the NNWSI Project participants to meet the requirements. A description of the NNWSI Project QA Program can be found in the NNWSI Project Quality Assurance Plan (NVO-196-17).

8.6.1 QUALITY ASSURANCE PLAN SUMMARY

The Waste Management Project Office (WMPO) approach to quality assurance is designed to ensure that technical items and activities are assigned a level of quality assurance for control and documentation that is consistent with the relative impact on public radiological health and safety, and relative importance to other U.S. Department of Energy (DOE) concerns. The purpose of the NNWSI Project Quality Assurance Plan (QAP) is to provide direction to the NNWSI Project participants to ensure a common approach to meeting the quality requirements that are applied to the NNWSI Project.

The NNWSI QA Program comprises all those planned and systematic actions that are necessary to provide adequate confidence that the mined geologic disposal system (MGDS) will perform satisfactorily in service. QA includes quality control, which comprises those quality assurance activities related to the physical characteristics of a material, structure, component, or system that provide a means by which to control the quality of the material, structure, component, or system to predetermined requirements. QA provides a multidisciplinary system of quality controls backed by verification activities that demonstrate the completeness and appropriateness of achieved quality.

The assurance of quality is recognized as an interdisciplinary activity involving many organizational components and is not regarded as the sole domain of an organization. It is the responsibility of all NNWSI Project staff to plan, perform, and document activities affecting quality in accordance with the NNWSI QAP and develop and implement verification and self-assessment activities to ensure compliance with these requirements. Each NNWSI Project participant's QA department is responsible for describing, monitoring, and verifying satisfactory accomplishment of quality related NNWSI Project activities.

The NNWSI Project QAP, NVO-196-17, describes the overall quality assurance requirements for the NNWSI Project. Quality Assurance Program Plans (QAPPs) of the WMPO and the individual participants of the NNWSI Project provide documented commitment to the NNWSI Project QAP. The QAPPs (equivalent to the term Quality Assurance administrative procedures in the U.S. Nuclear Regulatory Commission (NRC) Standard Review Plan) are the document(s) that describe the participant's QA program and the applicable QA requirements. The QAPPs also provide instruction to implement and apply the QA requirements to the technical activities. These documents are generated by the respective quality assurance organization, with assistance from the

technical staff. Internal implementing procedures (equivalent to the term technical procedures in the NRC standard review plan) are written by the technical staff, including QA, to show how they implement the QA requirements in their respective disciplines. The details of how each of these organizations will meet quality assurance requirements may differ among the participants. These details are given in the participants' QAPPs listed in Table 8.6-1.

The general approach to quality assurance during site characterization, design, construction, and operation will be to assign a level of quality assurance to each item and activity. The level of quality assurance is consistent with the relative importance of the item and activity to public radiological health and safety and to other DOE concerns. This approach incorporates three quality assurance levels (QA levels). One will be assigned to each technical item and activity of the NNWSI Project. All items and activities will be assigned an appropriate QA level in accordance with the following discussions.

QA Level I is assigned to those radiological health and safety related items and activities that are important to either safety or waste isolation and that are associated with the ability of a geologic nuclear waste repository to function in a manner that prevents or mitigates the consequences of a process or event that could cause undue risk to the radiological health and safety of the public. Items and activities important to safety are those engineered structures, systems, components, and related activities essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body or to any organ of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until the completion of the permanent closure of the repository. Items and activities important to waste isolation are those barriers and related activities that must meet the criteria that address postclosure performance of the engineered and natural barriers to prevent the release of radionuclides. The criteria for items or activities important to safety and waste isolation are found in 10 CFR Part 60 and 40 CFR Part 191.

QA Level II is assigned to those items and activities important to the reliability and maintainability of the repository, public and repository worker nonradiological health and safety, repository worker radiological health and safety, and other operational factors of the repository.

QA Level III is assigned to those items and activities not classified as QA Levels I or II.

QA Level I is the most stringent level of quality assurance. It is to be applied to those items and activities that may affect the ability of the repository to meet the preclosure and postclosure performance objectives specified by the NRC and the U.S. Environmental Protection Agency (EPA) for protecting public health and safety from radiological hazards. QA Level I items and activities that are on the Q-list (Sections 6.1.4 and 6.1.5) will form the basis for the NRC to authorize construction and to issue a license for the DOE to receive and possess source, special nuclear, and by-product material (waste) at the geologic repository. QA Level I control and documentation must be applied to site characterization and design activities, including data collection, investigation, analysis, design, construction,

Table 8.6-1. Organizations participating in the NNWSI Project and their Quality Assurance Program Plans (QAPPs)

Participating Organization	QAPP
1. Waste Management Project Office/ Nevada Operations Office (WMP0)	Waste Management Project Office Quality Assurance Program Plan NVO-196-18
2. Lawrence Livermore National Laboratory (LLNL)	Quality Assurance Program Plan --NNWSI Project
3. Los Alamos National Laboratory (Los Alamos)	LANL-NNWSI-QAPP; Quality Assurance Program Plan for Nevada Nuclear Waste Storage Investigations
4. Sandia National Laboratories (SNL)	SNL-NNWSI (Organization 6000) Quality Assurance Program Plan, SLTR 86-0001
5. Science Applications International Corporation (SAIC) Technical and Management Support Service (T&MSS)	T&MSS Quality Assurance Program Plan, QAPP-2.
6. United States Geological Survey (USGS)	NNWSI-USGS-QAPP-01, USGS Quality Assurance Program Plan
7. Fenix & Scisson, Inc. (F&S)	F&S Quality Assurance Program Plan QAPP-002
8. Holmes & Narver (H&N)	H&N-10471-1115, H&N QA Manual
9. Reynolds Electrical & Engineering Company (REEC0)	NNWSI QAPP, NTS 568-DOC-115

fabrication, operation, decommissioning, or sealing, that are specifically concerned with the protection of the public's health and safety relative to a radiological hazard. To keep radionuclides out of man's environment, a high-level radioactive waste repository will use engineered systems, structures, and components to contain the waste and ensure preclosure safety. The repository also will use the natural barriers to afford postclosure isolation. Within this context, QA Level I will be applied to:

1. Items and activities important to the preclosure radiological health and safety of the general public. Specifically, this means items and activities essential to the prevention or mitigation of an

accident that could result in a radiation dose, either to the whole body or to any organ, of 0.5 rem or greater, either at or beyond the nearest boundary of the unrestricted area, at any time until the permanent closure of the repository.

2. Activities that will provide site characterization data. Site characterization data are the field and laboratory data and subsequent analyses that provide the basis for determining and demonstrating that the natural and engineered systems of the repository are capable of providing postclosure waste containment and isolation. This includes data and analyses from all tests, experiments, and research that have a significant impact on site characterization or are an essential part of the site-related data base that directly support the final design of the repository and waste package as well as the assessment of MGDS performance. It also includes those activities (e.g., tests, experiments, and research) that are one of several independent activities contributing to a single base of information that is considered in formulating the repository design or performance assessment of the engineered or natural barriers.
3. Items and activities whose failure could cause a failure of a QA Level I item, or irretrievable loss of QA Level I data.
4. Items important to safety or waste isolation during the design phase conducted before application for an NRC license, procurement, or construction. One of the purposes of this design phase shall be to define in detail those items that are to be procured and/or constructed as a result of the design. As the design phase proceeds, each item shall be assigned a QA Level (I, II, or III as applicable). Once the QA Level for the item is approved, design activities associated with the item shall be governed by the QA Level assigned to the item.

QA Level II is the second highest level of quality assurance. QA Level II controls and documentation shall be applied to the NNWSI Project items and activities (described below) that are not associated with public radiological health and safety. The high-level waste (HLW) repository will use engineered systems, structures, and components that must be designed, constructed, fabricated, tested, and operated to meet the operational performance objectives and to minimize nonradiological hazards to the public and repository worker, and radiological hazards to the repository worker. Additionally, activities that have a major impact on Project costs or schedules that could delay the achievement of DOE/Office of Geologic Repositories (OGR) milestones must be appropriately controlled. Therefore, QA Level II must be applied as follows:

1. Where items and activities are essential to the design, construction, and operation of the repository or of the exploratory shaft facility, and could have a major impact on the nonradiological health and safety of the public and repository workers.

2. Where items and activities, if having failed or if performed inadequately, would cause repository workers to be exposed to radiation or radioactive contamination levels in excess of the limits expressed in 10 CFR Part 20.
3. Where items and activities involve the operational reliability and maintainability of engineered systems, structures, or components.
4. Where the design phases that involve the comparative technical analysis of alternatives/methods/equipment are conducted to determine which alternative/method/equipment is preferred. Where a particular item can be identified during this phase, a separate QA level assignment may be made for that item. Once the QA level assignment for that item is approved, design activities associated with the item shall be governed by the QA level assigned to the item.
5. Where items and activities, if failed, could result in a major cost overrun.
6. Where items and activities, if failed, could result in a major schedule slippage.

QA Level II activities may have as much importance to DOE as QA Level I activities; however, except when used to support a QA Level I activity as indicated in the following, they do not provide primary information in the licensing efforts. Activities controlled in accordance with a QA Level II requirement cannot be subsequently used as primary data to directly support QA Level I activities unless it can be substantiated that quality assurance requirements equivalent to those that would have been applied to a QA Level I activity were implemented or that a technical justification process (e.g., peer review) is applied.

QA Level III is the least stringent level of QA. QA Level III items and activities are such that they have no major function in the characterization of the site and design of the repository, but they require good practices for the intended use. Design phases that are purely preliminary and are conducted to define the range of individual alternatives/methods/equipment that are felt to be worthy of more detailed study shall be assigned a QA level of III before execution.

Data or data interpretations generated as a result of activities controlled in accordance with QA Level II or III programs, or activities performed before the complete implementation of the NNWSI Project QAP may be used in the licensing process as background or corroborative information.

8.6.2 REQUIREMENTS FOR QUALITY ASSURANCE

The DOE activities are intended to produce an adequate data base to permit the NRC to make licensing decisions for the geologic repository that are consistent with the protection of the public health and safety. A quality assurance program is essential to provide confidence that the data base adequately represents the actual site conditions and that the design has been properly developed based on these conditions. The QA requirements placed on the NNWSI Project are established from three main sources:

1. NRC.
 - a. 10 CFR 60 Subpart G, Disposal of High Level Radioactive Wastes in Geologic Repositories--Quality Assurance.
 - b. 10 CFR 50 Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.
 - c. NRC (1984) Standard Review Plan, Quality Assurance Programs for Site Characterization of High-Level Radioactive Waste Repositories.
2. DOE Nevada Field Operations Office.
 - a. DOE (1983c) 5700.6, Quality Assurance.
 - b. NV 5700.6, Quality Assurance.
3. DOE Office of Civilian Radioactive Waste Management (OCRWM).
 - a. OCRWM Quality Assurance Management Policies and Requirements.
 - b. OGR/B-3, OGR Quality Assurance Plan for High-Level Radioactive Waste Repositories.
 - c. ANSI/ASME (1983) NQA-1, American National Standard for Quality Assurance Program Requirements for Nuclear Facilities.

The WMPO has adopted the QA requirements from these documents, combined them with additional WMPO requirements, to develop the NNWSI Project Quality Assurance Plan (QAP) which identifies the QA requirements for the Project. The NNWSI QAP is the document that the WMPO uses to establish the quality assurance requirements for the NNWSI Project participants. Figure 8.6-1 identifies how the requirements for QA documents used across the entire Project are derived.

The NNWSI QAP is outlined in the same format as ANSI/ASME (1983) NQA-1, except that Criteria 3 has been identified as Design and Scientific Investigation Control. The quality assurance requirements in the NNWSI QAP for the three levels are as follows: The requirements of 10 CFR 50, Appendix B, ANSI/ASME (1983) NQA-1 (Basic, Supplemental, and selected Nonmandatory Requirements), and the NRC QA Standard Review Plan for HLW Geologic Repositories are applied to items and activities classified as QA Level I. ANSI/ASME (1983) NQA-1 basic requirements and selected Supplemental Requirements are applied to tasks classified as QA Level II. The QA

Figure 8.6-1. Criteria for quality assurance.

requirements imposed for QA Level III items and activities are those managerial, administrative, scientific, engineering, commercial, and laboratory practices that are commonly used by the organizations participating in the NNWSI Project.

8.6.3 ORGANIZATION OF PROJECT WITH RESPECT TO QUALITY ASSURANCE

Figure 8.6-2 is the organization chart of the NNWSI Project. The DOE undersecretary was given the responsibility to carry out the Nuclear Waste Policy Act of 1982 (NWPA, 1983). This responsibility has been delegated to the Office of Civilian Radioactive Waste Management (OCRWM) for the integration of QA and management policies and requirements for the entire program and for the overview of the activities performance by the operations offices. The DOE Nevada Operations Office (NV) has been delegated the responsibility for the implementation of the technical and QA activities of the NNWSI Project.

The DOE OCRWM provides programmatic and policy guidance, through the Office of Geologic Repositories (OGR), to ensure that adequate NNWSI Project QA programs are established, implemented, and maintained. The DOE/OGR provides QA guidance and overview to the NNWSI Project by implementing the requirements of the OGR QA Plan (QAP) (OGR/B3), which includes review and approval of the NNWSI Project QAP, NNWSI Project Administrative Procedures (APs), the Waste Management Project Office (WMPO) Quality Assurance Program Plan (QAPP), and WMPO implementing procedures, and conducting quality assurance audits.

The WMPO has been established within the DOE/NV for the implementation of the technical and quality assurance requirements of the NNWSI Project. The WMPO operates as a part of the DOE/NV under the programmatic guidance of the OCRWM. In matters of DOE policy, the DOE/NV works and cooperates with the OCRWM in establishing a consistent quality assurance approach for accomplishing the technical objectives of the geologic repository program.

The WMPO is programmatically responsible for management and technical direction of the activities of the participating organizations and Nevada Test Site (NTS) support contractors through the issuance of technical and programmatic guidance, technical integration of the NNWSI Project, project planning and documentation, and quality assurance programmatic guidance.

The WMPO director is responsible for the NNWSI Project management. Project management encompasses planning and directing activities; establishing goals and objectives, and assessing progress toward the attainment of those goals; administration of procurement of materials and services; preparing and issuing technical guidance; organizing and conducting peer reviews; overseeing compliance with laws, regulations, and DOE policies; and other administrative duties. The individual serving in the position of WMPO director has been officially delegated limited contractual authority and full responsibility to direct the DOE/NV contractors, national laboratories, and the U.S. Geological Survey (USGS) participation on the NNWSI Project.

Figure 8.6-2. Nevada Nuclear Waste Storage Investigations Project organization

The management and technical direction responsibilities of the WMPO focus in three areas, each under the direction of a Branch Chief. Each Branch Chief is responsible for implementing the QA program throughout their area of responsibility. The Regulatory and Site Evaluation Branch is responsible for site characterization (including geology, hydrology, geochemistry, and administrative support); performance assessment (including computer code documentation, analysis, field and laboratory experiments, and tests of radionuclide migration); drilling operations and borehole testing; regulatory interface; environmental analysis; and institutional liaison. The Technology Development and Engineering Branch is responsible for repository systems description, analysis, and integration; waste package design and development; design, construction, and operation of major test facilities; operational safety; repository engineering including conceptual design, rock mechanics, and borehole sealing; instrument and equipment development; and exploratory-shaft design, construction, and operation. The Systems and Project Control Branch is responsible for the administration and management support to integrate and control the NNWSI Project, including preparation of networks, monitoring milestones, overseeing issuance of project documentation, state liaison, transportation, socioeconomics, records management, and quality assurance records administration.

The WMPO uses a matrix organizational concept to support its activities. Figure 8.6-3 details the organization that provides matrix support. The matrix staff assists the WMPO by providing reviews, recommendations, management and direction, and expertise on various aspects of the NNWSI Project in terms of their respective responsibilities as established in accordance with the matrix organizational approach. Matrix support personnel perform quality related work under the controlling procedures of the WMPO QAPP. The matrix support personnel work under the cognizance of the WMPO Director or the WMPO Branch Chiefs.

The Quality Assurance Division (QAD) Director provides independent QA overview including QA guidance, surveillance, and audit capability for DOE/NV management; reviews and approves the NNWSI Project QAP, the WMPO QAPP, and implementing procedures for both documents. The QAD has assigned a Project Quality Manager (PQM), under the matrix organizational approach, dedicated to support the QA responsibilities on WMPO activities.

The dedicated PQM reports functionally to the WMPO Director for the maintenance and implementation of the NNWSI Project QAP and WMPO QAPP. The support provided by the PQM to the NNWSI Project includes the review of participating organizations' and support contractors' QAPPs, directing audits and surveillances, and coordination of the Quality Assurance Support Contractor (QASC) activities. The PQM is supported by the QASC to conduct WMPO QA activities. The responsibilities of the QASC are to provide support in the areas of (1) development, documentation, administration, and implementation of the NNWSI Project QAP and (2) development and implementation of the WMPO QAPP, which delineates the controls used by WMPO, WMPO matrix support, and the QASC to conduct their QA activities. QASC activities include participation in QA audits, review of test plans, provisions for QA surveillance and policy guidance, and review of the QAPPs prepared by the participating organizations and NTS support contractors. The overall responsibility to ensure that quality is maintained throughout the NNWSI Project is retained by the director of the WMPO.

--- MATRIX SUPPORT

..... CONTRACTUAL SUPPORT

Figure 8.6-3. Waste Management Project Office organization.

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The NNWSI Project QA organizational structure is such that if disputes in QA arise between the PQM and others (e.g., Branch Chief, Project participants), the disputes will be directed to the WMPO Director for arbitration. If not satisfied, the PQM has the authority (through the QAD Director) to have the DOE/NV Manager arbitrate. If still not satisfied with the resolution, the PQM has the responsibility to notify the OGR QA Manager.

Upon request of the WMPO, the Nevada Test Site Office (NTSO) may provide matrix support personnel that are responsible for field direction and coordination of (1) certain quality related or other work performed by the NTS support contractors and (2) design reviews performed by NTSO staff directly. This work may include architect-engineering, drilling, mining, construction, and logistical support performed at the NTS. The NTSO also acts on requests for NTS support contractor services submitted by participating organizations through the WMPO.

Upon request of the WMPO, the Health Physics and Environmental Division (HPED) may provide matrix support personnel that are responsible for review of procedures, facility designs, and operations plans applicable to radiological monitoring of the environment, radiological health of the public and radiological workers, and radiological operations at the NTS by the DOE/NV, its contractors, or the national laboratories. The HPED acts on requests for support submitted by participating organizations through the WMPO and provides design reviews, advice, and assistance to the WMPO.

Upon request of the WMPO, the Safety and Health Division (SHD) may provide matrix support personnel that are responsible for review of procedures, facility designs, and operations plans applicable to the occupational health and industrial and fire safety of site workers and facilities. The SHD acts on requests for support submitted by participating organizations through the WMPO and provides design reviews, advice, and assistance to the WMPO.

Upon the request of the WMPO, the Contracts and Property Division (CPD) may provide matrix support personnel that are responsible for preparing negotiation contracts and other agreements with the national laboratories and other federal agencies (except the NRC for which the DOE/HQ is responsible) on behalf of the DOE/NV in support of the NNWSI Project. The CPD acts on requests for support submitted by the WMPO and provides procurement package reviews, advice, and assistance to the WMPO.

The NTS support contractors, Fenix & Scisson, Inc. (F&S), Holmes & Narver, Inc. (H&N), and Reynolds Electrical and Engineering Company (REECo), provide support for site characterization. F&S is the architect-engineer (A-E) for drilling and mining for the NNWSI Project. F&S responsibilities also include field surveillance and inspection of drilling and mining, and subsurface facilities construction and testing. H&N is the A-E for above-ground facilities and provides material test laboratory support. H&N responsibilities include design and site preparation for surface facilities and drilling, including field inspection of facility construction. REECo is the prime support contractor for subsurface and surface construction, drilling, and mining. REECo assists in the operation and maintenance of the site facilities and provides procurement activities for the NNWSI Project when requested.

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The participating organizations are Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (Los Alamos), Sandia National Laboratories (SNL), Science Applications International Corporation (SAIC), and the U.S. Geological Survey (USGS).

LLNL is responsible for developing the waste package for the tuff environment, which includes the definition of the package environment, material development, package design, performance analysis, and testing.

Los Alamos is responsible for nuclide migration, geochemistry, mineralogy, and petrology studies. Los Alamos acts as the lead technical organization for the exploratory shaft testing, which includes coordination and scheduling of the exploratory shaft testing program.

SNL is responsible for repository systems development, data management, and analysis; systems performance assessment of the repository; conceptual design of the repository; equipment development and demonstrations; evaluation of thermal and mechanical properties of the host rock; and repository sealing performance requirements, materials evaluation, design, and testing.

SAIC is responsible for technical and management support services (T&MSS), which include technical and management assistance, advice, and consultation to the WMPO Director; research and technology development; Project and technical management studies; Project management system development and Project reporting; engineering and technical support for Project plans, reports, and presentations; institutional support; strategic planning; regulatory and environmental support; coordination of the WMPO peer review process; and conducting overview reviews for the WMPO when requested.

The USGS is responsible for site hydrologic and geologic characterization, including geology, hydrology, geophysical, and geochronology investigations, and tectonics, volcanics, and natural seismic studies.

All NNWSI Project participating organizations and NTS support contractors are responsible for providing assistance to other Project participants in areas of their respective expertise.

Participating organizations and NTS support contractors are responsible to the WMPO for the technical activities assigned to them per the NNWSI Project Work Breakdown Structure Dictionary, and NNWSI Project-specific technical and management plans. The technical activities are to be accomplished in accordance with the quality requirements in the NNWSI QAP and their respective QAPPs, which are approved by the WMPO.

Lines of communication among the WMPO, the participating organizations, and the NTS support contractors are described in the NNWSI Project QAP and the QAPPs of the respective organizations. From an overall NNWSI Project standpoint, these interfaces are exchanges of technical requirements of work to be performed until completion of the task. QAPPs for each participating organization and NTS support contractor describe the methods of conducting interorganizational interfaces, while the NNWSI Project administrative procedures are the procedures that provide the implementing interface controls used by all participating organizations and NTS support contractors.

QA personnel throughout the NNWSI Project report to management levels such that they have sufficient authority and organizational independence to identify quality problems; to initiate, recommend, or provide solutions; to verify implementation of solutions; and to stop unsatisfactory work. The organizational structure for executing the quality assurance programs varies from organization to organization, and each is described in the individual organization's QAPP. The Technical Project Officer of the respective participating organizations and NTS support contractors are responsible to the WMPO Director to ensure that the NNWSI Project activities for which they are responsible are performed in accordance with a QAPP and implementing procedures that are consistent with the NNWSI Project QAP.

8.6.4 APPLICATION OF QUALITY ASSURANCE

8.6.4.1 Quality assurance during site exploration

The NNWSI Project performed comprehensive exploration activities to evaluate the Nevada Research and Development Area (NRDA) of the NTS and nearby areas for relatively favorable locations for the permanent disposal of radioactive waste in a mined geologic repository. This exploratory phase began in 1977. The information obtained during this phase was used in the preparation of the NNWSI Project environmental assessment. In May 1986, Yucca Mountain was selected for the site characterization phase.

The exploration phase of the NNWSI Project included these general activities: site screening, preliminary physical testing, conceptual design work, and developmental work on analytical models. When these activities were initiated, there were no formal NRC QA requirements; hence, these activities were accomplished consistent with good scientific and engineering practices. The most significant aspects of the controls were as follows:

1. Design, testing, analytical work, and site exploration activities were performed by individuals who were qualified by education and experience.
2. The processes for analysis and site exploration, as well as the published results of technical work, were exposed to technical review.

The NNWSI Project QA Plan (QAP), NVO-196-17, was first issued in August 1980. The QA requirements of the plan were based on ASME/ANSI NQA-1, 1979. The document required that QA Program Plans (QAPPs) and implementing procedures be developed by all participating organizations of the NNWSI Project that were performing NNWSI Project tasks, including data gathering from field studies or evaluations made for the exploration phase. A list of the plans and/or procedures developed in response to the requirements of the NNWSI Project QAPP are listed in Table 8.6-2. These documents were developed at different points in the exploration phase and were subject to varying degrees of change during the time the exploration phase was undertaken.

Table 8.6-2. Quality assurance plans and procedures in effect during site exploration^a (page 1 of 12)

Document number	Title
NNWSI DOCUMENTS	
NVO-196-17	NNWSI Quality Assurance Plan
WMPO DOCUMENTS	
NVO-196-18	Management and Overview QA Program Plan
AP-NNWSI-17-01	NNWSI Files
AP-NNWSI-17-02	Activity Plan for the Data Base Management System
QMP-01-01	WMPO Organization
QMP-02-01	Indoctrination and Training
QMP-02-02	Qualification and Certification of Auditors
QMP-03-01	Peer Review
QMP-06-01	QMP Procedure Format and Preparation
QMP-06-02	Document Control
QMP-06-03	Document Review/Approval
QMP-07-01	Surveillance
QMP-11-01	QA Requirements and Responsibilities on NNWSI Drill Holes
QMP-15-01	Nonconformance Control
QMP-15-01	Drilling Program Nonconformance Reporting and Disposition Procedure
QMP-16-01	Corrective Action
QMP-16-02	Trend Analysis
QMP-17-01	NNWSI Record Management Plan

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Table 8.6-2. Quality assurance plans and procedures in effect during site exploration^a (page 2 of 12)

Document number	Title
WMPO DOCUMENTS (continued)	
QMP-18-01	Audits
SPI-110	Qualification of Quality Program Auditors
SPI-111	Audits of Quality Programs
SPI-112	Activity Plans and Activity Instructions
SPI-114	Nonconformance Reporting for Services and Activities
SPI-118	Verification of Services and Activities
SPI-119	Inspection and Surveillance
SPI-120	Control of Quality of Purchased Material, Equipment, and Services
SNL DOCUMENTS	
EPI I-1	Procedure Format and Preparation
EPI I-2	Controlled Document Transmittal
EPI II-1	Training and Indoctrination Program
EPI III-1	Control Requirements for the Design of Hardware, Experimental Programs, and Analytic Models
EPI III-2	Technical Review and Management Approval of Designs for Hardware, Experimental Programs, and Analytic Models
EPI III-3	Design Information Sources
EPI III-4	Design Definition System
EPI III-7	Control of Drawing Revisions (See also QAP III-6)
EPI III-9	Requests for Design Definition Services
EPI IV-1	Review and Approval of Documents

Table 8.6-2. Quality assurance plans and procedures in effect during site exploration^a (page 3 of 12)

Document number	Title
SNL DOCUMENTS (continued)	
EPI IV-2	Control of the Quality of Purchased Materials, Equipment, and Services
EPI V-1	Interactive Procedure Generation
EPI VI-1	Document Control System
EPI VI-2	Contractor Software QA Programs
EPI VI-3	QA Program for Academic Studies and Investigations
EPI VI-4	Contractor QA Requirements for Guidance for R&D Activities
EPI VII-1	Surveillance and Inspection
EPI VII-4	Receiving Inspection
EPI VII-6	Supplier QA Questionnaire
EPI VII-7	Verification of Services and Activities
EPI VIII-1	Identification Marking of Energy Programs Material
EPI IX-1	Control of Special Processes
EPI XI-1	Test Plan/Procedure Content and Control
EPI XI-5	Test/Experiment Logbook Content and Control
EPI XII-2	Calibration Program
EPI XII-3	Calibration of Equipment, Gages, and Standards
EPI XII-4	Calibration and Certification of Sandia Owned Testers
EPI XIII-1	Handling, Shipping, and Storage Procedures
EPI XIII-2	Movement of Materials and Equipment
EPI XIV-1	Status Indication of Items

Table 8.6-2. Quality assurance plans and procedures in effect during site exploration² (page 4 of 12)

Document number	Title
SNL DOCUMENTS (continued)	
EPI XVII-1	Project Records Collection, Filing, Storage, and Maintenance
EPI XVII-3	Conference/Telecon Notes
EPI XVIII-1	Audits of Quality Programs
EPI XVIII-2	Qualifications of Auditors
EPI XIX-1	Software Quality Assurance
QAP I-1	NNWSI Supplemental Quality Assurance Features
QAP I-2	NNWSI Procedure for Quality-Related Work Stoppage
QAP III-3	NNWSI Analysis and Calculation Control
QAP III-6	NNWSI Repository Design Changes (SNL)
QAP IV-1	Contractor QA Program Plan Evaluation
QAP V-2	NNWSI Test Plan/Procedure Control
QAP XI-2	Procedure for Reviewing, Approving, and Issuing NNWSI Technical Information Documents
QAP XI-11	Quality Assurance Procedure for Operation of the SNL NNWSI Core Library
QAP XI-13	SNL NNWSI Quality Assurance Procedure for Writing Letters of Criteria in Support of Laboratory Testing
QAP XVII-4	NNWSI QA Records Requirements
LOS ALAMOS DOCUMENTS	
NNWSI-QP-01	Quality Assurance Program Plan for NNWSI
TWS-MSTQA-QP-02	Quality Assurance Program Index
TWS-MSTQA-QP-03	Document Control Procedure

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Table 8.6-2. Quality assurance plans and procedures in effect during site exploration^a (page 5 of 12)

Document number	Title
LOS ALAMOS DOCUMENTS (continued)	
TWS-MSTQA-QP-04	Handling, Storage, and Shipping Procedure
TWS-MSTQA-QP-06	NNWSI Procurement Procedures
TWS-MSTQA-QP-07	Procedure for Technical Review of Publications
TWS-MSTQA-QP-08	Personnel Certification Procedure for NNWSI
TWS-MSTQA-QP-10	Document Control of the Exploratory Shaft Test Plan
TWS-MSTQA-QP-11	NNWSI Surveillance Procedure
TWS-MSTQA-QP-14	Research and Development (Experimental) Procedure
LLNL DOCUMENTS	
033-NNWSI-P.1.0	Organization
033-NNWSI-P.15.0	Nonconformance
033-NNWSI-P.16.0	Corrective Action
033-NNWSI-P.17.0	Quality Assurance Records
033-NNWSI-P.18.0	Audits
033-NNWSI-P.2.0	Assurance
033-NNWSI-P.4.0	Procurement Document Control
033-NNWSI-P.6.0	Document Control
033-NNWSI-R.10.0	Inspection
033-NNWSI-R.11.0	Test Control
033-NNWSI-R.13.0	Handling, Storage, and Shipping
033-NNWSI-R.14.0	Inspection, Test, and Operating Status
033-NNWSI-R.3.0	Design Control

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Table 8.6-2. Quality assurance plans and procedures in effect during site exploration^a (page 6 of 12)

Document number	Title
LLNL DOCUMENTS (continued)	
033-NNWSI-R.6.0	Document Control
033-NNWSI-R.7.0	Control of Purchased Materials, Equipment, and Services
033-NNWSI-R.8.0	Identification and Control of Materials, Parts, and Components
033-NNWSI-R.9.0	Control of Processes
033-NWMP-P.5.0	Instructions, Procedures, Drawings
033-NWMP-P17.0	Quality Assurance Records
033-NWMP-P17.1	Receipt and Review of QA Records
033-NWMP-P17.2	Identification and Indexing of QA Records
033-NWMP-P18.0	Audits
033-NWMP-P6.1	Issue of Controlled Documents
SAIC DOCUMENTS	
A 13	Corporate Purchasing Instructions for Purchase Requests
A 14	Corporate Purchasing Instructions for Purchase Orders
A 15	Corporate Purchasing Instructions for Processing Changes or Cancellation to PROs and POs
A 22	Corporate Purchasing Instructions for Preparation and Processing of Requests for Quotation
A 23	Corporate Purchasing Instructions for Subcontract
A 31	Corporate Purchasing Instructions for Subcontract Documentation Requirements

Table 8.6-2. Quality assurance plans and procedures in effect during site exploration² (7 of 12)

Document number	Title
SAIC DOCUMENTS (continued)	
A 39	Corporate Purchasing Instructions for Administration of POs and Subcontracts
AP 1.16	T&MSS Master Project File Description and Control
AP 2.1	Task Planning and Review
AP 2.3	Independent Review and Peer Review
AP 3.1	Training and Orientation of T&MSS Staff
B 18	Use of Consultants
B 3	Employment Records
QAPP-1	T&MSS Quality Assurance Program Plan
QP 2.2	Indoctrination and Training of Personnel Performing Quality Related Functions
QP 2.3	Auditor Qualification
QP 2.4	Assignment of Quality Levels
QP 3.1	Design Control
QP 3.2	Use and Control of Computer Programs
QP 4.1	Procurement Document Control
QP 5.1	Instructions, Procedures, and Drawings
QP 6.1	Document Control
QP 7.1	Control of Purchased Items and Services
QP 8.1	Identification and Control of Materials, Parts, and Components
QP 9.1	Control of Processes
QP 10.1	Test/Experiment Control

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Table 8.6-2. Quality assurance plans and procedures in effect during site exploration^a (page 8 of 12)

Document number	Title
SAIC DOCUMENTS (continued)	
QP 12.1	Control of Measuring and Test Equipment
QP 13.1	Control of Handling, Storage, and Shipping
QP 14.1	Control of Inspection, Test, and Operating Status
QP 15.1	Control of Nonconforming Items
QP 16.1	Corrective Action
QP 17.1	Quality Assurance Records
QP 18.1	Audits
USGS DOCUMENTS	
NNWSI-USGS-QAPP-01	Quality Assurance Program Plan
QMP 10.01	Surveillance Procedure
QMP 11.01	Preparation and Issuance of Tentative Technical Procedures
QMP 15.01	Procedure for Control of Nonconforming Items
QMP 16.01	Control for Corrective Action Procedure
QMP 17.01	Quality Assurance Records Management
QMP 18.01	Auditing Procedure
QMP 2.01	Management Assessment of the NNWSI USGS Quality Assurance Program
QMP 2.02	Indoctrination and Training
QMP 2.03	Certification of USGS Technical Personnel for the NNWSI Project
QMP 2.04	Certification of Fenix and Scisson Geologists

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Table 8.6-2. Quality assurance plans and procedures in effect during site exploration^a (page 9 of 12)

Document number	Title
USGS DOCUMENTS (continued)	
QMP 2.05	Qualification of Quality Assurance Program Audit Personnel
QMP 3.01	Procedure for Identification of Research/Experiment Activities
QMP 3.02	USGS QA Levels Assignment Procedure
QMP 3.04	Technical Review of NNWSI Publications of the U.S. Geological Survey
QMP 3.05	Work Request for NTS Contractor Services (Criteria Letter)
QMP 4.01	Procurement Document Control
QMP 5.01	Preparation of Technical Procedures
QMP 6.01	Document Control
QMP 8.01	Identification and Control of Geologic and Hydrologic Samples
REEC _o DOCUMENTS	
568-DOC-115	Quality Assurance Program Plan for the NNWSI Project
NQP 1.0	Organization
NQP 10.0	Inspection
NQP 11.0	Test and Experiment Control
NQP 12.0	Control of Measuring and Test Equipment
NQP 13.0	Handling, Shipping, and Storage
NQP 14.0	Inspection, Test, and Operating Status
NQP 15.0	Control of Nonconforming Items

Table 8.6-2. Quality assurance plans and procedures in effect during site exploration^a (page 10 of 12)

Document number	Title
USGS DOCUMENTS (continued)	
NQP 16.0	Corrective Action
NQP 17.0	Quality Assurance Records
NQP 18.0	Audits
NQP 2.0	Quality Assurance Program
NQP 3.0	Design Control
NQP 4.0	Procurement Document Control
NQP 5.0	Instructions, Procedures, and Drawings
NQP 6.0	Document Control
NQP 7.0	Control of Purchased Items and Services
NQP 8.0	Identification and Control of Materials, Parts, and Components and Samples
NQP 9.0	Control of Processes
F&S DOCUMENTS :	
QAP-1.1(N)	Organization
QAP-10.1(N)	Source Inspection
QAP-10.2(N)	Quality Assurance Surveillance of Neutron Hole Drilling Programs
QAP-11.1	Procedure for Permeability Tests of Underground Holes
QAP-11.4	Procedure for Surveillance of Seismic Testing Activities
QAP-12.1	Calibration Procedure
QAP-13.1	Handling, Storage, and Shipment

Table 8.6-2. Quality assurance plans and procedures in effect during site exploration^a (page 11 of 12)

Document number	Title
F&S DOCUMENTS (continued)	
QAP-14.1	Inspection, Test, and Operating Status
QAP-15.2(N)	Reporting Nonconformances on the NNWSI Project
QAP-16.1(N)	Corrective Action Procedure
QAP-17.1	Quality Assurance Records Procedure
QAP-18.1(N)	Audit Procedure
QAP-18.2(N)	Qualification and Certification of Auditors
QAP-2.1(N)	Quality Assurance Program
QAP-2.2(N)	Indoctrination and Training of Quality Assurance Personnel
QAP-2.3(N)	Preparation of Quality Assurance Procedures
QAP-3.1(N)	Engineering Drawings
QAP-3.2(N)	Engineering Specifications
QAP-5.1	Instructions, Procedures, and Drawings
QAP-6.1	Document Control
QAP-7.1	Supplier Survey
QAP-7.2(N)	Surveillance Inspection Requirement
QAP-8.1	Identification and Control of Items
QAP-9.1(N)	Control of Processes
QAPP-002	Quality Assurance Program Plan for the NNWSI Project
QRP-1	NNWSI Quality Assurance Records Procedure
H&N DOCUMENTS	
HN-1047-1115	QA Manual

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Table 8.6-2. Quality assurance plans and procedures in effect during site exploration^a (page 12 of 12)

Document number	Title
H&N DOCUMENTS (continued)	
4.6.2	Drill Rig Inspection and Certification
4.6.3	Nondestructive Testing Personnel Qualification and Certification
4.6.4	NDT Contractor Qualification, Certification and Audit
4.6.6	Boiler & Pressure Vessel Program
4.6.7	Welder Certification
4.6.8	Welding Inspector Qualification and Certification
4.6.9	Wire Rope Socket Installer Certification
4.6.12	Fire Sprinkler System Installation
4.6.14	Certification Requirements for Quality Audit Personnel
4.7.1	Calibration Program
4.7.2	Calibration of Electrical Electronic Instrumentation
4.7.3	Calibration of Flow Meters
4.7.4	Pressure Systems Inspection Procedure

^aNNWSI - Nevada Nuclear Waste Storage Investigations, WMPO - Waste Management Project Office, QA - Quality Assurance, QMP - Quality Management Procedure, SNL - Sandia National Laboratories, QAP - Quality Assurance Plan, R&D - Research and Development, LLNL - Lawrence Livermore National Laboratory, SAIC - Science Applications International Corporation, PRO - Purchase Requisition Order, PO - Purchase Order, T&MSS - Technical and Management Support Services, USGS - United States Geological Survey, NTS - Nevada Test Site, REECo - Reynolds Electrical and Engineering Company, F&S - Fenix & Scisson, H&N - Holmes & Narver, NDT - nondestructive testing.

Primary data or data interpretations generated before August 1980 that will be used during licensing will undergo an acceptance review process per the NNWSI Project administrative procedure for acceptance of data or data interpretations not developed under the NNWSI Project QAP.

8.6.4.2 Quality Assurance during site characterization

The NNWSI Project approach to identification of items and activities important to safety or waste isolation is encompassed in the NNWSI Project Quality Assurance level system as described in Section 8.6.1. Each NNWSI Project participant is to evaluate their assigned tasks (from the Waste Management Project Office) for identification and classification of items and activities that require QA level assignments. The NNWSI Project site characterization items and activities classified as QA Level I will be processed through the Office of Geologic Repositories guidance on Site Characterization Plan Q-list methodology. This process and NNWSI Project Q-list are identified in Sections 6.1.4 and 6.1.5.

The Quality Activities List is a list of activities that are associated with assessing the natural barriers important to waste isolation or activities whose undertaking could adversely affect the performance of the natural barriers. These activities will be controlled as QA Level I activities in accordance with the NNWSI Project QA Plan. The preliminary NNWSI Quality Activities List includes the following:

1. Data collection activities associated with the site characterization test as described in Section 8.3, which will be used as primary data to aid in formulating the description of the site.
2. Blasting of the shafts and drafts.

The rationale for inclusion of activities on the activities list is that they (1) will provide site characterization data which will be utilized to assess the performance of the natural barriers important to waste isolation and hence be used as primary data to support the license application and (2) if not performed in a controlled manner, could adversely affect the performance of the existing natural barriers.

The Quality Activities List is based on detailed planning of tests and analyses that is not presented in the SCP. This detailed planning will be presented in study plans. As study plans are developed, the QA Level for specific tests and analyses will be determined. For each test and analysis, the QA Level will be indicated and the rationale will be provided for any activity that is not judged to be QA Level 1. The Quality Activities List, and any changes to it, will be identified in the semiannual progress reports.

8.6.5 ADMINISTRATIVE QUALITY ASSURANCE PROCEDURES

The NNWSI Project Quality Assurance Plan (QAP) directs each participating organization in the NNWSI Project to prepare and submit to the Waste

Management Project Office (WMPO) a Quality Assurance Program Plan (QAPP) to control their particular technical tasks affecting quality. These QAPPs are equivalent to the QA administrative procedures identified in the NRC standard review plan (Section 8.6.1). The WMPO will review and approve each participant's QAPP, and changes thereto prior to use on site characterization and design activities, in accordance with OGR/B3. Table 8.6-1 lists the documents of the current QAPP of each participating organization. The latest approved and issued revisions of the documents will be applied during site characterization.

In accordance with the NNWSI Project QAP, the participating organizations will develop implementing procedures to show how the QA requirements of their QAPPs are implemented. The implementing procedures are equivalent to the term detailed technical procedures identified in the NRC standard review plan and are written by various disciplines, including QA. Implementing procedures are reviewed and approved by the organization's technical management and QA divisions.

The specific implementing procedures to be utilized for site characterization are provided in Chapter 8.3 with the specific test to be conducted during site characterization. Table 8.6-3 provides a listing of implementing procedures that will be generic to all site characterization tasks.

8.6.6 QUALITY ASSURANCE PLANS AND PROCEDURES FOR SPECIFIC PROGRAM AREAS

The QA Plans and Procedures that will be used to control the NNWSI Project site characterization and design activities are listed in Tables 8.6-1 and 8.6-3 or in Section 8.3. These plans and procedures include the implementing methods for design and site investigation control; procurement document control; instructions, drawings, and procedures; document control; control of purchased materials, equipment, and services; identification and control of material parts and components; control of processes; inspection; test and experiment control; control of measuring and test equipment; handling, storage, and shipping; control of inspection, test, and operating status; nonconformances; corrective action; quality assurance records; and audits. The QA requirements that are applied to the criteria, to ensure adequate controls, are found in the NNWSI QA Plan.

Detailed implementing procedures have been developed by the NNWSI Project participants' technical staff to provide instructions for the actual performance of the individual technical activities associated with site characterization. These procedures have been developed with the appropriate QA requirements included and are in accordance with the applicable QA Program Plan. Implementing procedures that will be used for conducting tests during site characterization are referenced in Section 8.3 of this plan. Implementing procedures that are not yet available at issuance of the SCP will be identified in future SCP progress reports and made available for review before testing begins.

Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project procedures generic to site characterization tasks²
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Number	Title
NNWSI DOCUMENTS	
NNWSI-AP-1.1Q	Administrative Procedure Preparation
NNWSI-AP-1.3Q	Documents requiring WMPO review
NNWSI-AP-1.5Q	Issuance of Controlled Documents
NNWSI-AP-1.6Q	Release of Unpublished Information
NNWSI-AP-1.8Q	NNWSI Project QA Records Management
NNWSI-AP-3.3Q	Change Control Process
NNWSI-AP-3.4Q	Project Technical Baseline
NNWSI-AP-3.5Q	Project Regulatory Baseline
NNWSI-AP-5.2Q	Screening and Identification of data and information for entry into the Technical Data Base
NNWSI-AP-5.3Q	Technical data and information submitted to the Reference Information Base
NNWSI-AP-5.4Q	Assignment of Quality Assurance Levels to NNWSI Project Activities and Items
NNWSI-AP-5.5Q	Software QA
NNWSI-AP-5.6Q	ESF Interface Control
NNWSI-AP-5.7Q	Site Integration Control
NNWSI-AP-5.8Q	NNWSI Project Management Assessment
NNWSI-AP-5.9Q	Acceptance of Data or Data Interpretations Not Developed under the NNWSI Project QA Plan
NNWSI-AP-5.10Q	Use of NTS Support Contractors on the NNWSI Project
NNWSI-AP-5.11Q	Calibration of M&TE utilizing NTS Support Contractors

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Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks^a
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Number	Title
WMPO DOCUMENTS	
QMP-01-01	WMPO Organization
QMP-01-02	Stop Work
QMP-02-01	Indoctrination and Training
QMP-02-02	Qualification and Certification of Auditors
QMP-02-03	Management Assessment of the NNWSI Project QA Program
QMP-02-04	Readiness Reviews
QMP-02-05	QA Commitment to Outside Agencies
QMP-03-01	Peer Review
QMP-04-01	Procurement Document Control
QMP-05-01	QMP Format and Preparation
QMP-06-02	Document Control
QMP-06-03	Document Review and Approval
QMP-07-02	Effectiveness of Participants QA Programs
QMP-07-03	Control of Purchased Materials and Service
QMP-15-01	Nonconformance Control
QMP-15-02	Usual Occurrence Reporting
QMP-16-01	Corrective Action
QMP-16-02	Trend Analysis
QMP-16-03	Deficiency Reporting
QMP-17-01	QA Records
QMP-18-01	Audits

Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks^a
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Number	Title
WMPO DOCUMENTS (continued)	
QMP-18-02	Surveillance
SAIC DOCUMENTS	
QP 2.2	Indoctrination and Training of Personnel Performing Quality Related Functions
QP 2.3	Auditor Qualification
QP 2.4	Assignment of Quality Levels
AP 2.1	T&MSS--Task Planning and Review
AP 2.3	T&MSS--Independent Review and Peer Reviews
AP 3.1	T&MSS--Training and Orientation of T&MSS Staff
B-3	Personnel Records (Education/Experience Verification only)
B-18	Use of Consultants
QP 3.1	Design Control
QP 3.2	Use and Control of Computer Codes
QP 4.1	Procurement Document Control
A-13	SAIC--Instructions for Preparation and Processing of Purchase Request Orders
A-14	SAIC--Instructions for Preparation and Processing of Purchase Orders
A-15	SAIC--Instructions for Processing Changes or Cancellations to Purchase Request Orders and Purchase Orders
A-22	SAIC--Instructions for Preparation and Processing of Requests for Quotations

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Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project procedures generic to site characterization tasks^a
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Number	Title
SAIC DOCUMENTS (continued)	
A-23	SAIC--Subcontracts
A-31	SAIC--Purchase Order and Subcontract Documentation Requirements
A-39	SAIC--Administration of Purchase Orders and Subcontracts
QP 5.1	Instructions, Procedures, and Drawings
QP 6.1	Document Control
QP 7.1	Control of Purchased Items and Services
QP 8.1	Identification and Control of Materials, Parts, and Components [includes geological and environmental samples as well as government furnished/purchased equipment (GFE/GPE)]
QP 9.1	Control of Processes
QP 10.1	Inspection
QP 11.1	Test/Experiment Control
QP 12.1	Control of Measuring and Test Equipment
QP 13.1	Handling, Storage, and Shipping (includes archival, geological, and environmental samples)
QP 14.1	Control of Inspection, Test, and Operating Status
QP 15.1	Control of Nonconforming Items
QP 16.1	Corrective Action
QP 17.1	QA Records
QP 18.1	Audits

Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks^a
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Number	Title
SNL DOCUMENTS	
QAP 01-03	Procedure for Quality-Related Work Stoppage
DOP 02-01	Requirements for Task Definition Statements
DOP 02-02	Study Plan Requirements
QAP 02-03	QA Level Determination and Assignment
DOP 02-04	Analysis Control and Verification
QAP 02-05	Training and Familiarization Program
DOP 02-06	Certification of Project Personnel
QAP 02-07	Certification of Quality Assurance Auditors
DOP 03-01	Reviewing, Approving, and Issuing NNWSI Engineering Drawings
DOP 03-02	Software Quality Assurance Requirements
DOP 03-03	Analysis Definition requirements (new title)
DOP 03-04	Design Investigation Control
DOP 03-05	Design Control and Verification
DOP 03-06	Design Change Control
DOP 03-07	Technical Data Base Requirements
DOP 03-09	SNL Interface Controls of Engineering Design
DOP 03-10	NNWSI Routine Design Calculations
DOP 04-01	Procurement Document Requirements
DOP 04-02	Changes to Procurement Documents
DOP 05-01	Quality Assurance Procedure Requirements
DOP 05-02	Technical Procedures Requirements

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Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project procedures generic to site characterization tasks^a
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Number	Title
SNL DOCUMENTS (continued)	
DOP 05-03	QA Review of DOPs
DOP 06-01	Document Control System
DOP 06-02	Procedure for Reviewing, Approving, & Issuing NNWSI Technical Information
DOP 07-01	Planning of Procurements
DOP 07-02	Evaluation for Acceptance of Purchased Items and Services
DOP 07-03	Evaluation of Contractor QA Programs
DOP 08-01	Sample Identification and Handling Requirements
DOP 08-02	Quality Assurance Procedure for Operation of the NNWSI Core Library
DOP 09-01	Control of Special Processes
QAP 10-01	Surveillance Requirements
QAP 10-02	Inspection
DOP 11-01	Experiment Procedure Requirements
DOP 11-02	Requirements for Experiment/Test Logbooks
DOP 11-03	Data Records Management System Interaction
DOP 11-05	Analysis of Data Gathered in Experiments or Equipment Tests
DOP 12-01	Calibration Program
DOP 13-01	Identification, Handling, Shipping, and Storage Procedures for Items
DOP 14-01	Status Indication of Items
QAP 15-01	Nonconformance Reporting and Controls

Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks^a
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Number	Title
SNL DOCUMENTS (continued)	
QAP 16-01	Corrective Action Requirements
DOP 17-01	Records Management
DOP 17-02	DRMS Operation
QAP 18-01	Audit Requirements
EPI III-3	Design Information Sources
EPI III-9	Request for Design Definition Services
EPI IV-2	Control of the Quality of Purchased Materials, Equipment, and Services
EPI VI-2	Contractor Software QA Programs
EPI VI-3	QA Program for Academic Studies and Investigations
EPI VI-4	Contractor QA Requirements for Guidance for R&D Activities
EPI VII-1	Surveillance and Inspection
EPI VII-4	Receiving Inspection
EPI VII-6	Supplier QA Questionnaire
EPI VII-7	Verification of Services and Activities
EPI VIII-1	Identification Marking of Energy Programs Material
EPI IX-1	Control of Special Processes
EPI XII-2	Calibration Program
EPI XII-3	Calibration of Equipment, Gages, and Standards
EPI XII-4	Calibration and Certification of Sandia Owned Testers

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Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks²
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Number	Title
SNL DOCUMENTS (continued)	
EPI XIII-1	Handling, Shipping, and Storage Procedures
EPI XIII-2	Movement of Materials and Equipment
EPI XVII-3	Conference/Telecon Notes
EPI XVIII-2	Qualifications of Quality Program Auditors
EPI XIX-1	Software Quality Assurance
LLNL DOCUMENTS	
033-NWMP-P 1.0	Organization
033-NWMP-P 2.0	Assurance
033-NWMP-P 2.2	Peer Review
033-NWMP-R 3A.0	Scientific Investigation Control
033-NWMP-R 3B.0	Design Control
033-NWMP-P 4.0	Procurement Document Control
033-NWMP-P 5.0	Instructions, Procedures, and Drawings
033-NWMP-P 5.1	Preparation of Technical Procedures
033-NWMP-P 5.2	Review & Approval of Technical Procedures
033-NWMP-P 6.0	Document Control
033-NWMP-P 6.1	Issue of Controlled Documents
033-NWMP-P 7.0	Control of Purchased Materials, Equipment, and Services
033-NWMP-R 8.0	Identification and Control of Materials, Parts, and Components
033-NWMP-R 9.0	Control of Processes

Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
 procedures generic to site characterization tasks^a
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Number	Title
LLNL DOCUMENTS (continued)	
033-NWMP-R 10.0	Inspection
033-NWMP-R 11.0	Test Control
033-NWMP-R 12.0	Control of Measuring and Test Equipment
033-NWMP-P 12.1	Laboratory Calibration of the Goodman Borehole Jack
033-NWMP-P 12.2	Calibrating Balances
033-NWMP-R 13.0	Handling, Storage, and Shipping
033-NWMP-R 14.0	Inspection, Test, and Operating Status
033-NWMP-P 15.0	Nonconformances
033-NWMP-P 16.0	Corrective Action
033-NWMP-P 17.0	Quality Assurance Records
033-NWMP-P 17.1	Receipt and Review of Quality Assurance Records
033-NWMP-P 17.2	Identification and Indexing of Quality Assurance Records
033-NWMP-P 17.3	Storage of Quality Assurance Records
033-NWMP-P 17.4	Transmittal of Quality Assurance Records
033-NWMP-P 17.5	Receipt and Verification of Film Received
033-NWMP-P 17.6	Retrieval of Quality Assurance Records
033-NWMP-P 18.0	Audits
033-NWMP-P 18.1	Surveillance
033-NWMP-P 18.2	Qualification of Quality Assurance Audit Personnel
033-NWMP-R 19.0	Software Quality Assurance

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Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks^a
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Number	Title
LLNL DOCUMENTS (continued)	
033-NWMP-R 19.1 (EQ3/6)	Appendix 1
033-NWMP-R 19.1 (EQ3/6)	Appendix 2
033-NWMP-R 19.1 (EQ3/6)	Requirements for Development and use of Scientific and Engineering Software
033-NWMP-R 19.2 (EQ3/6)	Coding Standards for Fortran Computer Codes
033-NWMP-R 19.3 (EQ3/6)	Acquisition and Evaluation of Computer Codes
033-NWMP-P 19.4 (EQ3/6)	Development of Computer Codes
033-NWMP-P 19.5 (EQ3/6)	Verification and Validation of Computer Codes
033-NWMP-P 19.6 (EQ3/6)	Documentation of Scientific and Engineering Software
033-NWMP-P 19.7 (EQ3/6)	Peer Review of Scientific and Engineering Software
033-NWMP-P 19.8 (EQ3/6)	Transfer of Computer Codes
033-NWMP-P 19.9 (EQ3/6)	Application of Scientific and Engineering Software
033-NWMP-P 19.10 (EQ3/6)	Error Reporting and Resolution
033-NWMP-P 19.11 (EQ3/6)	Working Environment for Storage, Development, and Application of Computer Codes
033-NWMP-P 19.12 (EQ3/6)	Backup and Archiving of Computer Codes
033-NWMP-P 20.0	Quality Assurance Level
033-NWMP-P 20.1	Numbering of Activities
033-NWMP-R 21A.0	Training
033-NWMP-R 21B.0	Qualification of Personnel
033-NWMP-P 22.0	Technical Review of Publications

Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks^a
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Number	Title
F&S DOCUMENTS	
QAP-1.1 (N)	Organization
QAP-2.1 (N)	Quality Assurance Program
QAP-2.2 (N)	Indoctrination and Training of Personnel
QAP-2.3 (N)	Preparation of QA Procedures
QAP-3.1	Engineering Drawings
QAP-3.2 (N)	Engineering Specifications
QAP-4.2 (N)	Procurement Authorization Form
QAP-5.1 (N)	Instructions, Procedures, and Drawings
QAP-6.1 (N)	Document Control
QAP-7.1 (N)	Supplier Survey
QAP-7.2 (N)	Surveillance Inspection Requirement
QAP-8.1 (N)	Identification and Control of Items
QAP-12.1	Calibration Procedure
QAP-9.1 (N)	Control of Processes
QAP 10.1 (N)	Source Surveillances
QAP-10.2 (N)	QA Surveillance of Neutron Hlz Drilling Program
QAP-13.1	Handling, Storage, and Shipment
QAP-14.1	Inspection, Test, and Operating Status
QAP-15.2 (N)	Reporting Nonconformance on the NNWSI Project
QAP-16.1 (N)	Correction Action Procedure
QAP-17.1	Quality Assurance Records Procedure

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Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks^a
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Number	Title
F&S DOCUMENTS (continued)	
QAP-18.1 (N)	Audit Procedure
QAP-18.2 (N)	Qualification and Certification of Auditors.
USGS DOCUMENTS	
NNWSI-USGS-QMPP-1.01	Organization Procedure
NNWSI-USGS-QMP-1.02	Stop Work Authority
NNWSI-USGS-QMPP-2.01	Management Assessment of the NNWSI-USGS Quality Assurance Program
NNWSI-USGS-QMPP-2.02	Indoctrination and Training
NNWSI-USGS-QMPP-2.03	Certification of USGS and USGS Contractor Personnel for the NNWSI Project
NNWSI-USGS-QMP-2.05	Qualification of QA Program Audit Personnel
NNWSI-USGS-QMP-3.01	Identification of Research/Experimental Activities
NNWSI-USGS-QMP-3.02	USGS QA Level Assignment
NNWSI-USGS-QMP-3.03	Scientific and Engineering Software QA
NNWSI-USGS-QMP-3.04	Technical Review of NNWSI-USGS Publications
NNWSI-USGS-QMP-3.05	Work Requests for NTS Contractor Services
NNWSI-USGS-QMP-3.06	Scientific Investigation Plan
NNWSI-USGS-QMP-3.07	Technical Review Procedure
NNWSI-USGS-QMP-4.01	Procurement Document Control
NNWSI-USGS-QMP-5.01	Preparation of Technical Procedures
NNWSI-USGS-QMP-5.02	Preparation and Control of Drawings and Sketches

Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks^a
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Number	Title
USGS DOCUMENTS (continued)	
NNWSI-USGS-QMP-5.03	Participant Control of the USGS QAPP and QMPs
NNWSI-USGS-QMP-6.01	Document Control
NNWSI-USGS-QMP-7.01	Certification of Suppliers
NNWSI-USGS-QMP-7.02	Receiving Inspection
NNWSI-USGS-QMP-7.03	Acceptance of Materials, Equipment and Services
NNWSI-USGS-QMP-8.01	Identification and Control of Geologic and Hydrologic Samples
NNWSI-USGS-QMP-9.01	Special Processes
NNWSI-USGS-QMP-10.01	Inspection (Surveillance)
NNWSI-USGS-QMP-11.01	Preparation and Issuance of Tentative Technical Procedures
NNWSI-USGS-QMP-12.01	Instrument Calibration
NNWSI-USGS-QMP-13.01	Handling, Storage, & Shipping of Instruments
NNWSI-USGS-QMP-15.01	Control of Nonconforming Items
NNWSI-USGS-QMP-15.02	Control of Unusual Occurrences
NNWSI-USGS-QMP-16.01	Control for Corrective Action Procedure
NNWSI-USGS-QMP-17.01	QA Records Management
NNWSI-USGS-QMP-17.02	Acceptance of Data not Developed under the NNWSI QA Plan
NNWSI-USGS-QMP-18.01	External and Internal Auditing
LOS ALAMOS DOCUMENTS	
TWS-QASQA-QP-02	Quality Assurance Program Index

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Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks^a
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Number	Title
LOS ALAMOS DOCUMENTS (continued)	
TWS-QASQA-QP-03	Document Control Procedure
TWS-QASQA-QP-04	Handling, Storage, and Shipping Procedure
TWS-QASQA-QP-06	NNWSI Procurement Procedures
TWS-QASQA-QP-07	Procedure for Technical Review of Publications
TWS-QASQA-QP-08	Personnel Certification Procedure for NNWSI
TWS-QASQA-QP-09	Records Control Procedure
TWS-QASQA-QP-10	Document Control of the Exploratory Shaft Test Plan
TWS-QASQA-QP-11	NNWSI Surveillance Procedure
TWS-QASQA-QP-12	Receiving Inspection
TWS-QASQA-QP-13	Conflict Resolution Procedure
TWS-QASQA-QP-14	Quality Assurance Procedure for One-Time Research and Development Work
H&N DOCUMENTS	
QAGL 1.0	Organization and Responsibilities of Quality Assurance Personnel
QAGL 2.0	Orientation and Training
QAGL 3.0	Drawing and Specification Review
QAGL 5.0	Generation and control of Quality Assurance Guidelines
QAGL 6.0	Generation and Control of Quality Assurance Guidelines
QAGL 8.0	Identification and Control of Material, Parts, and Components

Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks^a
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Number	Title
H&N DOCUMENTS (continued)	
QAGL 9.0	Control and Special Processes
QAGL 10.0	Inspection
QAGL 12.0	Control of Measuring and Test Equipment
QAGL 13.0	Handling, Storage, and Shipping
QAGL 14.0	Inspection, Test, and Operating Status
QAGL 15.0	Nonconformances
QAGL 16.0	Corrective Action
QAGL 16.2	Review of Nonconforming Documentation
QAGL 17.0	QA Records
QAGL 18.0	Audits
QAGL 18.1	Qualification of Audit Personnel
QAGL 18.2	Surveillance Activities
NNWSI-001	Generation and Control of NNWSI Procedures
NNWSI-002	Indoctrination, Training, Certification, and Qualification
NNWSI-003	Specification Preparation and Control
NNWSI-004	Controlled Distribution of Design Documents
NNWSI-005	Design Drawing Preparation and Control
NNWSI-006	Design Calculation
NNWSI-007	Work Initiation, Criteria Gathering, and Reporting
NNWSI-009	Stop Work Order

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Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
procedures generic to site characterization tasks^a
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Number	Title
SURVEY	
NNWSI-016	Survey Document Control and Distribution
NNWSI-017	Survey Department work function
NONDESTRUCTIVE TESTING	
NNWSI-022	Personnel Qualification and Certification
NNWSI-TBD	Filing and Retention of Testing and Inspection Reports
NNWSI-TBD	Magnetic Particle Testing
NNWSI-TBD	Liquid Penetrant Testing
NNWSI-TBD	Ultrasonic Testing
NNWSI-TBD	Radiography Testing
NNWSI-TBD	Standards Certification
NNWSI-TBD	Raw Film and Chemical Storage
NNWSI-TBD	Exposed Film Storage
NNWSI-TBD	Expendable Film Storage
NNWSI-TBD	Expendable Material Certifications
CONSTRUCTION SERVICES	
NNWSI-TBD	Ordering Materials
NNWSI-TBD	Stop Work
NNWSI-TBD	Vendor Requested Specification Deviations
NNWSI-TBD	Qualification of Personnel
NNWSI-TBD	Inspection

Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project
 procedures generic to site characterization tasks^a
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Number	Title
REECo DOCUMENTS	
NQP-1.0	Organization
NQP-2.0	Quality Assurance Program
NQP-2.1	Qualification and Certification of Inspection Personnel
NQP-2.2	Personnel Certification for QA Level 1
NQP-3.0	Design Control
NQP-3.1	Design Review
NQP-4.0	Procurement Document Control
NQP-5.0	Instructions, Drawings, and Procedures
NQP-5.1	Procedure Review
NQP-6.0	Document Control
NQP-7.0	Control of Purchased Items, and Services
NQP-7.2	Procurement Document Review
NQP-7.4	Annual Supplier Evaluation
NQP 7.5	Supplier Evaluation
NQP-8.0	Identification and Control of Materials, Parts, Components, and Samples
NQP-9.0	Control of Processes
NQP-9.1	Welding Procedure Qualification
NQP-9.2	Welder Certification
NQP-10.0	Inspection
NQP-11.0	Test and Experiment Control
NQP-12.0	Control of Measuring and Test Equipment

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Table 8.6-3. Nevada Nuclear Waste Storage Investigations Project procedures generic to site characterization tasks^a
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Number	Title
REECo DOCUMENTS (continued)	
NQP-13.0	Handling, Storage, and Shipping
NQP-14.0	Inspection, Test, and Operating Status
NQP-15.0	Control of Nonconforming Items
NQP-16.0	Corrective Actions
NQP-16.1	Request for Corrective Actions
NQP-17.0	Quality Assurance Records
NQP-18.0	Audits
NQP-18.1	Surveillance

^aNNWSI - Nevada Nuclear Waste Storage Investigations, WMPO - Waste Management Project Office, QA - Quality Assurance, QMP - Quality Management Procedure, SNL - Sandia National Laboratories, R&D - Research and Development, LLNL - Lawrence Livermore National Laboratory, SAIC - Science Applications International Corporation, USGS - United States Geological Survey, NTS - Nevada Test Site, REECo - Reynolds Electrical and Engineering Company, F&S - Fenix & Scisson, H&N - Holmes & Narver, NDT - nondestructive testing, M&TE - measuring and test equipment, DRMS - data record management system, QAPP - Quality Assurance Program Plan, ESF - exploratory shaft facility, T&MSS - technical and management support services, DOP - TBD - to be developed.

Nuclear Waste Policy Act
(Section 113)

Section 8.7

Consultation Draft

**DECONTAMINATION AND
DECOMMISSIONING**

Site Characterization Plan

***Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

Volume VII

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U.S. Department of Energy
Office of Civilian Radioactive Waste Management
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8.7 DECONTAMINATION AND DECOMMISSIONING

If Yucca Mountain is determined to be unsuitable for application for a construction authorization for a repository (NWP, 1983), the site will be decontaminated and decommissioned, and any significant adverse environmental impacts associated with site characterization activities will be mitigated. This section presents general plans for decontamination and decommissioning of the site and for mitigation of any significant adverse environmental impacts caused by site characterization. Specific plans for these activities will be prepared when necessary and in consultation with appropriate Federal and State agencies. At the present time, requirements for obtaining access to the land, including requirements for land restoration, are being discussed with Federal and State agencies. As study plans are developed and site characterization progresses, plans for decommissioning and decontamination will become more specific and will be described in SCP progress reports.

Decontamination of the site is discussed in Section 8.7.1. Section 8.7.2 describes the general decommissioning plans including possible strategies for alternative use of site characterization facilities. General plans for mitigation of significant adverse environmental impacts caused by site characterization activities are discussed in Section 8.7.3.

8.7.1 DECONTAMINATION

Decontamination activities involve the selective removal of radioactive material from a surface or from within another material. The plans for site characterization activities do not include the use of high-level radioactive materials. The radioactive sources and sensors that may be used by geophysical logging tools to investigate the movement of ground water during exploratory drilling are designed to be fully contained and retrievable, as addressed in Chapter 4 of the final environmental assessment for Yucca Mountain (DOE, 1986b). No radioactive tracers are currently planned to be used at the site during site characterization. Therefore, no decontamination is expected to be required after site characterization.

8.7.2 DECOMMISSIONING

Decommissioning is defined as the planned, orderly execution of steps to place a facility in a permanently nonoperable, safe condition. This would normally follow a determination that the Yucca Mountain site is unsuitable for consideration as a repository. The decommissioning of the exploratory shaft facility (ESF) and other lands disturbed by site characterization activities would be evaluated by the responsible Federal and State agencies. However, it is possible that these agencies would determine that an alternative use for the facilities is appropriate. If a near-term alternative use for the ESF was identified after site characterization had been terminated, a limited standby decommissioning could take place until the start of the alternative program. The utilities and ventilation systems would be left in place. Periodic maintenance would preserve the structural integrity of the

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facility. Physical security (adequate to prevent accidents and unauthorized access) would be retained at the surface.

If a long-term alternative use for the ESF is identified, a strategy to preserve the ESF for future use could be implemented. This strategy would entail removing the utilities and any salvageable materials from the interior of the facility and welding steel covers over the openings to prevent accidents or unauthorized access. After stabilization and rehabilitation of the surface, the sealed facility would require only a minimum degree of security to protect the shafts from vandalism and prevent accidents.

If no alternative use is identified, decommissioning would begin as soon as possible. Section 8.7.2.1 discusses decommissioning for surface-based characterization activities; Section 8.7.2.2 discusses decommissioning of the ESF.

8.7.2.1 Decommissioning for surface-based activities

Surface-based activities (activities on the surface not directly related to the ESF) do not require the construction of facilities. Therefore, decommissioning for these activities involves backfilling trenches with the material that was originally excavated and sealing drillholes.

Abandoned drillholes will be sealed with a ground-matching grout of a density that corresponds to that of the surrounding rock. Specific sealing requirements will be determined in cooperation with Federal and State regulatory agencies. After the injection of ground-matching grout, the surface casing will be filled with concrete to the surface and a concrete cap will be poured around the sealed hole. A permanent marker with pertinent data about the drillhole will be emplaced after surface restoration.

8.7.2.2 Exploratory shaft facility

Surface facilities at the ESF will be decommissioned by removing each structure and site pad and stabilizing and rehabilitating the land. Facilities will be removed by the most practical and cost-effective methods. Portable and prefabricated buildings will be emptied of their contents, dismantled, and removed from the site. The buildings will be used in other repository programs or salvaged in accordance with the Nuclear Waste Policy Act (NWPA) funding requirements (NWPA, 1983). Hoist equipment (including headframes), electric generators, electrical and water distribution systems, ventilation equipment, meteorological towers, and communications equipment will also be removed from the site and salvaged. Shaft collars, drill pads, and other foundations will be reduced to manageable pieces and trucked to appropriate disposal sites. Buried water, electricity, and sewage lines will be disconnected below the surface and left in the ground. Structures, equipment, pumps, and material-handling equipment will be removed from the shaft stations, underground drifts, and test rooms. Horizontal and vertical drillholes extending from the exploratory shaft and rooms will be sealed. Subsurface drifts and rooms will be backfilled with the material that was

originally removed during excavation or with an engineered material. The exploratory shafts (ES-1 and ES-2) will be stripped of equipment and structures. The shaft liners will be left in place.

The shafts will be backfilled with the material that was removed during excavation and placed in the muck-storage area. This will minimize the amount of material to be stabilized or disposed of from the surface. Depending on the specific goals of shaft decommissioning, other backfill material could be used. For example, information from site characterization may dictate that a grout that matches the density of the various rock layers should be used, rather than material from the muck-storage area.

8.7.3 PLANS FOR MITIGATION OF ANY SIGNIFICANT ADVERSE IMPACTS CAUSED BY SITE CHARACTERIZATION ACTIVITIES

The potential for significant adverse environmental impacts during site characterization will be minimized to the maximum extent practicable, as required by the Nuclear Waste Policy Act Section 113(a) (NWPAA, 1983). In addition, Section 113(c) of the NWPAA requires that the SCP include plans for the mitigation of any significant adverse environmental impacts caused by site characterization activities at a candidate site determined unsuitable as a repository.

Chapter 4 of the final environmental assessment prepared for the Yucca Mountain site (DOE, 1986b) concluded that conducting site characterization activities at Yucca Mountain would not result in significant adverse environmental impacts. The environmental assessment listed standard operating procedures or good engineering practices (e.g., collecting archaeological sites before their disturbance or avoiding the site altogether) that would reduce the potential for any significant adverse impact. In addition, the DOE has agreed to work with the states and Indian tribes to monitor the effects of certain site characterization activities and to jointly develop mitigation measures if significant adverse impacts appear likely to occur.

Should Yucca Mountain be found unsuitable as a repository, the DOE would consult with appropriate Federal and State agencies to develop specific mitigation plans. Because the ESF and many of the surface-based site characterization activities will be conducted on land administered by the Bureau of Land Management (BLM), the regulations concerning access to and mitigation of impacts on BLM lands were reviewed. Current plans call for the DOE to obtain access to BLM lands through a right-of-way authorization. To obtain a right-of-way authorization, the DOE may be required to submit a "right-of-way plan of development."

The plan of development may be offered by an applicant with any right-of-way application. Plans of development are always required at the application stage when an environmental impact statement is necessary or when the scope of the project proposal is major (BLM, 1985). A handbook published by the BLM explains that the plan of development can be used by the applicant to design specific construction, operation, maintenance, or termination features that will satisfactorily mitigate the impacts. The intended use of the plans by the BLM is to ensure that construction plans mitigate their resource

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concerns and, when approved by the BLM-authorized officer, become a binding requirement of the right-of-way grant (BLM, 1985). When a plan of development is not submitted with the right-of-way application, the BLM-authorized officer uses the best information available to estimate and analyze the environmental impacts associated with the proposed action and alternatives.

The plan of development, as outlined in the BLM handbook, includes a section entitled "stabilization and rehabilitation." This section describes the action(s) that will be taken by the holder to mitigate the anticipated negative impacts and restore the project area. Examples of mitigation measures listed in the handbook include soil replacement, recontouring of the disturbed right-of-way land, and placement of waterbars and other water control structures (BLM, 1985).

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Nuclear Waste Policy Act
(Section 113)

Consultation Draft

Site Characterization Plan

***Yucca Mountain Site, Nevada Research
and Development Area, Nevada***

Volume VII

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U.S. Department of Energy
Office of Civilian Radioactive Waste Management
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GLOSSARY

Definitions in this glossary reflect the usage of words and terms in the NNWSI Project SCP. These definitions may or may not be used in the same way by other projects or in other circumstances.

A horizon	The uppermost zone in the soil profile, from which soluble salts and colloids have been leached, and in which organic matter has accumulated.
abnormal	Describes events or conditions that do not occur on a routine basis or that are not expected during normal operations; also describes materials that are not handled routinely, such as experimental spent fuel.
absorbed radiation dose	A measure of the amount of energy deposited by ionizing radiation in a given mass of absorbing medium. The unit of absorbed radiation is the rad.
accelerometer	A motion detector whose response is linearly proportional to the acceleration of the earth materials with which it is in contact.
access drift	A drift that connects the mains and the perimeter drifts, delineating the waste emplacement panels and providing access to the waste emplacement drifts. In the vertical waste emplacement configuration, there is also a midpanel access drift that supplies additional ventilation to the more numerous drifts.
accessible environment	(1) The atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, and (5) all of the lithosphere that is beyond the controlled area.
accessory mineral	A mineral whose presence in a rock is not essential to the proper classification of the rock. Accessory minerals generally occur in minor amounts typically less than 1 weight percent; in sedimentary rocks they are mostly heavy minerals.
accidental radiological releases	Releases of radioactivity that deviate from the planned or expected behavior or course of events in connection with the operation of the facility and that have environmental protection or safety significance.
accretionary boundary	A boundary between two plates that are moving apart, with new oceanic type lithosphere being created at the seam.
acidic	A descriptive term applied to those igneous rocks that contain more than 66 percent SiO_2 .

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acoustic velocity log	Generic term for a well log that displays any of several measurements of acoustic waves in rocks exposed in a borehole.
actinides	Radioactive elements in the series beginning with atomic number 89 and continuing through 103.
activation products	The group of radionuclides that are formed as a result of neutron capture by chemical elements present in the fuel assembly hardware and fuel rod cladding.
active institutional controls	Controls instituted by a government to guard a repository against intrusion and to perform monitoring or maintenance operations.
actual retrieval period	The time required to retrieve the emplaced waste from the underground facility. For design purposes, this period is 34 years.
adsorption	The condensation of gases, liquids, or dissolved substances or solids.
advanced conceptual design (ACD)	The design phase that will be used to explore selected design alternatives and will firmly fix and refine the design criteria and concepts to be made final in later design efforts. The project feasibility will be demonstrated, life-cycle costs estimated, preliminary drawings prepared, and a construction schedule developed as required by DOE Order 6410.1.
advection	The movement of dissolved solids by ground-water flow.
advertent human intrusion	Intentional intrusion or entry into the repository for purposes of waste retrieval, or other disposal-related materials (i.e., canister materials).
aeromagnetic survey	A magnetic survey made with an airborne magnetometer from a moving aircraft.
aftershock	An earthquake that follows a larger earthquake or main shock and originates at or near the focus of the larger earthquake. Generally, major earthquakes are followed by a large number of aftershocks that decrease in frequency over time.
affected area	Either the area of socioeconomic impact or the area of environmental impact.

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affected Indian Tribe	Any Indian Tribe (1) within whose reservation boundaries a repository for radioactive waste is proposed to be located or (2) whose federally defined possessory or usage rights to other lands outside the reservation's boundaries arising out of congressionally ratified treaties may be substantially and adversely affected by the locating of such a facility, <u>provided</u> that the Secretary of the Interior finds, upon the petition of the appropriate governmental officials of the Tribe, that such effects are both substantial and adverse to the Tribe.
affected State	Any State that (1) has been notified by the DOE in accordance with Section 116(a) of the Nuclear Waste Policy Act as containing a potentially acceptable site, (2) contains a candidate site for site characterization or repository development, or (3) contains a site selected for repository development.
aggradation	The process of building up a surface by deposition.
aging	Storage of radioactive materials, especially spent nuclear fuel, to permit the decay of short-lived radionuclides.
air-cored	A core drilled using compressed air alone as the drilling fluid, rather than other drilling fluids such as air-foam or drilling mud.
air-fall tuff	See "ash-fall tuff."
air-foam method	A procedure for drilling wells into rock formations, wherein the well cuttings are returned to the ground surface in a mixture of compressed air and a chemical foaming agent. The method offers the advantage of using minimum drilling fluids, thus fluid migration into the rock formation is also minimized.
alkali flat	A level lake-like plain formed in a shallow depression where accumulated water evaporates depositing fine sediment, dissolved minerals, or efflorescent salts.
allochthonous	A term applied to rocks that have been transported to their present outcrop location by tectonic processes, as in a thrust sheet.

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alluvial fan	A low, outspread, relatively flat to gently sloping mass of rock material shaped like an open fan or segment of a cone made by a stream where it runs out onto a level plain or meets a slower stream. The fans generally form where streams issue from mountains onto low land.
alpha activity	See "alpha decay."
alpha decay	A radioactive transformation in which an alpha particle is emitted by a nuclide, thus changing one nuclide to another that has a lower atomic number and weight.
alpha particle	A positively charged particle emitted in the radioactive decay of certain nuclides. Made up of two protons and two neutrons bound together, it is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation: alpha, beta, and gamma.
alpha spectrometry	A method of determining the type and concentration of certain radioactive isotopes by analysis of the alpha wave spectra that are emitted.
alteration (geologic)	Changes in the chemical or mineralogic composition of a rock, generally produced by weathering, hydrothermal solutions, or metamorphism.
altithermal	A period of high temperature especially the post-glacial thermal optimum.
ambient radiation monitoring	The measurement of the level of radiation present in the surrounding environment.
amplitude (of a fold)	For a symmetrical, periodic fold system the amplitude of a fold is analogous to the amplitude of a wave form, (i.e., half the original distance between the antiformal and synformal enveloping surfaces).
anelastic strain	Time-dependent, but eventually recoverable strain that occurs in a (anelastic) body after change in applied stress.
angle of internal friction	The angle between a resultant force acting on a plane of friction and the perpendicular line to that plane.
anion exclusion	The virtual exclusion of anions from pores between adjacent grains in a compacted clay-water system as a result of the solution between the pores being composed of overlapping diffuse layers.

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antecedent moisture	The amount of moisture present in a soil mass at the beginning of a runoff period.
anticipated processes and events	Those natural processes and events that are reasonably likely to occur during the period the intended performance objective must be achieved.
anticline	A fold that is generally convex upward and the core of which contains stratigraphically older rocks.
Antler orogeny	An orogeny that extensively deformed Paleozoic rocks of the Great Basin in Nevada during late Devonian and early Mississippian time.
application	The act of making a finding of compliance or non-compliance with the qualifying or disqualifying conditions specified in the guidelines of Subparts C and D, in accordance with the types of findings defined in Appendix III of the guidelines (10 CFR 960).
aquefaction	The sudden large decrease of the shearing resistance of a cohesionless soil, caused by the collapse of the structure by shock or strain, and associated with a sudden but temporary increase of the pore fluid pressure. It involves temporary transformation of the material into a fluid mass.
aquifer	A formation, group of formations, or a part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.
aquitard	A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a storage unit for ground water.
areal power density (APD)	The concentration of thermal power produced by emplaced waste, averaged over the area of an emplacement panel, expressed in watts per square meter or in kilowatts per acre. The initial value (IAPD) at the time the waste is emplaced is a design input parameter used in far-field thermal and thermomechanical response calculations.
arid	A climate characterized by dryness. Variously defined as having precipitation amounts insufficient for plant life or for crops without irrigation. Arid regions have less than 25 cm (10 in.) of annual rainfall or a higher evaporation rate than precipitation rate.

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arroyo	A term applied in the arid and semiarid southwestern United States to a small, deep, flat-floored channel or gully of an ephemeral or intermittent stream.
articulation	The action or manner of jointing, or the state of being jointed.
ash	Pyroclastic material < 4.0 mm in diameter. This term refers to both unconsolidated detritus and the consolidated deposit.
ash-fall tuff	(1) A tuff deposited by volcanic ash settling out of the atmosphere, forming a blanketing deposit of relatively uniform thickness regardless of the underlying topography. (2) A deposit of volcanic ash resulting from such a fall and lying on the ground surface.
ash-flow tuff	A tuff deposited by a volcano-derived hot density current. It can be either welded or unwelded, and often fills in channels making the thickness of the resulting deposit a function of the underlying topography.
as low as reasonably achievable (ALARA)	As low as reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety, other societal and socioeconomic considerations, and the utilization of atomic energy in the public interest.
asthenosphere	A weak layer or shell of the earth below the lithosphere, in which isostatic adjustments take place, mafic magmas may be generated, and seismic waves are strongly attenuated.
astronomic forcing	Variations in the earth's orbit that influence climate by changing the latitudinal and seasonal distribution of incoming solar radiation.
atmospheric stability class	An index that indicates the atmosphere's ability to disperse airborne releases.
atomic energy defense activity	Any activity of the Secretary of Energy performed in whole or in part in carrying out any of the following functions: Naval reactors development, weapons activities, verification and control technology, defense nuclear materials production, defense nuclear waste and materials byproducts management, defense nuclear materials security and safeguards and security investigations, and defense research and development.

attenuation	(1) A reduction in the amplitude or energy of a signal, such as might be produced by passage through a filter. (2) A reduction in the amplitude of seismic waves, as produced by divergence, reflection and scattering, and absorption.
Atterberg limits	In a sediment, the water-content boundaries between the semiliquid and plastic states (known as the liquid limit) and between the plastic and semisolid states (known as the plastic limit).
autecology	The study of the relationships between individual organisms or species.
authiclastic	A term applied to rocks that have been brecciated in place by mechanical processes.
authigenic	(1) Generated on the spot. (2) Pertaining to minerals formed on the spot where they are now found, before burial and consolidation of sediment.
autochthon	A body of rocks that remains at its site of origin, where it is rooted to its basement. Although not moved from their site, autochthonous rocks may be mildly to considerably deformed.
B horizon	Soil layer characterized by the secondary accumulation or enrichment of clay, iron, or aluminum, and by the development of distinctive structures not present in the parent material.
back-arc spreading	Sea floor spreading center behind an island arc chain relative to a subduction boundary.
backfill	(1) The general fill that is placed in the excavated areas of the underground facility. Backfill materials may be either excavated tuff or other earthen materials. (2) The material or process used to refill an excavation.
background radiation	Radiation that is produced by sources other than the facility of specific interest, such as naturally occurring radioactive minerals in the earth, cosmic rays, naturally occurring radionuclides in living organisms, and fallout from weapons tests.
bacterial metabolites	An intermediary product of metabolism.
bailer	A long hollow, steel cylindrical container or pipe with a valve at the bottom for admission of fluids, attached to a wire line and used in cable-tool drilling for recovering and removing water, cuttings, and mud from the bottom of a borehole.

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bajada	A broad, gently inclined detrital surface extending from the base of a mountain range out into an inland basin, formed by the lateral coalescence of a series of alluvial fans, and having an undulating character.
barometric efficiency	The ratio of the product of the change in hydraulic head and the specific weight of water to the change in atmospheric pressure.
barrier	Any material or structure that prevents or substantially delays movement of water or radionuclides.
base flow	Sustained or fair-weather flow of a stream, whether or not affected by the works of man.
base level	(1) The theoretical limit or lowest level toward which erosion of the earth's surface constantly progresses but seldom, if ever, reaches. (2) The level below which a stream cannot erode its bed.
Basin-Range faulting	Faulting characterized by normal (extensional) fault movements. Regional geologic structure dominated by generally subparallel fault-block mountains separated by broad alluvium-filled basins.
bearing strength	The maximum load per unit area that the ground can support without failing in shear or causing excessive settlement of the soil under imposed loads.
bench-scale testing	Testing of materials, methods, or chemical processes on a small scale, such as on a laboratory worktable.
benchmark	(1) Comparison of the results of one computer code with the results of another code designed to solve an identical problem to show that they produce similar results. The particular problem for which this comparison is made is called a "benchmark problem." (2) A relatively permanent metal tablet or other mark firmly embedded in a fixed object, indicating a precisely determined elevation.
beta particle	A negatively charged particle, physically identical with the electron, that is emitted by certain radionuclides.
beta radiation	See "beta particle."
bifurcating	The separation or branching of a stream into two parts.
binding constant	A measure of the affinity of a microorganism to an actinide. Analogous to a sorption coefficient.

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biological half-life	The time required for an organism to eliminate half the amount of a radionuclide ingested or inhaled.
biosphere	The zone at and adjacent to the earth's surface where all life forms exist.
blind-hole drilling	A technique for sinking shafts. It uses a multiple-cone bit with a diameter larger than 6 feet.
blocking temperature	The temperature at which the potassium-argon clock is reset for a specific mineral.
blooie line	A pipe or flexible tube that conducts air or other gas laden with cuttings from the collar of a borehole to a point far enough removed from the drill rig to keep air around the drill free from dust.
body-wave	A seismic wave that travels through the interior of the earth (or other geologic body) and is not related to any boundary surface. A body wave may be either longitudinal (p-wave) or transverse (s-wave), depending on the direction of particle motion with respect to the direction of propagation and the direction of constant phase.
boiling water reactor (BWR)	A nuclear reactor system that uses boiling water in the primary cooling system. Steam from the primary cooling system turns turbines to generate electricity.
borehole	A hole made with a drill, auger, or other tools for exploring strata in search of minerals, supplying water for blasting, emplacing waste, proving the position of old workings or faults, or releasing accumulations of gas or water. Boreholes include core holes, dry-well-monitoring holes, waste-emplacement boreholes, and test holes for geophysical or ground-water characterization.
borehole deformation gauge	An instrument used to measure deformation or change in deformation of the wall of a borehole, in response to changes in applied stress in the volume of material containing the borehole. This phase typically is used in reference to a particular type of gauge developed by the U.S. Bureau of Mines (USBM), which measures the change in one or more diameters in response to overcoring of the borehole. The USBM borehole deformation gauge has also been used in relatively long-term monitoring applications.

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borehole-flow survey	A survey using a device called a "spin flow meter," the purpose of which is to determine the vertical velocity of ground water within the well bore.
borehole geophysical method	A method for investigating geophysical rock mass responses and structure in situ by means of instruments lowered into one or more boreholes. See also: "borehole-to-borehole geophysical method," "crosshole geophysical method," and "borehole-to-surface geophysical method."
borehole geophysical survey (directional survey)	Determination of the direction and deviation from the vertical of a borehole by precise measurements at various points along its central axis. Also, the record of information thus obtained.
borehole jacking	A test that measures in situ rock-mass deformation through the application of unidirectional pressures to the opposite sides of a borehole.
borehole-to-borehole geophysical method	A method for investigating geophysical rock mass responses and structure in situ by means of instruments lowered into adjacent boreholes. Electrical or seismic phenomena are propagated between the holes, yielding information about the intervening rock mass.
borehole-to-surface geophysical method	A method for investigating geophysical responses and structure in situ by means of instruments deployed in a borehole, and on the surface adjacent to the borehole. Electrical or seismic phenomena are propagated between the hole and the surface, yielding information about the intervening rock mass.
borescope	A straight-tube telescope with a mirror or prism used to visually inspect a cylindrical cavity
borosilicate glass	A silicate glass containing at least five percent boric acid and used to solidify commercial or defense high-level waste.
borrow area	An area in which earth material (sand, gravel, etc.) is taken to be used for fill at another location.
Bouger gravity	The observed value for gravitational acceleration at a point on the surface of the earth, corrected for latitude effects, elevation effects, the acceleration from a horizontal slab extending between the station elevation and the datum elevation (Bouger correction), and the acceleration from the terrain around the station.
boundary element method	A method for modeling the behavior of continuous physical systems in which modeling segments are only defined along the boundary of the modeled region.

Bowen ratio	The ratio of heat loss by conduction to heat loss by evaporation.
branch corridor	A corridor that runs at an angle to the main corridors of the repository and that leads to the storage rooms.
Brazil test	A method for the determination of the tensile strength of rock, concrete, ceramic, or other material by applying a compressive load radially to the outer surface of a test cylinder or disk, which is itself supported on the opposite side by a tangent plane.
breakout	(1) See "Demonstration Breakout Room." (2) The process of pulling up drill pipes or casings from a borehole and disconnecting them for stacking.
breccia	Rock consisting of sharp, angular fragments cemented together or embedded in a fine-grained matrix.
bridge plug	A downhole tool, composed primarily of slips, plug mandrell, and rubber sealing elements that is run in and set in dense, nonfractured rock in a borehole to permanently isolate a zone. Multiple bridge plugs may be set in a borehole to isolate numerous zones.
brittle-ductile	See "ductile-brittle transition zone."
broadband sound	Sound that encompasses the audible frequencies.
Brunauer-Emmett-Tesler (BET) surface area	The total surface area of a powder or of a porous solid measured by the volume of gas (usually N_2) adsorbed on the surface of a known weight of the sample.
bulk air permeability	The ease with which air moves through a medium due to the total pressure difference.
bulk aquifer properties	The properties of an aquifer representing the combined effect of all individual values or variations within that aquifer, including fracture and matrix properties.
bulk density	The mass of an object or material divided by its volume, including the volume of its pore spaces.
bulk modulus	A modulus of elasticity relating a change in volume to the hydrostatic state of stress. It is the reciprocal of compressibility.
bulk permeability	Volume-averaged permeability. See "permeability."

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bulk porosity	The total void volume divided by total volume of rock mass.
bulkhead	A tight partition of masonry, steel, or concrete used in the underground facility to control ventilation and to separate construction activities from waste emplacement activities.
burnup	A measure of nuclear-reactor fuel consumption expressed either as the percentage of fuel atoms that have undergone fission or as the amount of energy produced per unit weight of fuel.
byproduct material	Any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material.
cage	The platform of a mine hoist used to carry men or materials.
calc-alkalic series	An igneous rock or group of igneous rocks, in which the weight percentage of silica is between 56 and 61 when the weight percentages of CaO and $\text{K}_2\text{O}+\text{Na}_2\text{O}$ are equal.
calcic horizon	A diagnostic subsurface soil horizon, at least 15 cm thick, characterized by enrichment in secondary carbonates.
calcite and opaline silica deposits	See "calcite silica deposits."
calcite silica deposits	Deposits in the area of Yucca Mountain located at the surface and in fault zones consisting of calcite and opaline silica.
calcrete	A conglomerate consisting of surficial sand and gravel cemented into a hard mass by calcium carbonate, which precipitates from solution from infiltrating waters, or by calcium carbonate, which is deposited by the escape of carbon dioxide from vadose water.
caldera	A volcanic collapse structure, generally on the order of tens of kilometers in diameter, formed during the eruption of volumetrically large (tens to hundreds of cubic kilometers of dense rock equivalent) ash-flow and ash-fall tuff deposits.
calibration (of a model)	A part of the model validation process involving the trial-and-error adjustment of model parameters.

caliche	Gravel, sand, or desert debris cemented by porous calcium carbonate; also the calcium carbonate cement.
caliper log	A well log that shows the variation of diameter of an uncased borehole with depth.
calomel	A weathering product, Hg_2Cl_2 , of cinnabar, HgS .
candidate site	An area within a geohydrologic setting that is recommended for site characterization by the Secretary of Energy under Section 112 of the Nuclear Waste Policy Act of 1982, approved for characterization by the President under Section 112, or undergoing site characterization under Section 113.
canister	As used in this document, a canister is the initial metal receptacle in which solid radioactive waste is placed for transport to the repository. The canister is not intended to meet the 300- to 1000-yr containment requirement of 10 CFR 60.113 (a)(1)(ii)(A) (see "container").
capable fault	A fault that has exhibited one or more of the following characteristics, as described in 10 CFR Part 50: (a) movement at or near the ground surface at least once within the past 35,000 yr or movement of a recurring nature within the past 500,000 yr, (b) macroseismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault, or (c) a structural relationship to a capable fault according to characteristics (a) and (b) such that movement on one could be reasonably expected to be accompanied by movement on the other.
capillary barrier	An interface between two geologic media that impedes unsaturated water flow because the media have different hydrologic properties. For example, flow from a medium with small pores or interstices into a medium with larger pores is inhibited if the receiving medium is unsaturated.
capillary forces (pressure)	A difference in pressure across the interface between two immiscible fluid phases jointly occupying the interstices of a rock. It is due to the tension of the interfacial surface, and its value depends on the curvature of that surface.
capillary fringe	The zone immediately above the water table in which all of the rock pores are filled with water that is under less than atmospheric pressure and that is continuous with the water below the water table.
carbon-14 dating	See "radiocarbon dating."

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casing	(1) A liner in a shaft or borehole to prevent entry of loose rock, gas, or liquid, or to prevent the loss of circulating liquid into porous, cavernous, or fractured ground. (2) The process of inserting casing into a borehole (see "borehole liner" and "cladding hulls").
casing collar locator (CCL)	A well log used in conjunction with other logs, in cased holes, for depth control. The CCL responds to the thickness of ferrous metal at the threaded junctions between consecutive lengths of casing.
cask	A receptacle that holds one or more fuel assemblies, canisters, or disposal containers and provides shielding for highly radioactive materials during transportation. See "transporter cask," "shipping cask," and "transfer cask."
catchment area	(1) As applied to an aquifer, the recharge area and all areas that contribute water to it. (2) As applied to surface hydrologic systems, see "drainage basin."
cation exchange capacity (CEC)	A measure of the quantity of readily exchangeable cations neutralizing negative charge, expressed in moles of charge per unit mass.
cation-ratio dating	An experimental method for dating rock (desert) varnish. Curves (regression lines) representing the differential leaching rates of several minor elements in rock varnish (K+Ca:Ti) are calibrated using isotopically dated deposits to produce an area-specific plot of cation leaching ratios versus time. Using these calibrated cation-leaching curves, the time of initial varnish formation (minimum time since surface stabilization) can be dated for a variety of stable surfaces within the region.
Cauchy boundary condition	A semipervious boundary in flow through porous media occurring when a thin layer of reduced permeability is formed at the ground surface.
cauldron	A caldera that has been eroded below the level at which the original topography is no longer recognizable. The location is inferred on the basis of the geometry of the erupted rock units and by the structural modification of the precaldra rocks.
characterization parameter	A physical property or condition (either measurable or calculable) whose value is to be determined in the site program in order to obtain, compute or evaluate a performance parameter for a design or performance issue.

charophytes	One of a group of green algae in the order Charales and comprising the Stoneworts.
chelation	Decomposition or disintegration of rocks or minerals resulting from the action of organisms or organic substances.
chemisorption	A process in which a layer of atoms or molecules of one substance forms on the surface of a solid or liquid. The adsorbed layer is held by chemical bonds.
chromatographic	Of or relating to several techniques such that a distribution of a solute between a stationary phase and a mobile phase occurs. The stationary phase may be a solid or a liquid supported as a thin film on the surface of an inert solid. The mobile phase flowing over the surface of the stationary phase may be a gas or liquid. Types of chromatographic separations include adsorption, ion exchange, or partition (separation based on solubility) chromatography.
chronic intake	A continuous inhalation or ingestion exposure lasting for days or years.
cistern	An artificial reservoir for storing liquids, especially water.
cladding	The metallic outer sheath of a fuel element, generally made of stainless steel or a zirconium alloy.
cladding hulls	The empty metal tubes that remain after spent fuel is removed from them for reprocessing.
closed basin	A district draining to some depression or lake within its area, from which water escapes only by evaporation.
closed-system method	See "uranium-trend method."
closure	Final backfilling of the remaining open operational areas of the underground facility and boreholes after the termination of waste emplacement, culminating in the sealing of shafts.
cluster analysis	A procedure for arranging a number of objects in homogeneous subgroups based on their mutual similarities and hierarchical relationships.
cold trap	A tube whose walls are cooled with liquid nitrogen or some other liquid to condense vapors passing through it.

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cold working	The increased resistance to further plastic deformation. Occurs when a metal or alloy is plastically deformed at temperatures below the recrystallization temperature of the alloy.
collar	(1) The top or uppermost portion of a shaft. A concrete ring or slab around a shaft used to prevent water inflow and to support the headframe. (2) The threaded connector between consecutive lengths of casing.
colloform structures	Said of the rounded, finely banded kidney-like mineral texture formed by ultra-fine-grained rhythmic precipitation.
comb structures	A vein filling in which subparallel crystals, often of quartz, have grown perpendicular to the vein walls and thus resemble the teeth of a comb.
commercial waste	High-level radioactive waste generated in private industrial and other nongovernment facilities.
competent (geologic)	(1) A bed or stratum that is able to withstand the pressure of folding without flowage or change in original thickness. Competent strata tend to form parallel folds. (2) A bed or stratum that is resistant to weathering.
complementary cumulative distribution function (CCDF)	The CCDF is equivalent to one minus the cumulative distribution function.
complex response	Reaction of a fluvial system to a disruption of the equilibrium of the system.
complexing agent	A ligand (molecule or ion) that can donate one or more electron pairs to a metal atom or ion such that a complex is formed.
compliant-joint model	A conceptual and numerical model for a jointed medium whereby the deformation of the joints is treated separately from, and additionally to, the deformation of the intact material between joints. The stress-strain behavior of the joints and the matrix are idealized from observations of rock mass behavior. In general this approach does not allow for coupling of normal and shear joint responses. The total response of a representative volume of jointed material is posed as a constitutive stress-strain relationship for an equivalent homogenous material.
composite head	The combined or average hydraulic pressure of more than one hydrologic unit measured as a whole within a borehole.

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compressibility	The change of specific volume and density under hydrostatic pressure; reciprocal of bulk modulus.
compression index	The value of the slope of the line when the void ratio is plotted against the logarithm of the effective stress of a porous medium.
compressional wave	An elastic body wave for which particle motion is in the same direction as propagation, for an elastically isotropic medium. In an anisotropic medium the particle motion may deviate from the propagation direction. It is the fastest type of seismic wave and travels at about 6.0 to 7.7 km/s in the crust.
compressive strength	The maximum compressive stress that can be applied to a material, under given conditions, before failure occurs.
computed impedance tomography (CIT)	Tomographic imaging technique based on back projection along equal potential surfaces.
conceptual design (SCP)	This design phase will concentrate on the surface and underground system, structure, emplacement, and component designs that require site characterization data and will provide the information to ensure that data-gathering plans relative to design will be adequately included in the SCP. Known site-specific data will be incorporated to assist in the identification of additional data needs, and sufficient design detail will be developed to ensure that all site data needs are identified. Data-accuracy requirements will be established and site-specific licensing issues related to site characterization will be identified.
concordant	(1) A contact between an igneous intrusion and the country rock, which parallels the foliation or bedding of the latter. (2) Structurally conformable strata displaying parallelism of bedding or structure. (3) Radiometric ages determined by more than one method or by the same method from more than one mineral and that are in agreement.
conductivity	See "hydraulic conductivity" or "thermal conductivity."
conduits (hydrology)	A subterranean passage completely filled with water and always under hydrostatic pressure.

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confined aquifer	An underground water-bearing unit or formation with defined, relatively impermeable upper and lower boundaries. It contains confined ground water such that if penetrated by a well the water level will rise above the top of the aquifer.
confinement	As pertains to radioactivity, the retention of radioactive material within some specified bounds. Confinement differs from containment in that there is no absolute physical barrier in the former.
confining unit	A body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.
congruent leaching	A process of dissolving wherein the ratio of the rates of dissolution of constituents is proportional to their concentration ratios.
conjugate fault sets	A system of faults consisting of two sets symmetrically disposed about an inferred stress axis and of the same age and deformational episode.
connate water	Water no longer in circulation or contact with the present water cycle. Connate water is usually saline water trapped during the deposition of sediments and may be considered as "fossil water."
consolidation	The operation performed on spent fuel assemblies during which the upper and lower fuel-assembly tie plates are removed, the assembly spacer grids and any other assembly structural members are removed, and the fuel tubes are collected and formed into a closely packed bundle for insertion into a canister or container. The nonfuel structural members of the fuel assemblies are reduced in volume and placed in canisters or containers for shipment and disposal.
constant flux injection test	A type of hydraulic test, performed on a well, in which water is injected into an isolated interval of the well bore at constant flow rate. The method permits the evaluation of the hydraulic conductivity and storativity of a portion of the aquifer in the vicinity of the isolated interval.
constant head injection test	A test conducted to determine some hydraulic property, (i.e., hydraulic conductivity, transmissivity) in a well in which water is pumped in at a varied rate in order to keep the pressure or "head" constant.
constant-head node	A point within a numerical model at which the head is held constant.

constitutive model	A mathematical model of a material or a process that expresses its essential quality or nature. A constitutive model is expressed by constitutive equations that mathematically express the relationship between the quantities of interest (e.g., constitutive equations establishing a linear elastic relationship between stress and strain).
constrained modulus	Ratio of axial stress to axial strain for a material tested triaxially with the minor and intermediate principal stress directions constrained.
contact (geology)	A plane or irregular surface between two different types or ages of rocks.
contact-handled transuranic waste	Transuranic (TRU) waste, usually contained in metal drums, whose surface radiation dose rate (less than or equal to 0.2 rem per hour) is sufficiently low to permit direct handling. Such waste does not usually require shielding other than that provided by its container.
contact-handled waste	Low-level radioactive waste that can be handled manually without exceeding established radiation exposure guidelines.
container	The metal barrier portion of the waste package that is placed around the waste form.
containment	The confinement of radioactive waste within a designated boundary.
containment barriers	Natural or man-made components of geologic disposal system designed to confine radioactive waste within a designated boundary.
containment period	The first several hundred years following permanent closure of a geologic repository when radiation and thermal levels are high, the uncertainties in assessing repository performance are large, and special emphasis is placed on the ability to contain wastes by waste packages within an engineered barrier system.
continental margin	The environment between the shoreline and the abyssal ocean floor including the continental shelf, continental borderland, continental slope and continental rise.
continuous mining machine	A machine equipped with a rotating cutting head with pick-like bits for cutting into rock and for dropping the cuttings into a collection device for loading into cars or conveyors.

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continuum theory	In dealing with flow through porous media, the microscopic flow through the complex network of interconnected pores is disregarded in favor of the macroscopic overall average flow that takes place.
contoured stereonet	Stereonet plots containing multiple measurements from a geologic structure often reveal irregularities and the plot results in a scatter. Lines connecting areas of equal density (number of points per 1 percent area) are constructed to treat the data statistically.
control point	Any situation in a horizontal or vertical control system identified on a photograph and used as a base for a dependent survey.
controlled area	(1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system, and (2) the subsurface underlying such a surface location.
convection	A process of mass movement of portions of any fluid medium (liquid or gas) as a consequence of different temperatures in the medium and hence different densities. The process thus moves both the medium and the heat, and the term convection is used to signify either or both.
convective dispersion	Thermally induced dispersion of a liquid or a gas.
conventional light scattering (nephelometry)	The measurement of the cloudiness of a medium; especially the determination of the concentration or particle sizes of a suspension by measuring, at more than one angle, the scattering of light transmitted or reflected by the medium.
conventional shaft-sinking methods	Methods employing drilling, blasting, and mucking procedures in shaft construction.
convergence anchors	Fixtures set in rock serving as permanent reference points so that displacement between fixtures can be measured over time.
convergent boundary	A band along which moving plates collide and volume is lost either by shortening and crustal thickening or subduction and destruction of crust. The site of volcanism, earthquakes, trenches, and mountain building.

convergent flow	The coalescence of many overland flows downslope to make one large flow.
cooling (spent fuel)	Storage of fuel elements after discharge from reactors usually under water, to allow for the decay of short-lived radionuclides and hence the decrease of radioactivity and heat emission to acceptable levels. Synonymous with aging.
cordillera	A group of mountain ranges including valleys, plains, rivers, lakes, etc. Its component ranges may have various trends but the cordillera will generally have one general direction.
corebarrel	Device used to remove drilled core from a borehole.
corehead	A hollow, cylindrical drill bit for carving, removing and holding a core or sample of rock or soil material from the drill hole.
coring shovel	See "corebarrel."
cosmic-ray secondaries (secondary cosmic rays)	Radiation produced when primary cosmic rays enter the atmosphere and collide with atomic nuclei and electrons.
covariance	The arithmetic mean of the products of the deviations of corresponding values of two quantitative variables from their respective means.
credible abnormal conditions	The state of conditions expected to have a reasonable potential for occurring infrequently during the life of a repository. It is generally used to identify those conditions that need to be considered for use in developing contingency plans for related operations.
credible accident scenario	An accident scenario having a probability of occurrence of greater than a specified number to be determined.
credible scenario	A scenario having a probability of occurrence greater than or equal to 10^{-8} per year.
creep	Slow deformation that results from a long application of a constant stress.
crest-stage gauge	A gauge that records the highest level of a stream during a runoff event. A variety of different types of gauges do this, usually using floats to indicate the high-water mark.

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critical path	Environmental exposure pathway that dominates the transport of material from the source of emission to human receptors.
critical saturation	In an unsaturated environment, the saturation level that marks the transition between matrix-dominated fluid flow and fracture-dominated fluid flow.
critical threshold	The limits of equilibrium of a system, which when exceeded results in a change in the system or the system's responses. Examples include (1) sediment movement in streams, which begins at a critical threshold velocity, and (2) slope failure, which occurs when a critical threshold of slope stability is exceeded.
criticality	The condition in which a nuclear chain reaction is self supporting. It occurs when the number of neutrons present in one generation cycle equals the number generated by the previous cycle.
crosshole geophysical method	See "borehole-to-borehole geophysical method."
crosshole recirculation test	A type of well test, usually involving a chemical tracer (or sometimes conducted only with water) in which water is injected into one well, either at constant flow rate or, less frequently, at constant pressure, and withdrawn from a nearby second well, to be reinjected into the first well. Once steady flow is established, a chemical tracer may be injected, the concentration of which is recorded as a function of time in the recirculation loop. The test yields information on the hydraulic and dispersive properties of the aquifer.
crustifications	Those deposits of minerals that are in layers and form crusts that have been distinctively deposited from solution.
cryosphere	That portion of the earth's surface that is permanently frozen.
cumulative distribution function (CDF)	For a given value of ξ and a random variable R , the CDF of R at ξ is the function that gives the probability that R is less than or equal to ξ , written $P(R \leq \xi)$. That is, the CDF accumulates probabilities of all values of R less than or equal to ξ .
cumulative impact	Projected impact of a proposed facility in combination with other existing and proposed facilities and actions.

cumulative releases of radionuclides	The total number of curies of radionuclides entering the accessible environment in a 10,000-yr period.
Curie point	The temperature above which thermal agitation prevents spontaneous magnetic ordering. Specifically, the temperature at which the phenomenon of ferromagnetism disappears and the substance becomes simply paramagnetic.
cyclic deformation	Subjecting a sample to multiple loading cycles such that the peak load is never surpassed.
damaged zone	See "modified permeability zone."
damping factor	The ratio of the observed damping to that required for critical damping (the point at which the displaced mass returns to its original position without oscillation).
datum (in geology)	The top or bottom of a bed of rock, or any other surface, on which contours are drawn (e.g., a datum horizon).
daughter products	A nuclide that results from radioactive decay. For example, radium-226 decays to radon-222, which in turn decays to polonium-218. Thus, radon is the daughter of the radium, and the polonium is the daughter of the radon.
debris (geomorphology)	Any surficial accumulation of loose material detached from rock masses by decay and disintegration; mainly consists of rock fragments and soil.
debris cone	An alluvial fan with steep slopes and composed of coarse fragments.
decay (radioactive)	(1) The process whereby radioactive materials undergo a change from one nuclide, element, or state to another, releasing radiation in the process. This action ultimately results in a decrease in the number of radioactive nuclei present in the sample. (2) The spontaneous transformation of one nuclide into a different nuclide or into a different isotope of the same nuclide.
decay chain	The sequence of radioactive disintegrations in succession from one nuclide to another until a stable daughter product is reached.

decay coefficient	A constant, characteristic of a nuclear species, which expresses the probability that an atom of the species will decay in a given time interval. For a large number of atoms of a species, the decay constant is the ratio between the number of decaying atoms per unit of time and the existing number of atoms.
decollement	Detachment structure of strata due to deformation, resulting in independent styles of deformation in the rocks above and below. A decollement is associated with folding and overthrusting.
decommissioning	The permanent removal from service of surface facilities and components necessary for preclosure operations only, after repository closure, in accordance with regulatory requirements and environmental policies.
decontamination	The removal of unwanted material (especially radioactive material) from the surface of or from within another material.
deconvolution technique	A linear mathematical operation whereby the effects of convolution on a signal are reversed to recover the signal. Convolution has many analogs in nature, such as multiple additive reflections of a seismic signal from different reflecting horizons in a layered sequence of geologic strata.
decoupling	The act of disconnecting differing mechanical stress regimes by an interfering boundary such as a fault or fault zone.
decrepitation	The shattering of a rock mass or rock sample caused by the buildup of excessive pressures in contained fluids as a result of heating, or the action of differential thermal expansion or contraction of its heated grains.
defense high-level waste	High-level radioactive waste generated by activities related to the national defense program, including the manufacture of nuclear weapons, the operation of naval reactors, and research and development at weapons laboratories.
deflectometer	A displacement-measuring instrument that is installed in a drillhole or embedded in a structure such as a dam. The deflectometer detects relative displacement of different points along the drillhole, in the plane perpendicular to the hole axis. The instrument may consist of an assembly that is permanently installed, or a sonde that is deployed within special tubing or casing.

deformation modulus	See "modulus of deformation."
degradation	The general lowering of the surface of the land by erosive processes, especially by the removal of material by flowing water.
delta function	A mathematical function that is infinite when its argument is zero, and zero elsewhere, and has the property that its integral over any interval that includes zero is unity.
demonstration breakout room (DBR)	A horizontal drift, located in an exploratory shaft, which will accommodate a number of rock mechanics tests to be performed during ESF construction.
dense rock equivalent (DRE)	A measure of volume used when describing tuff deposits. DRE is the equivalent volume of a tuff deposit when it is compressed to the density of hard rock of equivalent composition.
density borehole compensated (DBC) log	The record resulting from use of formation density logging tool with multiple detectors, which allows an adjustment to the density value for each depth point to compensate for borehole rugosity at or near that point. (See "formation density log with dual proximity" and "multidetector compensated gamma-gamma tool.")
desert pavement	A residual concentration of wind-polished, gravel-sized rock fragments, mantling a desert surface where wind has removed most of the smaller particles, and the lag surface protects the underlying material from further eolian erosion.
desert varnish	A thin, dark, shiny film or coating, composed of hydrated manganese and iron oxides with trace silica, formed on the surfaces of rock fragments, as well as on ledges and rock outcrops in desert regions. It is believed to be caused by exudation of mineralized solutions from within and deposited by evaporation on the surface.
design bases	The principal determinants that establish the overall repository design. There are two bases for the repository design: (1) the waste to be disposed and (2) the geologic characteristics of the site.
design-basis event	A credible accident or natural phenomenon (e.g., earthquakes or flood) that is used to establish design bases because its consequences are the most severe of all those postulated for other credible accidents or phenomena.

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design earthquake	A hypothetical earthquake against which protective measures are taken.
design life	The period of time for which a structure, system, or component is designed to perform its intended function. The repository design life ends when the repository is of no further operational use, waste retrieval is no longer a concern, and closure and decommissioning begin.
design package	Consists of the design of the repository (design drawings), supporting analysis, operating plan, and equipment demonstrations.
desorption	Freeing from a sorbed state. Removing a sorbed substance by the reverse of adsorption or absorption.
determination	A decision by the Secretary of Energy that a site is suitable for site characterization for the selection of a repository site or that a site is suitable for the development of a repository, consistent with applications of the guidelines of Subparts C and D in accordance with provisions set forth in Subpart B of 10 CFR Part 960.
development area	The underground area being prepared for emplacement of waste packages. Development includes excavation of the emplacement drifts and boreholes, installation of rock support in the drifts, and outfitting the emplacement boreholes with liners and covers. As the panel from the development of a panel is completed, bulkheads are installed to seal the panel from the development area and the panel is added to the ventilation circuit for the waste emplacement area.
deviatometer	A geophysical instrument that is lowered into a well in order to measure the deviation of the well from a vertical line originating at the bottom of the well. Most deviatometers use the earth's magnetic field for positional reference although some are gyroscopic in nature.
deviatoric stress	In the engineering discipline of rock mechanics, the difference between the major principal stress and the minor principal stress.
dielectric constant	The force F between two electric charges e , separated by a distance r in a vacuum, is given by $F = e^2/r^2$. In any other medium this relationship becomes $F = e^2/Dr^2$ where D is the dielectric constant of the medium. The dielectric constant is a measure of the polarity of the medium.

differential extension	A situation in which the offset or separation along the strike of a fault or fracture increases in one direction from an initial point and decreases in the other direction.
differential thermal analysis (DTA)	Thermal analysis carried out by uniformly heating or cooling a sample that undergoes chemical or physical changes, while simultaneously heating or cooling in identical fashion a reference material that undergoes no changes.
diffusion	<p>If the concentration at one surface of a layer of a liquid is d_1 and at the other surface, d_2, the thickness of the layer h and the area under consideration A, then the mass of the substance that diffuses through the cross-section A in time t is</p> $m = \frac{\Delta A (d_2 - d_1)t}{h}$ <p>where Δ is the coefficient of diffusion.</p>
diffusivity	Diffusivity or coefficient of diffusion is the amount passing through an area in a given direction in a given amount of time.
dilatancy	An increase in the bulk volume during deformation caused by a change from close-packed structure to open-packed structure, accompanied by an increase in the pore volume. The latter is accompanied by rotation of grains, microfracturing, and grain boundary slippage.
dip slope	A slope of the land surface with a slope angle approximately equal to the dip of the underlying rocks.
direct tensile strength	A directional property of a material that is determined by measuring the tensile force required to induce failure. The force exerted on the sample must be purely tensile, if possible, and not be compressive nor involve applied shear stress.
Dirichlet boundary condition	A boundary condition encountered in flow through porous media that occurs when the flow domain is adjacent to a body of open water.
discharge flux	The amount of flux discharging from a specified region.

discordant	(1) A contact between an igneous intrusion and the country rock that is not parallel to the foliation or bedding of the latter. (2) Structurally unconformable. Said of strata lacking parallelism of bedding or structure. (3) Said of radiometric ages, determined by more than one method for the same sample or for coexisting minerals that are in disagreement beyond experimental error. (4) Said of topographic features that do not have the same or nearly the same elevation.
dispersivity	A characteristic property of a porous medium which is one of two components of the coefficient of hydrodynamic dispersion. Also known as dynamic dispersion.
displacement	A general term for the relative movement of the opposing sides of a fault.
disposal	The emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste and the isolation of such waste from the accessible environment.
disposal container	See "container."
disposal system	See "mined geologic disposal system."
disqualifying condition	A condition that, if present at a site, would eliminate that site from further consideration.
disruptive event	A natural or human-induced event that would change the geohydrologic, geochemical, or rock characteristics of the site from their present conditions or adversely affect the expected performance of the engineered barrier system.
disruptive scenarios	See "disruptive event."
dissemination	Said of a mineral constituent of a rock deposit in which the desired minerals occur as scattered particles in the rock.
dissolution kinetic parameters	Those physical and chemical conditions that influence the rate at which a mineral will dissolve.
distribution coefficient (K_d)	The ratio of the activity on solid phase per unit mass of solid to the activity in solution per unit volume of solution under equilibrium conditions. This ratio not under equilibrium conditions is given by R_d .

distribution function (statistical)	The distribution function $F(x)$ (x is assumed to be continuous) is the probability of occurrence in the interval $(x, x + \Delta x)$ divided by Δx as the interval size (Δx) shrinks to zero.
disturbed conditions	Conditions arising from the occurrence of disruptive events.
disturbed zone	That portion of the controlled area, excluding shafts, whose physical or chemical properties are predicted to change as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change of properties could have a significant effect on the performance of the repository.
divergent zone	See "accretionary plate boundary."
dolly	A device that cradles the waste container within the horizontal emplacement borehole. The dolly is emplaced in the borehole along with the container it carries.
domino model	See "planar-rotational faults."
dose	The quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body.
dose commitment	The integrated dose that results from an intake of radioactive material when the dose is evaluated from the beginning of the intake to a later time; also used for the long-term integrated dose to which people are considered committed because radioactive material has been released to the environment.
dose equivalent (radiation)	An estimate of the amount of biological damage done by the deposition in tissue of a given unit of absorbed radiation dose. The dose equivalent is obtained by multiplying the absorbed radiation dose by a quality factor. The unit of dose equivalent is the rem.
dose limit	The limit established by the U.S. Environmental Protection Agency or the U.S. Nuclear Regulatory Commission for the exposure of people to radiation.
double-couple focal mechanism	Simplist mechanism causing displacement along a fault and conserving angular momentum such that the net torque is zero.
double-ring infiltro- meter	A device used to measure infiltration. Consists of two concentric rings placed around a testing area.
down-dip	A direction that is downward and parallel to the dip of a structure or surface.

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downwasting	The general term for the dislodgement and downslope transport of soil and rock material under the direct application of gravitational body stress.
drag fold	A minor fold, usually one of a series, formed in an incompetent bed lying between more competent beds, produced by movement of the competent beds in opposite directions relative to one another.
drainage basin	A region or area bounded by a divide and occupied by a drainage system; specifically the tract of country that contributes water to a particular stream channel or system of channels, or to a lake, reservoir, or other body of water.
drainage capture	See "stream capture."
drawdown	The lowering of the water table or potentiometric surface caused by pumping.
drift	Horizontal, or nearly horizontal, mined passageway. (See "main," "emplacement drift," and "perimeter drift.")
drift-pumpback test	A type of well test involving a single well and a chemical tracer in which the tracer is injected into an isolated interval of the well, allowed to drift with the natural motion of the ground water, and then pumped back out. The temporal variation of the returning tracer's concentration provides information on the dispersive and transport properties of the aquifer.
drill-and-blast mining	A method of mining in which holes are drilled into the rock and then loaded with explosives. The blast from the explosives breaks the rock so that the rock can be removed. The underground opening is expanded by repeated drilling and blasting.
drill and test	Hydrologic testing of selected rock intervals when each interval is first penetrated by a borehole. This testing takes place before a borehole is completed to its total depth.
drill cutting (well cuttings)	Rock chips cut by a bit in the process of well drilling, and removed from the hole in the drilling fluid in rotary drilling, in the bailer in cable-tool drilling, or by air when air is the drilling fluid.

drilling fluid	The circulation medium used in drilling to remove cuttings from the bit, to carry cuttings to the surface for disposal, to cool the bit, to stabilize the borewall in open intervals (as with drilling mud), and to energize downhole drilling tools (as with mud meters or air hammers).
drillstring	(1) A term used in rotary drilling for the assemblage in a borehole of drill pipe, drill collars, drill bit, and core barrel (if in use), connected to and rotated by the drilling rig at the surface. (2) A term used in cable drilling for the assemblage in a borehole of drill bit, drill stem, cable, and other tools, connected to the walking beam at the surface.
drive core	A core sample acquired by special tools that force a sampling cup or tube into the borewall. This method works best in soft rock formations.
Drucker-Prager yield criterion	This criterion is used to evaluate the yield response of a material subjected to a three-dimensional stress field. It states that the material will yield in a ductile fashion if the combination of stresses, as computed by an equation defining the criterion, exceeds the experimentally determined limiting values of the criterion for that material.
drusy cavities	An irregular cavity or opening in a vein or rock, having its interior surface or walls lined (encrusted) with small projecting crystals usually of the same minerals as those of the enclosing rock, and sometimes filled with water.
dry-bulb (DB) temperature	Temperature that is indicated by a conventional dry thermometer and is not dependent on atmospheric humidity.
dual induction focused log (DIFL)	A geophysical logging tool for measurement of the formation resistivity, that uses several coils to focus the signal, enhancing the true formation response at the expense of the material nearest the borehole, and improving vertical (axial) resolution.
ductile-brittle transition zone	The hypothesized zone of decoupling at the transition between brittle and ductile behavior that occurs at a depth of approximately 15 km in the Great Basin. Below this zone, extension probably occurs by ductile stretching, thinning, or intrusions of basaltic material from below or by a combination of these factors. Earthquakes generally do not occur below the transition zone.

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ductile fold	A fold that undergoes plastic deformation rather than brittle deformation. The beds, especially the competent beds, tend to be the same thickness regardless of their position on the fold. The incompetent beds may thin at the limbs and thicken at the hinges.
durations (coda)	The latter part of a seismogram following the early, identifiable surface waves and in which arrive long trains of waves. It may last for hours, especially if long oceanic paths are involved.
duripan	A diagnostic subsurface soil horizon that is characterized by cementation by silica and by accessory cements. Duripans occur mainly in areas of volcanism that have arid or Mediterranean climates.
dust devils	A small but vigorous whirl-wind, usually of short duration, rendered visible by dust, sand and debris picked up from the ground.
dynamical models (statistical)	A model is said to be dynamic if it possesses either or both of these properties: (1) at least one variable occurs in the governing equations with value taken at different points in time or in the form of time-derivatives, etc., (2) at least one equation contains a function of time.
earth flow	A slow flow of unconsolidated earth material lubricated with water, occurring as either a low-angle terrace flow or a somewhat steeper but slow hillside flow.
earthquake focal mechanisms	All processes that take place at the focus of an earthquake. All kinds of faulting (thrust, normal, strike-slip) give rise to different, yet common forms of energy release. If the earthquakes generating these faults are considered as point sources, the "focal mechanism" can be analyzed by looking at the radiation pattern (zones of dilatation and compression).
eddy-correlation technique	A method of studying the effects of sea surface on the air above it by measuring simultaneous fluctuations of the horizontal and vertical components of the airflow from the mean.
effective bulk permeability	The permeability of a portion of rock mass sufficiently large to include the effects of cracks, joints, faults, etc, as well as the effects of interconnected pores. See also "permeability."

effective neutron multiplication factor, K_{eff}	The ratio of the number of neutrons in a given generation to the number of neutrons in the immediately preceding generation. For criticality, K_{eff} must be unity (if $K_{eff} > 1$ then supercritical).
effective permeability	The measure of the ease with which a particular fluid can move through a porous medium. For example, soils have differing effective permeabilities for water and air.
effective porosity	The amount of interconnected pore space and fracture openings available for transmission of fluids, expressed as the ratio of the volume of the interconnected pores and fracture openings to the volume of rock.
effective precipitation	That part of precipitation producing runoff.
effective saturated thickness	That thickness of an aquifer contributing to the flow of ground water.
elastic compression	Compression in which the strain is reversible and the body recovers its original shape when the stresses are removed.
elastic modulus (modulus of elasticity)	The ratio of stress to its corresponding strain under given conditions of load, for materials that deform elastically.
elastic-plastic media	A material in which instantaneous elastic strain at a constant stress is followed by continuously developed permanent strain as long as the stress is maintained.
elastoplastic strain hardening	Material behavior in which the rate of development of permanent, plastic strain in an elastic-plastic material subjected to constant stress diminishes as the total amount of such plastic strain accumulates.
electric log (E-log)	The generic term for a well log that displays electrical measurements of induced current flow (e.g., resistivity log, potential curve log) in the rocks of an uncased borehole.
electrical conductivity	A measure of the ease with which a conduction current can be caused to flow through a material under the influence of an applied electric field. Electrical conductivity is the reciprocal of resistivity.
electrical resistivity	The electrical resistance per unit length of a unit cross-sectional area of a material.

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electrical survey (ES)	A generic term referring to the combined use of several geophysical logging tools: self potential (SP), resistivity in short and long normal configuration, and resistivity in a lateral configuration. These logs are sensitive to the following properties of the geologic section penetrated by a drillhole: resistivity of the rock matrix, porosity, electrical properties of the formation fluid, electrical properties of the drilling and or other fluid in the well base, electrical anisotropy and inhomogeneity of the rock, and the temperature downhole.
electrochemical potentiokinetic reactivation (EPR)	Electrical force generated by means of chemical action in manufactured cells (dry batteries) or by natural means (galvanic reaction).
electron microprobe	An analytical instrument that uses a finely focused beam of electrons to excite x-ray emission from selected portions of a sample. From the emitted x-ray spectrum the composition of the sample at the point of excitation can be determined.
electron spin resonance	Resonance occurring when electrons undergoing transitions between energy levels in a substance are irradiated with electromagnetic energy of a proper frequency to produce maximum absorption.
electrostatic adsorption	The removal of a solute particle from a solution as a result of an electrostatic charge disparity between the particle and the rock matrix. A particle with a strong charge disparity may displace one with a weaker disparity on the rock matrix in a process known as ion exchange.
elute	To remove adsorbed material from an adsorbent by means of a solvent.
emplacement	The act of placing waste containers in prepared positions. For the proposed repository at Yucca Mountain, two methods are currently being considered: emplacement of a single waste container in a shallow vertical borehole in the floor of the emplacement drift or emplacement of multiple waste containers in long horizontal boreholes in the wall of the drift.
emplacement borehole	A borehole used specifically for emplacement of waste.

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emplacement borehole liner	A sleeve placed in a vertical or horizontal borehole to prevent sloughed rock from interfering with the emplacement or removal of waste packages. It does not serve a shielding or containment function. The liner runs the complete length of horizontal boreholes, but, in vertical boreholes, extends only from the mouth of the borehole to just below the shoulder of the emplaced waste container. See "casing."
emplacement drift	A drift in which waste emplacement boreholes are located.
emplacement envelope	The components that surround the emplaced waste containers(s). The emplacement envelope includes boreholes, liner(s), borehole shield plug, and borehole cover.
emplacement horizon	The specific geologic stratum or portion thereof in which waste will be emplaced below the earth's surface. A portion of the Topopah Spring Member of the Paintbrush Tuff is currently the target emplacement horizon at Yucca Mountain.
en echelon	Geologic features that are in an overlapping or staggered arrangement (e.g., faults). Each is relatively short, but collectively they form a linear zone in which the strike of the individual features is oblique to that of the zone as a whole.
engineered barrier system (EBS)	(1) The waste packages and the underground facility (10 CFR Part 60); (2) The man-made components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. The EBS includes the radioactive-waste form, radioactive-waste canisters, materials placed over and around such canisters, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility (10 CFR Part 960).
enrichment	The processes by which the relative amount of one constituent material or element contained in a rock is increased. This may be due either to the removal of other constituents selectively, or to the introduction of increased amounts from an external source.
environmental assessment (EA)	The document required by Section 112(b)(1)(E) of the Nuclear Waste Policy Act of 1982.
environmental impact statement (EIS)	The document required by Section 114 of the Nuclear Waste Policy Act of 1982.

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epeirogeny	Movements of uplift and subsidence that have produced the broader features of the continents and oceans, e.g., plateaus and basins, in contrast to orogeny, which has produced mountain chains.
ephemeral drainage	Drainage of a stream or portion of a stream that flows briefly in direct response to precipitation in the immediate vicinity, and whose channel is at all times above the water table.
epicenter (earthquake)	The point on the earth's surface directly above the exact subsurface location of an earthquake.
epiclastic rock	A rock formed at the earth's surface by consolidation of fragments of preexisting rocks. A sedimentary rock whose fragments are derived by weathering or erosion.
epithermal	Said of a hydrothermal mineral deposit or alteration typically formed within about 1 kilometer of the earth's surface in a temperature range of 50 to 200°C.
epithermal neutron log	A well log of the wall-contact sonde type that measures epithermal neutron radiation in the 0.1 to 100 eV energy range, which is induced by bombardment with neutrons at several MeV energy. Similar to the thermal neutron tool but relatively insensitive to the presence of thermal neutron absorbers such as chlorine, boron, or lithium.
epithermal neutron porosity	A porosity estimate determined from the epithermal neutron response. Generally calculated using either (1) a calibration relationship developed using samples of the formation material, or (2) a standard calibration relationship that ensures full saturation with fresh water, and a rock matrix of pure limestone.
equivalent continuum model	A conceptual and numerical model whereby the mechanical, thermomechanical, hydrologic, or geochemical response of a locally heterogeneous rock mass is characterized on a relatively large scale by the appropriate properties of a homogeneous continuum.
equivalent energy density concept	A procedure for determining the areal power density for wastes that differ in age and burnup from the average values used in determining the design basis areal power density. The equivalent areal power density is that waste loading that deposits the same energy in the host rock over a fixed period of time (usually 2,000 years) as would waste having the average characteristics.

eugeosyncline	A geosyncline in which volcanism is associated with clastic sedimentation; the volcanic part of an orthogeosyncline, located away from the craton.
Eulerian-Lagrangian solution technique	Technique for the solution of ground-water flow and transport.
Eureka low	A subprovince of the Great Basin with anomalously low heat flow in southern Nevada.
evaluation	The act of carefully examining the characteristics of a site in relation to the requirements of the qualifying and disqualifying conditions specified in the guidelines of 10 CFR 960 Subparts C and D. Evaluation includes the consideration of favorable and potentially adverse conditions.
evapotranspiration	A term embracing that portion of the precipitation returned to the air through direct evaporation or by transpiration of vegetation; no attempt is made to distinguish between the two.
EX-size borehole	A 38-mm (1.5-in.) diameter borehole.
exfoliation	The process by which concentric scales, plates, or shells of rock, from less than a centimeter to several meters in thickness, are successively spalled or stripped from the bare surface of a larger rock mass.
expected partial performance measure (EPPM)	A measure for determining whether a scenario class needs to be included in the final calculation of the complementary cumulative distribution function (CCDF).
expected repository performance	The manner in which the repository is predicted to function, considering those conditions, processes, and events that are likely to prevail or may occur during the time period of interest.
explicit-dynamical models	General circulation models in which day-to-day synoptic-scale weather systems and their associated patterns of precipitation are treated explicitly, requiring time steps of the order of minutes to hours for the atmospheric portion of the climate model.
exploratory shaft	A vertical shaft of sufficient depth to allow in situ characterization of the emplacement horizon. The shaft is large enough to allow people and test equipment to be transported from the surface to the underground excavations.

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exploratory shaft facility (ESF)	The exploratory shafts, any associated surface structures, and underground openings constructed for the purpose of site characterization.
exposure	The radiation dose received by the absorption of radiation or the intake of a radionuclide by any individual.
extensometer	A device used to measure deformation.
extraction ratio	The ratio of the excavated area of all drifts to the total area. (Note that in the case of horizontal emplacement orientation, the area of the emplacement boreholes is not included in the ratio.)
fabric	The spatial and geometrical configuration of all those components that make up a deformed rock, including texture, structure, and preferred crystallographic orientation.
faceted spur	A ridge, or a divide between stream valleys that has an inverted-V face in cross section, produced by faulting or erosion.
facility	Any structure, system, or system component, including engineered barriers, created by the DOE to meet repository performance or functional objectives.
facility cask	See "transporter cask."
falling head injection test	A test to determine the hydraulic conductivity in which the hydraulic head is allowed to fall during a specified period of time. The hydraulic conductivity is calculated from the drop in hydraulic head and the cross-sectional area.
fallout	Fission and activation products, produced by the above-ground detonation of a nuclear device, that precipitate back down to the land surface.
fan	See "alluvial fan."
fanglomerate	A sedimentary rock consisting of slightly water-worn heterogeneous fragments of all sizes, deposited in an alluvial fan and later cemented into a firm rock.
far field	That portion of the host rock surrounding the underground facility within which the thermal effects of the emplaced waste can be analyzed by considering only the areal power density without consideration of the specific geometric characteristics of the underground facility.

fault	A fracture or zone of fractures along which there has been displacement of the side relative to one another, parallel to the fracture or zone of fractures.
fault trace (line)	The line of a fault plane on the ground surface or on a reference plane.
favorable condition	A condition that, though not necessary to qualify a site, is presumed, if present, to enhance confidence that the qualifying condition of a particular guideline can be met.
felsic	A mnemonic term derived from "Fe" for feldspar, "l" for feldspathoids, and "s" for silica and applied to light-colored rocks containing an abundance of one or all of these constituents.
ferricrete	A conglomerate consisting of surficial sand and gravel cemented into a hard mass by iron oxide derived from the oxidation of percolating solutions of iron salts.
ferruginous zone	Pertaining to or containing iron (e.g., a zone in a sandstone that is cemented with iron oxide).
Fickian dispersion	Dispersion that follows Fick's first law: The mass of diffusing substance passing through a given cross section per unit time is proportional to the concentration gradient.
field density test	See "rubber-balloon method."
final procurement and construction design	The design that will develop the final (working) drawings and specifications for procurement and construction. The completion of this design phase will match the completion of the Title II design effort for the entire repository. This design phase will emphasize the completion of design of ancillary support items, final design refinement for the items necessary to demonstrate compliance with the design criteria and performance objectives of 10 CFR Part 60, the development of construction bid packages for all systems, and the development of final procurement and construction schedules.
fines	Clay- and silt-sized soil particles with a maximum particle size less than 8 mm.

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first motion	The initial motion of the ground resulting from a seismic event. A first-motion study or fault-plane solution, is a technique by which motion on fault planes associated with earthquakes can be determined, thus giving information on the orientation of faults and slip directions of earthquakes.
first-order landscape element	The primary divisions of the earth's physiographic features, consisting of the continents and ocean basins.
first-year activities	Site characterization activities, as defined by the NWPA, that will be initiated during the first year of site characterization.
fission product	A nuclide produced by the fission of a heavier element.
fission track dating	A method of calculating an age in years by determining the ratio of the spontaneous fission-track density to induced fission tracks. The method which has been used for ages from 20 years to 1.4×10^9 years, works best for micas, tectites, and meteorites, and is also useful for determining the amount and distribution of the uranium in the sample.
fission tracks	The paths of radiation damage made by the spontaneous fission of uranium-238 impurities.
flatjack	A hollow metal cushion formed of two nearly flat plates, butt-welded around the edges, and inflated under controlled pressure to bear against restraints. A flatjack is used to test in situ stress and rock-mass deformability.
flocculent	The act or process by which a number of individual, minute, suspended particles are tightly held together in clot-like masses or are loosely aggregated or precipitated into small lumps, clusters, or granules.
flow breccia	A breccia that is formed contemporaneously with the movement of a lava flow; the cooling crust becomes fragmented while the flow is in motion and is either incorporated into the flow, or falls in front of the moving flow and is overridden.
flow path	The theoretical line that ground water follows in moving from a recharge area to a discharge area.
flow rocks	Igneous rocks that have been emplaced by the physical process of flowing.

flow unit	A group of stacked pyroclastic deposits that were emplaced as separate ash-flow tuffs during the same or closely associated eruptive event(s).
fluid density log	A record in a wellbore of the variation of the density of a fluid column with depth. The record is most commonly made during the drilling process as a means of assessing the properties and performance of the drilling fluid.
fluid inclusion	A cavity, typically 1.0 to 100.0 microns in diameter, in a mineral containing liquid or gas, formed by the entrapment in crystal irregularities of fluid, commonly that from which the rock crystallized.
fluid potential	The mechanical energy per unit mass of a fluid, (e.g., water or oil), at any given point in space and time, with respect to an arbitrary state and datum. The fluid potential is the total head multiplied by the acceleration due to gravity.
fluid pressure (hydrostatic pressure)	The pressure exerted by water at any given point in a body of water at rest. The hydrostatic pressure of ground water is generally due to the weight of water at higher levels in the zone of saturation.
flume	An artificial, inclined channel used for conveying water.
fluorometry	Measurement of the intensity and color of fluorescent radiations.
flushing fluid (drill fluid)	Usually pure or mud-laden water (sometimes applied to compressed air, natural gas, or oil) circulated through a drill string to keep the bit cool and to wash away the cuttings produced by the bit face. Also called circulation fluid.
flux	The ratio of the volume of fluid per unit area per unit time. Also known as specific discharge.
fluxgate magnetometer	An electrical instrument that measures the change in magnetic field along the axis of its sensor with a sensitivity of one gamma or more. Used on the ground, it measures the relative vertical magnetic intensity.
fly ash	All particulate matter that is carried in a gas stream.
focal depth (depth of focus)	The distance from the focus of an earthquake to the epicenter.

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focal mechanism (fault-plane solution)	Determination of the orientation of a fault plane and the direction of slip motion on it from an analysis of the sense of the first motion of the P waves or the amplitudes of the P waves, S waves, and surface waves.
focal sphere	An arbitrary reference sphere drawn about the hypocenter or focus of an earthquake, to which body waves recorded at the earth's surface are projected for studies of earthquake mechanisms.
focus	The initial rupture point of an earthquake where strain energy is first converted to elastic wave energy.
foliation	A general term for a planar arrangement of textural or structural features in any type of rock. The planar structure that results from flattening of the constituent grains of a metamorphic rock.
forging	Using compressive force to shape metal by plastic deformation.
formation density log (FDL)	Vertical profile of changes in density of a formation around a borehole. The intensity of scattered gamma radiation induced by irradiating the formation with medium-energy gamma rays reflects the electron density of the formation, which is proportional to true blue density. This technique is mainly used as a porosity indicator.
formation density log (FDL) with dual proximity (FDD)	A formation density logging tool with two or more detectors at different distances from the gamma source to compensate for the effects of mud cake and possibly formation invasion, and to detect borehole rugosity effects.
formation water	Water present in a water-bearing formation under natural conditions, as opposed to introduced fluids such as drilling mud.
fractional crystallization	Crystallization of a magma body in which newly formed crystals are removed from communication with a melt before they can react with the residual liquid.
fracture	A general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress. Fractures include cracks, joints, and faults.
fracture conductivity	The hydraulic conductivity within a fracture or system of fractures.

fracture contact area	The cumulative area of a rock fracture over which the mating walls of the fracture are actually in mechanical contact. Expressed as a proportion of the total fracture area.
fracture flow	The movement of water through a fracture system.
fracture permeability	Permeability as a result of fractures. Where fracture density is high, fracture permeability is high.
fracture pore system	See "fractured porous media."
fracture porosity	The portion of large-scale rock-mass bulk porosity that is caused by voids associated with opening or aperture of fractures.
fractured porous media	Media exhibiting porosity resulting from the presence of joints or other fractures as well as from the rock medium itself.
free air	That portion of the earth's atmosphere, above the planetary boundary layer, in which the effect of the earth's surface friction on the air motion is negligible.
free energy	The maximum amount of work in addition to expansion work that can be obtained from a given process occurring at constant temperature and pressure.
free flow	In hydraulics, flow that is not disturbed by submergence or backwater.
free surface	The upper surface of a layer of fluid where the pressure on it is equal to the external atmospheric pressure.
free water	Water in the soil in excess of field capacity that is free to move in response to the pull of gravity.
Freundlich isotherm	A mathematical model representing the partitioning of solutes between liquid and solid phases in a porous medium as determined by laboratory experiments. The Freundlich isotherm is commonly expressed in graphical form where mass sorbed per unit mass of dry solids is plotted against the concentration of the constituent in solution.
frit glass	(1) A glass containing fluxing material and employed as a constituent in a glaze body, or other ceramic composition. (2) A glassy material produced by fusing a mixture or enamel and quenching it in water.

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fuel	As used in this document, fissionable material usable as the source of power when placed in a critical arrangement in a nuclear reactor.
fuel assembly	A single mechanical unit consisting of a number of fuel rods held together by a mechanical support structure designed to maintain proper spacing of the fuel rods and facilitate their handling.
fuel burnup	See "burnup."
fuel cladding	See "cladding."
fuel consolidation	The removal of spent-fuel rods from an assembly and repacking in a denser array to reduce the volume per metric ton of fuel. See "consolidation."
fuel element	See "fuel assembly."
fuel rod	A long, slender, cylindrical tube (usually made of stainless steel or Zircaloy) containing nuclear fuel in the form of uranium oxide fuel pellets. Also called "fuel pin."
gamma-gamma density log	See "formation density log."
gamma radiation	Electromagnetic ionizing radiation that is emitted from a nucleus during some types of radioactive decay processes. Gamma radiation can penetrate various thicknesses of absorbing material, depending primarily on the energy of the gamma ray and the composition of the material. Gamma radiation is primarily an external radiation hazard.
gamma ray log	A radioactivity log obtained by recording the natural radioactivity of the rocks traversed by a cased or uncased borehole or well, and expressed by measuring the intensity of naturally emitted gamma rays and plotting the data as a function of depth.
gamma-ray spectrum log	The radioactivity log curve of the intensity of broad-spectrum undifferentiated natural gamma radiation emitted from the rocks in a cased or uncased borehole. It is used for correlation and for distinguishing shales (which are usually richer in naturally radioactive elements) from sandstones, carbonates, and evaporites.
gangue	A valueless rock or mineral aggregate in an ore; that part of an ore that is not economically desirable, but cannot be avoided in mining.

gap-grain boundary inventory	Portions of the radionuclides in spent fuel that are segregated in part from the matrix and exist in concentrations higher than those found in the matrix, at the location of the grain boundary or between the fuel pellet and cladding.
gas chromatograph-mass spectrometer (GCMS)	An analytical technique that interfaces a gas chromatograph with a mass spectrometer. This technique utilizes the separation capabilities of the gas chromatograph such that the separated phases can be analyzed by the mass spectrometer. The resulting mass spectrum contains information on the structure of organic compounds and mixtures of organic compounds. This technique is also useful in detecting isotopes used in tracer studies.
gas drive	A process for recovering fluid from a porous rock, either in situ or in the laboratory, in which injection of a gas at elevated pressures is used to displace the fluid. The method is commonly applied in recovering oil from petroleum reservoirs after pumping becomes unproductive.
gas tracer test	A test in which slowly moving air currents can be directly observed by using smokes. These may range from simple dust clouds, through various chemical smokes, to more refined techniques employing gas and radioactive tracers.
general siting guidelines	Technical criteria established by the DOE to be used in the site selection process.
geodetic survey	Survey in which account is taken of the figure and size of the earth and corrections are made for earth curvature.
geodetic trilateration	Determining the relative position of points on the on the earth's surface by using a method of surveying in which the lengths of the three sides of a series of touching or overlapping triangles are measured and the angles are computed from the measured lengths.
geologic disposal system (GDS)	See "mined geologic disposal system."
geologic repository	A system requiring licensing by the NRC that may be used for the disposal of radioactive wastes in excavated geologic media. A geologic repository includes (1) the geologic repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.

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geologic repository operations area	A high-level radioactive waste facility that is part of a geologic repository, including both surface and subsurface areas and facilities, where waste-handling activities are conducted.
geopetal structure	Pertaining to any rock feature that indicates the relation of top to bottom at the time of formation of the rock.
geophone	See "seismometer."
geosyncline	Large, generally linear trough that subsided deeply throughout a long period of time during which a thick sequence of stratified sediments accumulated.
geothermal gradient	The change in temperature of the earth with depth expressed either in degrees per unit depth, or in units of depth per degree.
geothermometer	A mineral or mineral assemblage whose composition, structure, or inclusions are fixed within known thermal limits under particular conditions of pressure and composition and whose presence denotes a limit or range for the temperature of formation of the enclosing rock.
geotomography	A geophysical technique for acquisition and analysis of data in order to image the internal characteristics of a rock sample or in situ rock mass, using measurements made externally to the sample or from shafts and boreholes.
geotransport	Movement of radionuclides through subsurface soils and rocks, especially the movement of radionuclides in ground water.
gouge (fault gouge)	Soft, uncemented pulverized clayey or claylike material, commonly a mixture of minerals in finely divided form, found along some faults or between the walls of a fault, and filling or partly filling a fault zone; a slippery mud that coats the fault surface or cements the fault breccia. A gouge is formed by the crushing and grinding of rock material as the fault developed, as well as by subsequent decomposition and alteration caused by underground circulating solutions.
gradation	The proportion of material of each particle size, or the frequency of distribution of various sizes, constituting a particulate material such as a soil, sediment, or sedimentary rock. The limits of each size are chosen arbitrarily.
grain density	Density of the solid components of a rock.

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gravimeter log	A record of the gravity effects in boreholes to determine average rock densities.
gravitational potential	The amount of work that must be done to move a particle of unit mass to a specified position from a reference position.
gravity anomaly	The difference between the observed value of gravity at a point and the theoretically calculated value. It is based on a simple gravity model, usually modified in accordance with some generalized hypothesis of variation in subsurface density as related to surface topography.
gravity survey	Measurements of the gravitational field at a series of different locations. The object is to associate variations with differences in the distribution of densities and hence rock types.
greatest potential adverse impact	The maximum dose to an individual at the nearest unrestricted location. Equals the dose to the "maximum individual."
gross thermal loading	The total waste heat generation divided by the gross area of the repository. See "areal power density."
ground magnetic	A determination of the magnetic field at the surface of the earth by means of ground-based instruments.
ground surface infrared radiation	Electromagnetic radiation lying in the wavelength interval from about 0.8 microns to an indefinite upper boundary sometimes arbitrarily set at 1,000 microns. Bounded by visible radiation at its lower limit and microwave radiation at its upper limit.
ground truth	Data collected at ground sites used to verify or refute remote sensing data.
ground water	All subsurface water as distinct from surface water.
ground-water sources	Aquifers that have been or could be economically and technologically developed as sources of water in the foreseeable future.
groundmass	The material between the larger conspicuous crystals in an igneous rock.
grout curtain	An area into which grout has been injected to form a barrier around an excavation or under a dam through which ground water flows at a reduced flow.

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guideline	A statement of policy or procedure that may include, when appropriate, qualifying, disqualifying, favorable, or potentially adverse conditions as specified in the "guidelines."
guidelines	Part 960 of Title 10 of the Code of Federal Regulations--General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories.
hackly fracture	The property of a fracture or break along jagged surfaces as shown by certain minerals or rocks.
half-closure stress	The stress applied perpendicular to a fracture, required to reduce the unstressed aperture by half.
Harden Profile Index	A numerical soil index that relates 10 soil properties for each soil horizon. It is used to estimate ages of deposits or geomorphological events, and to condense descriptive field data to a numerical scheme that depicts the overall development of the soil profile.
headframe	The steel or timber frame at the top of a shaft that supports the sheave or pulley for the hoisting cables and serves various other purposes.
heat of hydration	The quantity of heat liberated or consumed when a substance takes up water.
heat-dissipation probe	An instrument used to measure matric potential in unsaturated rock.
heat pulse log	The record produced by a geophysical tool for measuring small amounts of axial flow in a borehole. The tool is typically stationed at a fixed depth, energized so as to heat a small volume of borehole fluid, and monitored to detect passage of heated fluid at detectors on the tool.
heavy liquid	In analysis of minerals, a liquid of high density, in which specific-gravity tests can be made, or in which mechanically mixed minerals can be separated.
high-angle fault	A fault with a dip greater than 45 degrees.
high-level radioactive waste	The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and other highly radioactive material that the NRC, consistent with existing law, determines by rule requires permanent isolation.

higher-level finding	Finding that must be made for each qualifying and disqualifying condition of the DOE's Siting Guidelines (10 CFR Part 960) at or before the repository site selection decision point. Higher level findings are Level 2 or Level 4 findings, which are defined in 10 CFR Part 960, Appendix III.
highly populated area	Any incorporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2,500 or more persons, or any census-designated place (as defined and delineated by the Bureau) of 2,500 or more persons, unless it can be demonstrated that any such place has a lower population density than the mean value for the continental United States. Counties or county equivalents, whether incorporated or not, are specifically excluded from the definition of "place" as used herein.
horst	An elongated, relatively uplifted crustal unit or block that is bounded by faults on its long sides.
host rock	The geologic medium in which radioactive waste is emplaced. (At Yucca Mountain, the likely host rock will be the welded tuff of the Topopah Spring Member of the Paintbrush Tuff.)
hot cell	A facility that allows remote viewing and manipulation of radioactive substances.
hot-wire anemometer flow meter	Device for measurement of very low air velocities and the fluctuating velocities that occur in turbulent flow. Basically, it consists of a wire or wires, usually platinum, supported in a frame and heated electrically. When exposed to an air current the heated wires cool, and as a result its electrical resistance alters. Measurements of resistance change may be correlated with the velocity of the air flow that caused the change.
human interference	Actions of humans in the future that could interfere with isolation of radioactive materials placed in a repository. Includes direct contact with waste, such as drilling of wells or sinking of shafts and withdrawal of contaminated water or rock materials.
human interference (inadvertent)	The result of future human activities that inadvertently modifies the ability of a mined geologic disposal system to effectively isolate waste through the modification of the baseline hydrologic, geochemical, or rock characteristics. Includes activities such as extensive ground-water withdrawal or irrigation near the controlled area boundary.

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human intrusion	Human activities conducted at the site that inadvertently result in direct contact with waste materials, or the creation of pathways to the accessible environment (i.e., exploratory drilling).
hydraulic barrier	A natural or artificial obstacle (e.g., a dike or fault gouge) to the movement of ground water.
hydraulic bulk conductivity	Conductivity of bulk rock mass.
hydraulic conductivity	The volume of water that will move through a medium in a unit of time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of the flow.
hydraulic conductivity ellipsoid	A three-dimensional ellipse in which the square roots of the values of the principal hydraulic conductivities are the major axes. The hydraulic conductivity ellipsoid is used to graphically determine the conductivity value for any direction of flow in an anisotropic medium.
hydraulic fracturing	The fracturing of a rock in a fluid reservoir by pumping in water (or other fluid) and sand (or other granular material) under high pressure. The purpose is to produce artificial openings in the rock in order to increase permeability or to measure the secondary stresses in situ. The pressure opens cracks and bedding planes, and the sand introduced into these cracks serves to keep them open when the pressure is reduced.
hydraulic gradient	A change in the static pressure of ground water, expressed in terms of the height of water above a datum, per unit of distance in a given direction.
hydraulic head	The height above sea level to which a column of water can be supported by the static pressure at that point. The total hydraulic head is the sum of elevation head (elevation above an arbitrary location) and pressure head.
hydraulic-stress test	Any procedure in which stresses (by pumping, injection, slugging, etc.) are imposed on an aquifer in order to evaluate its transmissive and/or storage properties.
hydrochemical facies	The diagnostic chemical character of ground-water solutions occurring in hydrologic systems. It is determined by the flow pattern of the water and by the effects of chemical processes operating between the ground water and the minerals within the lithologic framework.

hydrodynamic dispersion	The velocity distribution due to laminar flow through the pores combined with the effect of tortuous flow paths.
hydrofrac	See "hydraulic fracturing."
hydrofracture measurement	A method for measuring secondary principal stresses in situ by inducing artificial fractures. See "hydraulic fracturing."
hydrogen index log	See "neutron log."
hydrologic balance	The relative states of inflow, outflow, and storage of moisture over a given area of the earth's surface.
hydrologic tracejector	A geophysical tool for measuring axial flow in a borehole. The tool is typically stationed at a fixed depth, then caused to eject a small amount of miscible fluid containing a radioactive tracer, into the borehole fluid. The tool is then monitored to detect passage of the tracer at detectors on the tool.
hydrometer analysis	A method to determine the particle-size distribution of a sediment consisting of silt-size or finer particles.
hydrosphere	The aqueous envelope of the earth, including the ocean, all lakes, streams, and underground waters, and the water vapor in the atmosphere.
hygrometer	An instrument that is used to measure the humidity of the air.
Hypalon	Brand name for an impermeable synthetic fabric manufactured by Dupont.
hypocenter	The focus or specific point at which initial rupture occurs in an earthquake.
ice shelves	Floating ice permanently attached to a land mass.
imbricate thrusts	A set of nearly parallel and overlapping fault planes characterized by rock slices that are approximately equidistant and have the same displacement.
impedance	The product of seismic velocity and density.
incision	The process whereby a downward-eroding stream deepens its channel or produces a narrow steep-walled valley. Especially the downcutting of a stream during, and as a result of rejuvenation, whether due to relative movement (uplift) of the crust or other cause.

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indirect tensile strength test	See "Brazil test."
indirect test	See "Brazil test."
induced polarization	The production of a double layer of charge at a mineral interface, or production of changes in double layer density of a charge, brought about by application of an electric or magnetic field.
induction electrical survey (IES)	An electric-log curve obtained in an uncased borehole by transmitting coils (led with a constant alternating current) that induce concentric eddy currents in the rocks surrounding the borehole. These in turn induce fields that are detected by receiver coils. The magnitude of the fields is proportional to the conductivity of the surrounding rocks, and the log gives a continuous record of conductivity with depth.
inductively coupled plasma (ICP) spectroscopy	An analytical method that uses inductively coupled plasma to convert the sample solution to an atomic vapor for analysis with a multichannel analyzer. This method provides a rapid means of chemically analyzing solutions, providing multi-element analytical data rather than data on a single element as is the product of atomic absorption spectrometry.
industrial minerals	Any rock, mineral, or other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels, and gemstones; one of the nonmetallics.
information needs	(1) The lowest level of the issues hierarchy for performance and design issues. They comprise requirements for additional data or analyses about particular natural conditions or design elements. (2) Additional information needed to satisfy information requirements, (i.e., information requirements minus available relevant information) and thereby demonstrate compliance with regulations, etc.
ingestion-dose pathway	Those components of the food chain or water system that might contribute to the radiation exposure of an individual as the result of an intake of food or water.
inoculate	To implant microorganisms into a culture medium.
insolation	Protection against direct solar radiation provided by Earth's atmosphere.

institutional controls	Administrative controls, records, physical constraints, and combinations thereof that would limit intentional or inadvertent human access to the waste emplaced in a repository.
instrumental neutron activation analysis (INAA)	A technique for the trace element analysis of rocks and minerals using a sample that has been bombarded with neutrons in a reactor. From the identities of the radioisotopes, the identities of the parent elements in the sample can be determined. The quantity of the parent element can then be calculated.
interbasin flow	The flow of water between adjacent surface or ground-water basins.
interface zone (hydrology)	The contact zone between two fluids of different chemical or physical makeup.
interflow (water storm seepage)	The runoff (water) infiltrating the surface soil and moving toward streams as ephemeral shallow perched ground water above the main ground-water level. Interflow is usually considered part of direct runoff.
interfluve	The relatively undissected upland between adjacent streams flowing in the same general direction.
interglacial	Pertaining to or formed during the time interval between two successive glacial epochs or between two glacial stages.
intermittent stream	A stream that flows only periodically, as, after a rainstorm, during wet weather, or during part of the year.
internal drainage	Surface drainage in which the water does not reach the ocean, such as drainage toward the central part of an interior basin.
intrinsic dispersion	The variation with frequency of seismic velocity in an elastic material because of variations in the elasticity. Distinguished from the geometric dispersion associated with the physical configuration of the material.
intrinsic permeability (specific permeability)	Pertaining to the relative ease with which a porous medium can transmit a liquid under a hydraulic or potential gradient. It is a property of the porous medium and is independent of the nature of the liquid alone.

intrusion (igneous)	(1) The process of emplacement of magma in preexisting rock, (2) magmatic activity, or (3) the igneous rock so formed within the surrounding rock.
inverse problem	The problem of gaining knowledge of the physical features of a disturbing body by analysis of its effects. Finding the model from observed data.
ion chromatography	A term referring to analytical techniques that involve the chromatographic separation of ions utilizing high performance separation technology and automatic detection systems. The techniques involved usually employ ion exchange column systems using detection systems such as conductivity detectors or electrochemical detectors in a continuous flow system. Generally, this technique is used for separating and quantifying ions with pKa values greater than 7.
ion-microprobe	An instrument that uses a focused beam of ions that, in striking the surface of a sample, produces a resulting emission of ions from the surface of the sample. These ions are collected and analyzed. This technique complements the electron microprobe technique by providing information on the concentration and distribution of isotopes of the elements in the surface of a solid. This technique can handle detection of elements lighter than sodium, which generally is the limit of the electron microprobe.
ionic strength	A measure of the average electrostatic interactions among ions in a solution; it is equal to one-half the sum of the terms obtained by multiplying the molality of each ion by its valence squared. For a simple salt like KNO_3 , the ionic strength is equal to its concentration. ³ For a mixture of KNO_3 with AgIO_3 , the ionic strength varies as a function of the concentration of each salt.
ionizing radiation	Any radiation (e.g., alpha, beta, and gamma radiation) displacing electrons from atoms or molecules, thereby producing ions.
irreversible reaction	A reaction that proceeds in one direction.
island arc	A chain of islands usually with a curving archlike pattern, generally convex toward the open ocean, having a deep trench or trough on the convex side and usually enclosing a deep basin on the concave side. They are usually affiliated with subduction zones.

isolation	The inhibiting of the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits.
isolation barrier	The earth material around the underground disposal rooms; it acts to prevent radioactivity from entering the biosphere.
isometric	Used to describe minerals that form within the crystallographic system and whose structure is that of three equal and mutually perpendicular axes.
isostatic anomaly	The isostatic anomaly is defined as the observed Bouguer anomaly, corrected for the isostatic compensation that is theoretically required to support the weight of topographic features on the earth's crust, or the density deficiency associated with the oceans. The isostatic compensation correction is calculated by assuming that the total weight per unit area of any column of crustal material is the same if the bottom of the column is taken at a particular compensation depth (Pratt model or density contrast (Airy model)).
isotopic dating	See "radiometric dating."
isotopic exchange	A process whereby atoms of the same element in two different molecules or in different sites in the same molecule exchange places. The equilibrium in such an exchange reaction is influenced slightly by the relative masses of the two atoms which exchange; the process forms the basis of one of the methods of isotope separation and concentration.
issue	A question relating to the performance of the mined geologic disposal system that must be resolved to demonstrate compliance with the applicable Federal regulations (including 10 CFR Part 60, 10 CFR Part 960, 40 CFR Part 191, and 10 CFR Part 20). See Section 8.1.1.
joint	A surface of fracture or parting in a rock, without displacement.
kataseism	Earth movement toward the focus of an earthquake.
Kelvin equation	An equation giving the increase in vapor pressure of a substance that accompanies an increase in curvature of its surface; the equation describes the greater rate of evaporation of a small liquid droplet compared with that of a larger one, and the greater solubility of small solid particles compared with that of larger particles.

key	To establish a mechanical bond in a construction joint to stabilize the rock mass.
key block analysis	A method of analysis for estimating support requirements for underground openings, using a topological treatment of rock-mass joint orientations.
kinematic	The analysis of displacements and strains; it is based on geometric analysis plus a number of assumptions regarding the manner in which geometrical relationships serve to indicate displacements.
kinetics	A branch of science that deals with the effects of forces upon the motions of material bodies or with changes in a physical or chemical system.
Klinkenberg permeability (factor)	A factor indicating the dependence of measured permeability of a porous medium to gas pressure. This permeability is larger than that of a liquid because of the slip phenomenon in which the velocity of a gas layer in the immediate vicinity of the surface of the grains is finite in contrast of the zero velocity of a liquid.
Kriging	A statistical procedure that uses information from the degree of spatial continuity of a regionalized variable to find an optimal set of weighting factors that are used in the estimation of a geologic surface at the unsampled points. The method also provides measures of the uncertainty of the estimate.
lagging	Heavy planks or timbers used to support the roof of a mine, or for floors of working places and for the accumulation of rocks and earth in a stope.
laminations	The finest stratification or bedding typically exhibited by shales and fine-grained sandstones.
Landsat V Thematic Mapper imagery	Multispectral scanner remote sensing imagery from the Landsat V satellite.
Langmuir isotherm	A mathematical model representing the partitioning of solutes between liquid and solid phases in experiments. It is commonly expressed in two-ordinate graphical form where mass sorbed per unit mass of dry solids is plotted against the concentration of the constituent in solution.
lanthanides	Any element in a series of elements of increasing atomic numbers beginning with lanthanum (57) or cerium (58) and ending with lutetium (71).

lapse rates	The decrease in an atmospheric variable with height; the variable is temperature unless otherwise specified.
lateral faulting	A fault in which the net slip is practically in the direction of the fault strike.
lateral flow	Any flow where the major flow component is horizontal.
lateral offset	The horizontal distance one fault block moves in relation to the other.
leakance (leakage coefficient)	The quantity of water that flows across a unit area of the boundary between the main aquifer and its overlying or underlying semiconfining layer per unit head difference across this semiconfining layer.
lenticle	A small lentil.
lentil	A minor rock-stratigraphic unit of limited geographic extent, being a subdivision of a formation and similar in rank to a member, and thinning out in all directions.
license application	An application for a license from the U.S. Nuclear Regulatory Commission to construct a repository.
license application design	The design phase that completes the resolution of design and licensing issues identified and assessed in earlier design phases and will develop the design of the items necessary to demonstrate compliance with the design requirements and performance objectives of 10 CFR Part 60. Design requirements resulting from safety and reliability analyses will be fully integrated in this design to support the safety analysis report.
licensing	The process of obtaining the permits and authorizations required to site, construct, operate, close, and decommission a repository.
licensing assessment	An assessment of whether a license application complies with all of the requirements that it purports to meet. For this program it is the sum of the individual findings for each of the requirements of 10 CFR 60.
ligand	A group, ion, or molecule coordinated to a central atom in a complex.

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light water reactor (LWR)	A nuclear reactor that uses ordinary water as a moderator, in contrast to heavy water (a compound of hydrogen and oxygen containing a higher proportion of the hydrogen isotope deuterium).
linear energy transfer (LET)	A measure of the energy deposited by ionizing radiation per unit of path length. The quality factor used in determining dose equivalent is based on the LET.
linear expansion	The change in linear dimension of a solid resulting from the change in temperature. The coefficient of linear expansion is the change in a solid's unit linear dimension per 1 degree change in temperature.
linear variable differential transformer	Sensor used to measure displacements and relate them to changes in electrical outputs.
lineation	A general, nongeneric term for any linear structure in a rock (e.g., flow lines, slickensides, linear arrangements or components in sediments, or axes of folds).
liner	See "emplacement borehole liner."
liquefaction	In cohesionless soil, the transformation from a solid to a liquid state as a result of increased pore pressure and reduced effective stress.
liquid penetrant testing	A penetrant method of nondestructive testing used to locate defects open to the surface of nonporous materials; penetrating liquid is applied to the surface and after 1 to 30 minutes excess liquid is removed, and a developer is applied to draw the penetrant out of defects, thus showing their location, shape, and size.
listric surface	A curvilinear, usually concave-upward surface of a fracture or fault that curves, at first steeply then more gently, from a horizontal position. Listric surfaces bound wedge-shaped masses, appearing to be thrust against or along each other.
lithophysae	Bubblelike structures in rocks, generally hollow, composed of concentric shells of finely crystalline alkali feldspar, quartz, and other materials.
lithostatic load	The force exerted on an object or underground structure by the weight of overlying material in the lithosphere.
lithostatic pressure	The stress to which a rock formation is subjected by the weight of the overlying rocks in the lithosphere.

load cell	A strain-gaged cylinder or cell that can be calibrated to measure compressive loads directly.
local magnitude (M_L)	The logarithm of the amplitude of an earthquake wave with a 1-s period measured exactly 100 km away from the earthquake. This mathematical relationship holds only for shallow focus events and a correction factor must be added if the amplitude of the wave is not recorded at a position exactly 100 km away from the event.
logging cable	A survey cable or hoist cable containing one or more insulated electrical conductors enclosed in a tightly wrapped sheath of steel wires.
logging sondes	A downhole device containing the measuring instrument in logging a well or borehole, lowered on a logging cable (wire line) (e.g., a circular container used in electric logging and in which the electrode devices are set).
logistic regression	A regression analysis for sparse data using a maximum likelihood method.
loss of containment	The time at which the ensemble of waste packages first fails to conform to the numerical interpretation of "substantially complete containment."
low-angle fault	A fault with a dip of 45 degrees or less.
low-level waste (radioactive)	Radioactive material that is not either high-level radioactive waste, spent nuclear fuel, transuranic waste, or byproduct material as defined in Section 11a(2) of the Atomic Energy Act of 1954.
lower-level finding	A finding that must be made for each qualifying and disqualifying condition of the DOE's Siting Guidelines (10 CFR Part 960) at or before the site nomination and recommendation decision point. Lower level findings are Level 1 or Level 2 findings, which are defined in 10 CFR Part 960, Appendix III.
lysimeter	A structure used to measure quantities of water used by plants, evaporated from soil, and lost by deep percolation. It consists of a basin, having closed sides and a bottom fitted with a drain, in which soil is placed and plants are grown. Quantities of natural and artificial precipitation are measured, the deep percolate is measured and analyzed, and water taken up by the plants is weighed.
macroscopic continuum approach	See "continuum theory."

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magnetic log	Record of the magnetic susceptibility of the rocks surrounding a borehole using electromagnetic induction.
magnetic particle testing	A nondestructive method of inspection for determining the existence and extent of possible defects in ferromagnetic materials. Finely divided magnetic particles applied to the magnetized part are attracted to and outline the pattern of any magnetic leakage fields created by discontinuities.
magnetic polarity time scale	A chronology based on counting reversals of the earth's magnetic field.
magnetic survey	A survey made with a magnetometer on the ground or in the air that reveals local variations, or anomalies, in the total intensity, component intensity, or component direction of the earth's magnetic field.
magnetic susceptibility	The ratio of induced magnetization to the strength of the magnetic field causing magnetization.
magneto-stratigraphy	All parts of stratigraphy based on paleomagnetic signatures.
magnetotelluric (MT) method	An electromagnetic method of surveying in which natural electric and magnetic fields are measured. Usually the two horizontal electric-field components plus the three magnetic-field components are recorded.
main	One of the three main drifts that run from the base of the two ramps and men-and-materials shafts through the underground facility to provide access to the waste emplacement panels. See "tuff main," "service main," and "waste main."
man-rem	A unit used in health physics to compare the effects of different amounts of radiation on groups of people. It is obtained by multiplying the average dose equivalent to the whole body or a given organ or tissue (measured in rems) by the number of persons in that population.
mantle	The zone of earth below the crust and above the core, which is divided into the upper mantle and the lower mantle, with a transition zone between.
marker bed	A geologic formation that is distinctive and easily recognized over long distances, especially in the subsurface.
mass conservation	The physical principal that mass cannot be created or destroyed in the absence of fission or fusion.

mass spectrometer	An instrument that is composed of an (1) inlet system, (2) ion source, (3) electrostatic accelerating system, and (4) detector and readout-system. This instrument produces charged particles consisting of the parent ion and ion fragments of the original molecule and sorts these ions according to their mass to charge ratios (mass spectra).
mass spectrometry	An analytical technique that uses a mass spectrometer to produce a mass spectrum of the ions, molecules, functional groups, etc., present in the sample. The mass spectra are used to identify the structure of organic compounds and in analyzing complex organic mixtures.
mass transfer kinetics (sorption kinetics)	The process study of the kinetics of sorption as a function of water velocity. The adsorption of radionuclides is a dynamic process and has a reaction rate. This process study evaluates the kinetic limitations of sorption in an advective system.
mass wasting	A general term for the downslope movement of soil and rock material under the direct influence of gravity. The debris removed is not carried within, on, or under another medium.
massif	Body of intrusive igneous or metamorphic rock at least 10 to 20 miles in diameter occurring as a structurally resistant mass in an uplifted area that may have once been a mountain core.
matrix	Relatively fine-grained material in which coarser fragments or crystals are embedded; also called groundmass.
matrix diffusion	The movement of dissolved species from water in the connected pore space to water in the dead end pore spaces by the action of gradients in species concentration. In particular, the connected pore spaces may be fracture networks and the dead end pore spaces may be matrix pores.
maximally exposed individual	See "maximum individual."
maximum individual	A hypothetical member of the public whose habits, activities, and location tend to maximize the radiological dose received from some given operation.
maximum individual dose	The highest radiation dose delivered to the whole body or to an organ that a person can receive from a release of radioactivity. The hypothetical person who receives this dose is referred to as the maximally exposed individual.

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maximum permissible concentrations	The average concentration of a radionuclide in air or water to which a worker or member of the general population may be continuously exposed (40 hours per week only for workers) without exceeding regulatory limits on external or internal radiation doses. Specified in Appendix B of 10 CFR Part 20.
mechanical	A term applied to the material properties that govern the physical response of a material to applied physical stress or to the analysis of that response (e.g., mechanical properties, mechanical analysis).
mechanical dispersion	A microscopic mixing process caused entirely by the motion of fluid in a porous medium.
melange terrain	Composed of a heterogeneous mixture of rock material. Specifically, a mappable body of deformed rocks consisting of a pervasively sheared, fine-grained, commonly pelitic matrix, thoroughly mixed with angular and poorly sorted inclusions of native and exotic tectonic fragments, blocks, or slabs.
Mercalli intensity	A scale for measuring earthquake intensity in terms of the effects perceived by people near the earthquake.
mercury injection method	A method used for determining the porosity of a rock sample.
mesostasis	The last-formed interstitial material of an igneous rock.
metalogenic provinces	An area characterized by a particular assemblage of mineral deposits, or by one or more characteristic types of mineralization. A metallogenic province may have had more than one episode of mineralization, or metallogenic epoch.
metamorphic grade	The intensity or rank of metamorphism, measured by the amount or degree of difference between the original parent rock and the metamorphic rock.
metasomatic	The process by which one mineral is replaced by another of different chemical composition owing to reactions set up by the introduction of material from external sources.
metastable	Pertaining to a body or system existing at an energy level above that of a more stable state and requiring the addition of a small amount of energy to induce a transition to the more stable state.

metastable (radionuclide)	A state of temporary nuclear stability that occurs in some types of radioactive decays. During these decays (called isomeric transition), an intermediate product is formed by the first stage of decay. This product has a half-life long enough to be considered a separate isotope.
meteoric water	(1) Water occurring in or derived from the atmosphere. (2) Pertaining to water of recent atmospheric origin.
mined geologic disposal system (MGDS)	A system, requiring licensing by the NRC, that is used for the disposal of high-level radioactive waste in excavated geologic media. It is synonymous with "geologic repository."
mineral assemblages	The minerals that compose a rock, especially an igneous or metamorphic rock. The term includes the different kinds and relative abundances of minerals, but excludes the texture and fabric of the rock.
mineral paragenesis	A general term for the order of formation of associated minerals in time succession, one after another.
mineral stability	The tendency of a mineral species to remain unaltered under the conditions of temperature and pressure currently experienced.
mini-sosie (shallow seismic reflection)	A method of acquiring and analyzing seismic reflection data to image the subsurface. One or more tamping-type vibrators are used in conjunction with a geophone array. Deconvolution of the recorded wave-trains is required to eliminate the signature of the source vibrators.
miogeosyncline	A geosyncline in which volcanism is not associated with sedimentation.
mitigation	(1) Avoiding an impact altogether by not taking a certain action or parts of an action, (2) minimizing impacts by limiting the degree or magnitude of the action and its implementation, (3) rectifying an impact by repairing, rehabilitating, or restoring the affected environment, (4) reducing or eliminating an impact over time by preservation and maintenance operations during the life of the action, or (5) compensating for the impact by replacing or providing substitute resources or environments.
mixing height (or depth)	The height above the surface of the earth defining a layer where vigorous vertical mixing occurs; this mixing layer represents the vertical extent to which pollutants can be mixed in the atmosphere.

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modal petrography	The analysis of the actual mineral composition of a rock, usually expressed in weight or volume percentages.
modified Mercalli scale	An earthquake intensity scale having 12 divisions ranging from I (not felt by people) to XII (damage nearly total), commonly abbreviated MM.
modified permeability zone (MPZ)	The zone immediately surrounding an underground excavation in which the permeability of the rock mass has been altered due to stress redistribution and blast damage effects.
modulus of deformation	Experimentally determined coefficient of proportionality relating applied stress to observed strain.
modulus of elasticity	See "elastic modulus."
modulus of rupture	The maximum tensile stress in a sample undergoing bending, or the maximum shear stress in a sample undergoing torsion, corresponding to peak load.
modulus of subgrade	See "modulus of subgrade reaction."
modulus of subgrade reaction	Coefficient of proportionality (C_p) in the empirical expression: $P_s = (C_p)(S),$ where P_s is the soil pressure and S is equivalent to the settlement resulting from external pressure.
Mohorovicic Discontinuity	The boundary surface that marks a rapid change in seismic velocity. It marks the level at which P-wave velocities change abruptly. Its depth ranges from about 5 to 10 km beneath the ocean floor to about 35 km below the continents, although it may reach 60 km or more under some mountain ranges. It is variously estimated to be between 0.2 and 3 km thick.
Mohr-Coulomb criterion	A criterion of failure for solid material undergoing loading, relating peak stress conditions to confining pressure. May be used for intact material, or used to represent the minimum "residual" strength reached by a material subjected to deformation beyond the peak.
moisture-retention curve	A graph showing the percentage of soil moisture (by mass or volume) versus applied tension.
molecular diffusion	Macroscopic transport of mass, independent of any convection within the system.

molecular sieve	A term used to describe the function of zeolite materials, which are clay-like in chemical nature, and from which all water can be removed without alteration of their molecular structure. As a result of this, the material becomes microporous to such an extent that about half its volume is occupied by very small holes or channels. The material thus readily adsorbs molecules that are small enough to enter the pores vacated by the water molecules. Zeolites therefore act as selective devices that adsorb smaller molecules readily but exclude larger ones. For this reason, they are called molecular sieves.
molecular-sieve adsorption	The removal of a solute particle from a solution as the solution is forced through a material whose molecular structure is such that its physical arrangement precludes the passing of (and thus traps) the solute particle.
moments (statistical)	In general, the mean value of a power of a variate.
Monte Carlo simulation	A random-sampling process for generating uniformly distributed pseudorandom numbers and using these to "draw" random samples from known frequency distributions.
morphometric analysis	The measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landforms. The main aspects examined are the area, altitude, volume, slope, profile, and texture of the land as well as the varied characteristics of rivers and drainage basins.
morphotectonics	The tectonic interpretation of the morphological or topographic features of the earth's surface. It deals with their tectonic or structural relations and origins, rather than their origins by surfacial processes of erosion and sedimentation.
motile	Exhibiting or capable of movement.
muck	Broken rock or ore that results from excavation during mining operations.
mud cake	The material filling the cracks, crevices, pores, etc. of the rock or adhering to the walls of the borehole. The cake may be derived from the drill cuttings, circulating drill mud, or both. It is formed when the water from the drilling mud filters into porous formations, leaving the mud ingredients as a caked layer adhering to the walls of the drillhole.

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multibarrier system	A system of natural and engineered barriers, operating independently or relatively independently, that acts to contain and isolate the waste.
multidetector compensated gamma-gamma tool	See "formation density log with dual proximity."
multidetector compensated neutron porosity tool	See "neutron borehole compensated log."
multiple point borehole extensometer (MPBX)	Instrument placed in boreholes, drilled in walls of mined openings and tunnels and used to measure relative displacement changes parallel to the borehole axis in response to excavation or other loading of rocks in response to excavation or changes in the stress field.
multivalent	An element is said to be multivalent when one atom of that element can hold more than one atom of hydrogen in chemical combination if negative, or can displace in a reaction if positive.
multiwell aquifer test	A test to determine an aquifer's capacity; it involves adding or withdrawing measured quantities from more than one well and measuring the resulting changes in hydraulic head.
mylonite	A deformed rock or texture with a streaky or banded structure produced by shearing of rocks. Often used as a sense-of-shear indicator.
natural background radiation	Radiation that occurs naturally in the environment from such sources as cosmic rays, the naturally occurring radioactive elements in the earth, and naturally occurring radionuclides in living organisms (different from "background radiation").
natural barrier	The physical, mechanical, chemical, and hydrologic characteristics of the geologic environment that individually and collectively act to minimize or preclude radionuclide transport.
natural gamma log	A geophysical wireline method whereby a gamma radiation detector such as a scintillation counter is used in a borehole to record the variation of natural gamma activity with depth.

natural system	A host rock suitable for repository construction and waste emplacement and the surrounding rock formations. Includes natural barriers that provide containment and isolation by limiting radionuclide transport through the geohydrologic environment to the biosphere and provide conditions that will minimize the potential for human interference in the future.
near-field	That portion of the rock surrounding emplaced waste in which analysis of the thermal and thermomechanical effects of the waste must consider the specific geometric characteristics of the underground facility, including borehole size and orientation, standoff distance, drift shape dimensions and spacing, or overall layout of the facility.
neotectonics	The study of the post-Miocene structures and structural history of the earth.
net infiltration	The amount of precipitation that enters the unsaturated zone below the surficial root zone.
Neumann boundary condition	A boundary condition in which the flux normal to the boundary surface is prescribed for all points. A special case of this type of boundary is the impervious boundary where the flux normal to the boundary vanishes everywhere.
neutron activation analysis	A quantitative analytical technique for elemental analysis that involves the production of a radioactive isotope by the capture of neutrons by the nuclei of the substance to be analyzed. The identification of the radioactive isotopes is done by measurement of the half-life (or energy of the beta particles) or by the gamma-ray spectrum.
neutron borehole compensated (NBC) log (compensated log)	A well log made with a mandrell-type neutron logging tool having two neutron detectors. The neutron porosity is derived from the ratio of the counting rates of the two detectors.
neutron log	A radioactivity log that measures the intensity of neutrons or gamma rays produced when rocks around a borehole are bombarded by neutrons from a synthetic source.
neutron moisture tube	A probe lowered into an access hole used for measuring water content of soil and rocks as indicated by the scattering and absorption of neutrons emitted from a source, and the resulting gamma radiation received by a detector.

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neutron-neutron log (NNL)	Any of the several neutron log curves that measures the abundance of neutrons of a discrete energy range. Neutrons arrive at the detector after "random walk" scattering and slowing, most effectively by hydrogen nuclei. Depending on the neutron-energy selectivity level of the indicator, these curves may be divided into epithermal neutron log and thermal neutron log types.
neutron probe	A probe that measures the intensity of radiation (neutrons or gamma rays) artificially produced when rocks around a borehole are bombarded by neutrons from a synthetic source. The results are recorded on a neutron log.
neutron scattering	The change in direction of neutrons caused by collision with nuclei in a material.
neutron soil-moisture meter	See "neutron moisture tube."
nivation	The process of excavation of a shallow depression in a mountainside by removal of fine material around the edge of a shrinking snow patch or snowbank, chiefly through sheetwash, flow, and solution in meltwater.
no-flow boundary	See "Neumann boundary condition."
nodal plane	A plane through the earthquake focus in which no energy of the longitudinal wave kind is radiated but where transverse wave energy is at a minimum.
nonradiological risk	A risk from sources other than exposure to radiation.
normal conditions	The state or conditions expected to be present most of the time. It is generally used to indicate conditions of temperature, opening stability, equipment, etc., expected about 90 percent of the time.
normal fault	A fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of the fault is usually 45 to 90 degrees measured from the horizontal.
nuclear borehole geophysical log	Log that measures and records radiations from rocks penetrated by a borehole or well. A sonde (on a wire line) is lowered and raised making measurements of radioactive properties of the rocks as a function of depth. Used in cased and uncased holes.
nuclear fuel cycle	Those operations associated with the production of electrical power for public use by any fuel cycle through utilization of nuclear energy.

NX-sized borehole	The letter code for a 76-mm (3-in.) borehole from which a 54.8-mm (2.16-in.) diameter core is typically extracted.
oblique extension	Extension along a fault in which the motion is a combination of slip along the dip of the fault plane and slip that is purely horizontal.
observation well	A special well drilled in a selected location for the purpose of observing parameters such as fluid levels and pressure changes.
occupational dose	The radiation dose received by a person in a restricted area or in performing work duties involving exposure to radiation.
occupational exposure	The absorption of radiation or the ingestion of a radionuclide by any individual on duty and engaged in operations involving the management, storage, and disposal of radioactive waste.
oceanic mixed layer	The surface layer of the ocean that is well mixed by winds, waves, seasonal cooling, and salinity increases resulting from evaporation.
ODEX drilling method	An under-reamer type percussion drilling method that uses special tools to pull a string of casing into the hole as the hole is drilled. The under-reamer type bit provides a clearance hole for the casing, while providing a means to extract the drill string and tools. The ODEX system is often used with a downhole hammer, and may be used with various drilling fluids including mud, foam, or air alone.
off-normal	See "abnormal."
offsite	That area not under effective control of persons possessing or using spent nuclear fuel or radioactive waste.
ongoing activities	Site characterization activities, as defined by the NWPA, that were in progress at the time of Presidential approval (May 1986).
open-system method	See "uranium-trend method."
operational phase	The period of time from the receipt of the first waste at the site of the repository to closure and decommissioning.
orbital elements	A set of seven parameters defining the orbit of a body attracted by a central inverse-square force.

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orogeny	The process of forming mountains, particularly by folding and thrusting.
orographic	Said of the precipitation that results when moisture-laden air encounters a high barrier and is forced to rise over it, such as the precipitation on the windward slopes of a mountain range facing a steady wind from a warm ocean. Also, said of the lifting of an air current caused by its passage up and over a mountain.
osmotic potential	The pressure that is developed across a membrane, which is permeable to the solvent but not the solute, when differing concentrations of a solute are placed in contact with opposite sides of the membrane, and flux of solvent across the membrane is not allowed.
outflow	Water that flows out (e.g., ground-water seepage and stream water flowing out of a drainage basin). Also, the amount of water that has flowed out.
out-year activities	Site characterization activities, as defined by the NWPA, that will be initiated after the first year of site characterization.
overburden stress (geostatic pressure)	The vertical pressure at a point in the earth's crust, equal to the pressure caused by the weight of a column of the overlying rock or soil.
overcoring	(1) A process for determining stress components in a rock mass. The process consists of drilling a small diameter borehole and inserting deformation-sensing devices. Subsequently, a larger diameter hole is drilled concentrically with the first hole and, in doing so, relieves the stress in the rock cylinder. The measured deformations are related to stresses through elastic relationships. (2) (rock mechanics) A method of measuring in situ stress. The method involves installation of multidirectional strain recording devices in small boreholes and removing the devices by the coring and enclosing wall rock while recording the resulting strain relief. (3) The drilling of a relatively larger diameter core, encompassing a preexisting, smaller diameter hole. The larger and smaller holes need not be concentric.
overcoring stress	In situ stress determined by the method of overcoring.
overdraft	Withdrawal of ground water in excess of replenishment.

overpack	Any receptacle, wrapper, box, or other structure that becomes an integral part of a radioactive waste package and is used to enclose a waste container for purposes of providing additional protection or for meeting the requirements of an acceptance or isolation criterion for a specific site. An overpack is often used to encase a damaged or contaminated waste package for which repair or decontamination is impractical.
oversaturated	Contains, because of its manner of preparation, more solute than normally expected under the given condition.
oxidation-reduction reaction	A chemical reaction in which one or more electrons are transferred between two or more chemical constituents of the system.
oxygen-isotope analysis	Analysis of the fractionation of oxygen isotopes (oxygen-18/oxygen-16) in oxygen-bearing geologic materials which may be used as an indication of the source or temperature of formation of the materials.
P-wave	See "compressional wave."
pack rat midden	Preserved plant remains, dung, and refuse deposited in rock cavities by rodents of the genus Neotoma and held together by dried urine.
packaging	The container, any overpacks and their contents, excluding radioactive materials and their encapsulating matrix but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for absorbing mechanical shock, external fittings or handling devices, neutron absorbers or moderators, and other supplementary equipment that surrounds the radioactive material.
packer	A removable device used in drilled holes to isolate one part of a borehole from another in order to carry out studies of particular formations or parts thereof.
packer tests	An in situ flow test carried out in a drillhole by isolating an interval of uncased (open) hole and injecting water or gas into the interval. The rate of inflow is measured at a range of values of constant injection pressure. The tests may be performed in some cased holes if the test interval is perforated.

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packer-injection tests	A variety of tests whereby a liquid (usually water) or gas is injected into a "sealed off" or isolated portion of a borehole or well to obtain data on such things as formation permeability and fracture flow parameters of rocks.
paleo-	A combining form denoting the attribute of great age or involving ancient conditions (e.g., paleoclimate, paleosol, paleohydrology).
palynology	The branch of science concerned with the study of pollen of seed plants and spores of other embryophytic plants, whether living or fossil.
pan evaporation data	Data collected on evaporation rates by directly measuring the drop in water level in the evaporation pan at specific time intervals.
panel	A nearly rectangular section of the underground layout sized to accommodate a certain amount of waste and used in planning, scheduling, and design analyses.
paragenesis	See "mineral paragenesis."
partial penetration	A well that does not fully penetrate the aquifer under development.
partial pressure	The pressure exerted by a specified component in a mixture of gases.
particle-tracking technique	A numerical procedure commonly used in calculating the dispersive transport properties of an aquifer. In practice, mathematical points or "particles" are permitted to move (1) in the direction of water flow to simulate advection, and (2) in accordance with some random statistical distribution (frequently Gaussian) to simulate dispersion.
particle velocity	The velocity with which an individual particle of water moves through the subsurface.
Pasquill stability class	See "atmospheric stability class."
passive institutional control	(1) Permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4) other methods of preserving knowledge about the location, design, and contents of a disposal system.

passive margin	In plate tectonics, movement along extensional ridges occurring in such a way as not to deform or distort the large bodies of horizontally stratified sediments lying in the continental margin.
Peclet number	A dimensionless quantity that measures the magnitude of advective transport relative to the magnitude of diffusive transport.
Peltier type thermocouple psychrometer	A water potential thermocouple psychrometer that is wetted by passing a current through the thermocouple junction, causing it to cool below the dewpoint, resulting in the condensation of water vapor on the sensing junction.
perched ground water	Unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Its water table is a perched water table. Perched ground water is held up by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.
perched spring	A spring whose source of water is a body of perched ground water.
perennial stream	A stream that flows throughout the year and from source to mouth; a permanent stream.
perennial yield (safe yield)	That rate at which water can be withdrawn from an aquifer without depleting the supply to such an extent that withdrawal at this rate is harmful to the aquifer itself, or to the quality of the water, or is no longer economically feasible.
performance allocation	A part of the process for developing strategies for the resolution of issues, used to guide the site characterization program. See Section 8.1.2.
performance assessment	Any analysis that predicts the behavior of a system or system component under a given set of constant and/or transient conditions. Performance assessments will include estimates of the effects of uncertainties in data and modeling.
performance confirmation	The program of tests, experiments, and analyses that is conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure can be met.
performance criterion	A criterion establishing qualitative operational, safety, or environmental limits.

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performance goal	A specific value assigned to a performance measure as part of the performance-allocation process.
performance measure	A physical quantity that describes the performance of a system, system element, structure, component, or process in meeting the licensing strategy for an issue.
performance objective	The predetermined standard or specification used to evaluate the acceptability of each system, structure, or component during a performance assessment. Different performance objectives may be suitable for the preclosure and postclosure periods.
performance parameter	In performance allocation, a physical quantity (either measurable or calculable) used to evaluate a performance measure.
perimeter drift	The drift that encircles the emplacement area, advancing in a clockwise direction as the emplacement area is developed. It functions as the exhaust airway for the emplacement area.
perlitic	The texture of a glassy igneous rock that has cracked due to contraction during cooling, the cracks forming small spheruloids. It is generally confined to natural glass, but occasionally found in quartz and other noncleavable minerals and as a relict structure in devitrified rocks.
permanent closure	See "closure."
permeability	In hydrology, the capacity of a medium (rock, sediment, or soil) to transmit ground water. Permeability depends on the size and shape of the pores in the medium and how they are interconnected.
permeametry	Determination of permeability of a material by passing a liquid through a sample of known dimensions and recording the pressure drop and flow rate through the bed.
permissible dose	That dose of ionizing radiation that, in light of present knowledge, carries negligible probability of causing a severe somatic injury or a genetic effect.
persistence (of discontinuity)	One of the ten parameters selected to describe discontinuities in rock masses, being the discontinuity trace length as observed in an exposure, which may give a crude measure of the areal extent or penetration length of a discontinuity. Termination in solid rock or against other discontinuities reduces the persistence.

petrofabric	The actual rock fabric as analyzed on the thin-section or micro scale, including grain shapes and relationships.
phenocryst	A large crystal in a groundmass of smaller crystals or glass.
phreatophyte	A plant that consumes and then transpires inordinate amounts of water compared to xerophytes.
physical adsorption (physisorption)	The process by which molecules stick to a surface by van der Waals forces. In physisorption no chemical bonds are broken. The molecule is not changed in content but it may be bent or stretched in the proximity of the surface.
phytoliths	A discrete, distinctively shaped, minute (less than 30 microns in diameter) solid body of isotropic silica originally precipitated by terrestrial plants as unwanted material or as reinforcement or cell structures.
Picard iteration	A method that gives approximate solutions of an initial value problem which is of the form $y' = f(x,y)$, $y(x_0) = y_0$ and is assumed to have a unique solution on some interval containing x_0 .
piezometer	An instrument for measuring the change of pressure of a material subjected to hydrostatic pressure.
piezometric surface	The elevations to which water will rise in artesian wells, or wells penetrating confined aquifers; determined by both water pressure and elevation of the aquifer.
pillar	A solid mass of rock left standing to support a mine roof.
pintle	Handling fixture on the waste container; a knob welded to one end of the waste container that can be grappled by the handling mechanism in the surface facility or during emplacement or retrieval operations.
piper diagram	A trilinear graph designed to represent chemical analyses of water as percentages of total equivalents per liter.
placer	A surficial deposit formed by mechanical concentration of mineral particles from weathered debris. The common types are beach placers and alluvial placers. The mineral concentrated is usually a heavy mineral such as gold, cassiterite, or rutile.

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planar-rotational faults	A group of parallel faults in which both the faults and beds rotate together during extension, much like tilting dominos. These types of faults generally have no penetrative deformation, pressure solution, or bedding-plane slip associated with them.
plane-strain	A state of strain in which all displacements that arise from deformation are parallel to one plane, and the strain normal to that plane is zero.
plate	A segment of the lithosphere that is internally rigid and moves independently over the interior, meeting in convergence zones and separating at divergence zones.
plate bearing	A procedure performed in small tunnels or adits to measure the deformation characteristics of a rock mass.
plug	A sealing component used for structural support.
plugback	To cement off a lower section of casing in a drill-hole to block fluids below from rising in the casing to a higher section being tested.
plunge (structural geology)	The inclination of a fold axis or other geologic structure, measured by its departure from horizontal.
pluvial	Pertaining to rain or to precipitation. Also said of a climate characterized by relatively high precipitation.
pneumatic testing	Pressure testing of a process vessel by the use of air pressure.
Poisson's ratio	The ratio of the lateral strain to the longitudinal strain in a body that has been stressed longitudinally within its elastic limit.
population dose	The sum of the radiation doses received by the individual members of a population exposed to a particular source or event. It is expressed in units of man-rem.
pore pressure (neutral stress)	The stress transmitted by the fluid that fills the voids between particles of a soil or rock mass (e.g., that part of the total normal stress in a saturated soil caused by the presence of interstitial water).
porosity	The ratio of the total volume of interstices in rock or soil to its total volume, expressed as a percentage or as a fraction.
postclosure	The period of time after the closure of the geologic repository.

postclosure system guideline	Guideline that establishes waste containment and isolation requirements that are based on NRC and EPA regulations. It is also a qualifying condition.
potassium-argon dating (K-Ar)	Determination of the age of a mineral or rock in years. Ratio of radiogenic argon-40 to potassium-40 and the known radioactive decay rate of potassium-40 to argon-40.
potential evapotranspiration	The amount of water that would be removed from the land surface by evaporation and transpiration processes if sufficient water were available in the soil to meet the demand.
potential field	A field which obeys Laplace's equations, such as gravity, magnetic, or electrical fields.
potentially acceptable site	Any site at which, after geologic studies and field mapping but before detailed geologic data gathering, the DOE undertakes preliminary drilling and geophysical testing for the definition of site location.
potentially adverse condition	A condition that is presumed to detract from expected system performance, but further evaluation, additional data, or the identification of compensating or mitigating factors may indicate that its effect on the expected system performance is acceptable.
potential Q-scenario	Used to designate an accident scenario in which the probability and dose consequence are sufficiently close to the Q-scenario criteria that a change in assumptions or data used in analyses could cause the criteria to be exceeded.
potentiometric surface	An imaginary surface representing the total head of ground water and defined by the level to which water will rise in a well. It is usually represented as a contour map in which each point tells how high the water would rise in a well tapping that aquifer at that point.
power spectrum	The series of squared Fourier coefficient values.
pozzolan	Siliceous material, such as diatomaceous earth, opaline chert, and certain tuffs, that can be finely ground and combined with portland cement. Portland-pozzolan cements are highly resistant to penetration and corrosion by salt water.
preclosure	The period of time before and during the closure of the geologic repository.

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preclosure radiological safety	The siting and design considerations important in protecting the public and the repository workers from exposures to radiation during repository operations and prior to repository closure.
pressure head	The height of a column of liquid supported, or capable of being supported, by pressure at a point in the liquid.
pressure plate apparatus	An instrument used for determining pressure head in unsaturated rock.
pressurized water reactor (PWR)	A reactor system that uses pressurized water in the primary cooling system. Steam formed in a secondary cooling system is used to turn turbines to generate electricity.
pre-waste- emplacement	Before the authorization of a repository construction by the NRC.
primary area	The surface location, as indicated on a map, of the principal area that may be suitable for waste emplacement. When projected downward along the location of faults and other geologic features, the boundaries of the primary area encompass the principal region within the target emplacement horizon that is considered potentially suitable for waste emplacement. See "emplacement horizon."
primary porosity	The porosity that developed during the final stages of emplacement or that was present within particles at the time of deposition. Primary porosity includes all predepositional and depositional porosity of a particle, sediment, or rock.
primer	A cap, tube, or wafer containing percussion powder or compound used to ignite an explosive charge.
principal stress	A stress that is perpendicular to one of three mutually perpendicular planes that intersect at a point in a body on which the shearing stress is zero; a stress that is normal to a principal plane of stress. The three principal stresses are identified as least or minimum, intermediate, and greatest or maximum.
probable maximum flood	The most severe flood reasonably possible based on comprehensive hydrometeorological application of probable maximum precipitation and other hydrologic factors favorable for maximum flood runoff.

product	A description of a result obtained from a design activity, including for example, design drawings, a design report, supporting analyses, a report of equipment demonstration, an operations plan, etc. A product of a design activity may be an input item for another design or performance-assessment activity.
protected area	An area encompassed by physical barriers and to which personnel access is controlled.
proton spinner magnetometer	The proton (hydrogen nucleus) has a magnetic movement because of its spin. The spin axis precesses in the presence of a magnetic field, giving rise to an alternating magnetic field with a characteristic frequency that is proportional to the strength of the applied field. In the magnetometer, a strong field is briefly applied to align the spin axis in a sample of fluid. When the initial pulse stops, precession follows at a particular frequency. The alternating field is detected by a measurement coil, and the frequency is counted to determine the strength of the ambient field.
prototype weldments	A model (whose component parts are joined by welding) suitable for use in complete evaluation of form, design, and performance.
provenance	A place of origin. The area from which the constituent materials of a sedimentary rock or facies are derived.
proxy data	Any geologic evidence of past climate. Paleoclimate can not be directly measured in the field, therefore, evidence collected in the field is used to infer these past climatic parameters.
psychrometer	A hygrometer consisting of two similar thermometers with the bulb of one being kept wet so that the cooling that results from evaporation makes it register a lower temperature than the dry one. The difference between the readings constitutes a measure of the dryness of the atmosphere.
psychrometric chart	A nomograph for graphically obtaining relative humidity, absolute humidity, and dew point, from wet- and dry-bulb thermometer readings.
public radiation safety assessment package	A general approach to the resolution of Issue 2.1 including the following design steps: a design evaluation, identification of radiation source characteristics, a radionuclide transport evaluation, a public radiation exposure calculation, and a performance evaluation for compliance with goals.

pumping test	(1) Yield of water. A test made with a pump in a new well to determine its water-yielding capacity. Quantities and water levels are recorded during the test period. The test pumping rate is usually greater than that at which water will be required and covers a period sufficiently long to indicate whether the yield can be maintained. (2) Quality of water. Taking water samples during the test to determine by chemical analyses, the chief constituents and organic purity. Tests may extend over about 14 days and finally a full mineral analysis is often made and may be used to prescribe treatment and purification processes.
pycnometer	A standard vessel often provided with a thermometer for measuring and comparing the densities of liquids or solids.
pyroclastic	Pertaining to clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent. Also, pertaining to rock texture of explosive origin.
pyrophoric	(1) Igniting spontaneously. (2) Emitting sparks when scratched or struck, especially with steel.
Q-List	A list of geologic repository structures, systems, and components that have been determined to be important to safety, waste isolation, or both, and are thereby subject to the highest Quality Assurance (QA) Level (Quality Assurance Level I) of the formal QA Plan.
Q-scenario	An accident scenario that exceeds a probability of occurrence of 10^{-5} per year and causes an offsite dose of 0.5 rem or greater.
QA Level I	Those radiological health and safety related items and activities that are important to either safety or waste isolation and are associated with the ability of a geologic nuclear waste repository to prevent or mitigate the consequences of a process or event that could cause undue risk to the radiological health and safety of the public. Items and activities important to safety are those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose either to the whole body or to any organ of 0.5 rem or greater either at or beyond the nearest boundary of the unrestricted area at any time until the completion of the permanent closure of the repository. Activities important to waste isolation are those that must meet the criteria that address postclosure performance of the engineered and natural

QA Level I (continued)	barriers to prevent the release of radionuclides. The criteria for items or activities important to safety and waste isolation are found in 10 CFR Part 60 and 40 CFR Part 191.
QA Level II	Those activities and items related to the systems, structures, and components that require a level of quality assurance sufficient to provide for reliability, maintainability, public and repository worker nonradiological health and safety, repository worker radiological health and safety, and other operational factors that would have an impact on the environment and on DOE and WMPD concerns.
QA Level III	Those activities and items not classified as QA Levels I or II.
qualified site	A site that, having been characterized, is considered to be technically suitable for a repository.
qualifying condition	A condition that must be satisfied for a site to be considered acceptable with respect to a specific guideline.
quality assurance (QA)	All the planned and systematic actions necessary to provide adequate confidence that a structure, system, or component is constructed to plans and specifications and will perform satisfactorily.
quality control	Quality assurance actions that provide a means to control and measure the characteristics of an item, process, or facility to established requirements.
quality factor (radiation)	A measure of the relative biological damage from a given type of radiation related to linear energy transfer (LET).
radar remote sensing	A remote sensing system that has a microwave energy source and a microwave detector for intercepting and measuring returned radar signal. Returned signals are processed to give an image of returned microwave energy, which can be correlated to topography and geologic features. See "side-looking airborne radar."
radial borehole test (azimuthal survey)	A survey method in which potential electrodes are moved along radii about a drillhole containing a fixed current electrode. The second current electrode (infinite electrode) is a great distance away.
radiation dose	The quantity of radiation absorbed per unit of mass by the body or any portion of the body.

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radiation field intensity	In general, the quantity of radiant energy at a specified location passing perpendicularly through unit area in unit time.
radiation zone	An area that contains radioactive materials or radiation field in quantities significant enough to require the control of personnel entry to the area.
radioactive decay	A spontaneous nuclear transformation (disintegration) in which nuclear particles or electromagnetic energy (such as alpha particles, beta particles, or gamma photons) are emitted.
radioactive-waste facility	A facility subject to the licensing and related regulatory authority of the NRC pursuant to Sections 202(3) and 202(4) of the Energy Reorganization Act of 1974 (88 Stat. 1244).
radiocarbon dating	The determination of the age of a material by measuring the proportion of the isotope carbon-14 (radiocarbon) in the carbon that it contains. The method is suitable for the determination of ages up to about 60,000 yr.
radiography testing	A method used to determine flaws in pipe or other metals by use of a source emitting x-rays or gamma rays, which penetrate the metal and are transcribed onto film.
radioisotope	A radioactive isotope of an element.
radiological environmental monitoring	The measurement of radioactive contaminant concentrations or radiation intensity in the environment.
radiological exposures to public	The radiation dose received by the absorption of radiation or the intake of radionuclides by an individual except when that individual is a worker engaged in operations involving the management, storage, and disposal of radioactive waste.
radiolysis	The decomposition of molecules (often the water molecule) due to interactions with gamma radiation.
radiometric dating	The calculation of the age of a material by a method based on the decay of radionuclides that occur in the material.
radionuclide	An unstable radioactive nuclide that decays toward a stable state at a characteristic rate by the emission of ionizing radiation(s).

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radionuclide retardation	The process that causes the time required for a given radionuclide to move between two locations to be greater than the ground-water travel time because of physical and radionuclide interactions between the radionuclide and the geohydrologic unit through which the radionuclide travels. See "retardation."
raise boring	A mining method by which a vertical circular opening is excavated from the bottom up using a special drill bit.
random walk theory	A succession of movements along line segments where the direction, and possibly the length, of each move is randomly determined.
reasonably achievable	Mitigation measures or courses of action shown to be reasonable considering the costs and benefits in accordance with the National Environmental Policy Act of 1969. See "as low as reasonably achievable."
reasonably available technology	Technology that exists and has been demonstrated, or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time periods.
reasonably foreseeable releases	Releases of radioactive wastes to the accessible environment that are estimated to have more than one chance in 100 of occurring within 10,000 yr.
recharge (hydrologic)	The process by which water is added to the zone of saturation, either directly into a geologic formation or indirectly by way of another formation or through unconsolidated sediments.
recurrence interval	(1) The average time interval between occurrences of a hydrologic or geologic event of a given or greater magnitude. (2) In an annual flood series, the average interval in which a flood of a given size recurs as an annual maximum. (3) In a partial duration series, the average interval between floods of a given size, regardless of their relationship to the year or any other period of time. This distinction holds even though for large floods recurrence intervals are nearly the same on both scales.
regulated area	An area to which public access is limited or controlled.
regulatory agency	The government agency responsible for regulating the use of sources of radiation or radioactive materials or emissions and responsible for enforcing compliance with such regulations.

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relative age	The geologic age of a fossil organism, rock, geologic feature, or event, defined relative to other organisms, rocks, features, or events rather than in terms of years.
relative permeability	The ratio between the effective permeability of a given fluid at a partial saturation to the permeability at 100 percent saturation (the absolute permeability). It ranges from zero at low saturation to 1.0 at a saturation of 100 percent.
relative porosity	The ratio of the volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage.
release limit	A regulatory limit on the concentration or the amount of radioactive material released to the environment; usually expressed as a radiation dose.
remanent magnetization	Permanent magnetization induced by an applied magnetic field, causing an alignment of magnetic domains or particles, which is then fixed in the material through the effects of cooling, deposition, mechanical shock, or other process, rendering the material permanently magnetized.
remote-handled TRU waste	Transuranic waste that requires shielding in addition to that provided by its container in order to protect people nearby because its surface dose rate (greater than 0.2 rem/hr) precludes safe direct handling.
remote sensing	Collection of information about an object by a recording device that is not in physical contact with it. The term is usually restricted to include methods that record reflected or radiated electromagnetic energy, rather than methods that involve significant penetration into the earth. The technique employs such devices as the camera, infrared detectors, microwave frequency receivers, and radar detectors.
removal	The removal of emplaced waste for performance confirmation, inspection, analysis, or any other purpose not directly related to public health and safety (and the environment).
repository	See "geologic repository."
repository area boundary	See "controlled area."

residual gravity	In gravity prospecting, the portion of a gravity effect remaining after removal of some type of regional effect; usually the relatively small or local anomaly components of the total or observed gravity field.
residual saturation	The saturation at which the water network in the rock pores becomes disconnected and the water conductivity is zero.
residual stress (ambient stress field)	The concept of residual stress is based on the coexistence of locked-in strains, resulting from crystal distortion due to past external loads, and locking strains that constrain them. The residual stresses giving rise to locked-in and locking strains are present in finite bodies with no external loads applied on their boundaries, thus the vector sum of residual stresses within such bodies is zero. The strains are stored by cementation, and physical and chemical reaction between anisotropic grains which occur while under applied stress.
resistivity imaging technique	A geophysical prospecting method in which direct measurements are made of the ratio of voltage to current. The current is a function of the conducting property of a rock and is controlled by its water content and its salinity. If these values are high then its conductivity is also high and its electrical resistivity is low.
resistivity survey	Any electrical exploration method in which current is introduced in the ground by two contact electrodes and potential differences are measured between two or more other electrodes.
resonant column test	A test to study the effects of variations in stress or strain amplitudes while a cylindrical column of soil is vibrated in either the longitudinal or torsional mode, normally in a triaxial cell.
response surface	A nonlinear function that describes the manner in which the output varies with changes in input variable.
restricted area	Any area to which access is controlled by the DOE for purposes of protecting individuals from exposure to radiation and radioactive materials before repository closure, but not including any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

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resurgent caldera	A caldera that has been subjected to broad upwarping or doming after formation. Resurgence usually results in formation of a highly faulted structural dome in the center of the caldera.
retardation	The act or process that reduces the rate of movement of a chemical substance in a water stream relative to the average velocity of the water. The movement of the chemical substance in the water can be retarded by sorption and desorption reactions, by precipitation and dissolution reactions, and by diffusion into the pore water of the rock matrix. See "radionuclide retardation."
retention curve	See "moisture-retention curve."
retention pond	An earthen structure designed to hold stormwater runoff; sometimes used to mean an evaporation pond.
retrievability	The capability that is provided by the repository system--by means of design approaches, construction methods, and operating procedures--to allow waste retrieval to be performed.
retrievability period	The time during which emplaced waste is capable of being retrieved. For design purposes, this period begins with emplacement of the first waste and ends 50 years thereafter at the end of the caretaker period.
retrieval	The act of intentionally removing radioactive waste from the underground location at which the waste had been previously emplaced for disposal.
retrograde metamorphism	A type of polymetamorphism by which metamorphic minerals of a lower grade are formed at the expense of minerals characteristic of a higher grade metamorphism. A readjustment necessitated by a change in physical conditions (e.g., a lowering of temperature).
reverse air-vacuum drilling	A drilling method using reverse circulation (down the annulus and up the drill pipe) with air as circulation medium, to avoid fluid loss into the formation and to provide high quality in situ moisture content data. Circulation is forced by drawing a vacuum on the drill pipe at the surface.
reverse drilling (rotary)	A method of drilling in which drilling fluid is forced to the bit by way of the annulus, around the drill pipe, and flows back to the surface up the inside of a rapidly rotating drill stem.

Richard's equation	The mathematical equation generally used to describe flow through an unsaturated porous medium.
Richter magnitude	See "Richter scale."
Richter scale	A numerical scale of the energy released by an earthquake, as measured on an instrument (e.g., a seismometer) that transforms the mechanical effects of earth shocks into electrical signals.
ring-fracture zone	A steep sided fault pattern cylindrical in outline and associated with caldera subsidence.
rock burst	A sudden yielding that occurs when a volume of rock is strained beyond its elastic limit and the accompanying failure is such that the accumulated energy is released instantaneously. A rock burst can vary from the splitting off of small slabs of rock to the collapse of large pillars, roofs, or other massive parts of a mine.
rock quality designation (RQD)	A drill core quality rating used as a parameter for classification of rock quality. Evaluated by determining the percentage of recovery of core in lengths that are greater than twice the diameter of the core.
rock varnish	See "cation-ratio dating."
roof loading	Any covered structure, not classified as a bridge, that constitutes a transverse drain, waterway or other opening under a road, railroad canal, or similar structure.
rotary drilling	A drilling process consisting of a rotating drill pipe at the bottom of which is attached a hard toothed drill bit.
rubber-balloon method (field density test)	A method to determine field or in situ density of naturally occurring soils or fill materials for the control of compaction.
rubidium-strontium dating	Determination of an age for a mineral or rock in years based on the ratio of radiogenic strontium-87 to rubidium-87 and the known radioactive decay rate of rubidium-87.
rupture zone	A zone in the lithosphere characterized by brittle or ductile fracturing of rock.
sand-cone method	A standardized method for measuring bulk density of granular materials including alluvium, whereby a bulk sample is weighed in a conical vessel of prescribed dimensions.

saturated conductivity	See "hydraulic conductivity."
saturated flow	Ground-water flow through the saturated zone.
saturated zone	That part of the earth's crust beneath the water table in which all voids, large and small, are ideally filled with water under pressure greater than that of the atmosphere.
scaling	(1) The removal of loose rock from a newly blasted wall or roof. (2) The term scaling can be used to describe, for example, the conducting of experiments, previously done at a laboratory scale, at a field scale (the scaling of experiments). Differences in the results of the experiments may be due to a scaling effect.
scanning Auger technique	A surface analytical technique.
scanning-transmission electron microscope	A type of electron microscope that has the capability of forming the electron beam into a fine probe and scanning it across a thin specimen. The transmitted scanned beam is collected below the specimen by a solid-state detector and is reproduced electronically as an image on a cathode-ray tube.
scarification	The process of breaking up and loosening the surface of a material.
scouring	An erosional process, especially by moving water.
seafloor spreading ridge	An extensional ridge associated with a continuous seismic mountain range extending through the ocean where oceanic crust is increasing by convective upwelling of magma. The new material moves away at a rate of 1 to 10 cm/yr.
seal	An engineered component that reduces water flow.
secondary compression	The reduction in volume of sediments under constant pressure that results from changes in the internal structure of the sediments.
secondary creep	Time-dependent strain occurring under constant stress at a minimum and almost constant rate.
secondary mineral	A mineral formed later than the rock enclosing it, usually at the expense of an earlier-formed primary mineral, as a result of weathering, metamorphism, or solution.

secondary porosity	The porosity developed in a rock after its deposition or emplacement, through such processes as solution or fracturing.
Secretary	The Secretary of Energy.
sediment yield	The amount of material eroded from the land surface by runoff and delivered to a stream system.
seep	An area, generally small, where fluid percolates slowly to the land surface. For water, it may be considered as a synonym of seepage spring, but it is used by some for flows too small to be considered as springs.
seepage face	A belt along a slope, such as the bank of a stream, along which water emerges at atmospheric pressure and flows down the slope.
seiche	A periodic oscillation of a body of water whose period is determined by the resonant characteristics of the containing basin as controlled by its physical dimensions. These periods generally range from a few minutes to an hour or more.
seismic	Pertaining to, characteristic of, or produced by earthquakes or earth vibrations.
seismic acceleration	The acceleration associated with the passage of seismic waves at the surface or subsurface, as applicable.
seismic belt	An elongate earthquake zone such as the belts of the circum-Pacific, the Mediterranean and trans-Atlantic, the mid-Atlantic, and the mid-Indian.
seismic lines	The route taken on the surface for deploying seismic sources and detectors in the performance of seismic reflection or seismic refraction surveys.
seismic loading	A temporary stress generated during a seismic cycle.
seismic pumping	A concept for ground-water movement in response to stress and strain changes associated with seismic activity, for which direct evidence is very sparse or nonexistent.
seismic reflection survey	A survey based on measurement of the travel times of waves that originate from an artificially produced disturbance and are reflected back to the surface at nearly vertical incidence from boundaries separating media of different elastic-wave velocities.

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seismic refraction survey	A program to map geologic structure by using head waves. Head waves involve energy that enters a high-velocity medium (refractor) near the critical angle and travels in the high-velocity medium nearly parallel to the refractor surface. The objective is to determine the arrival times of the head waves to map the depth to the refractors in which they traveled.
seismic velocity	The rate of propagation of an elastic wave, usually measured in kilometers per second. The wave velocity depends on the type of wave as well as the elastic properties and density of the earth material through which it travels.
seismogenic	Capable of generating seismic waves and a seismic event of significant magnitude.
seismometer	An instrument that detects and measures ground motion and produces a signal proportional to the displacement of the point where the instrument is in contact with the earth. May be used in a broad context to refer also to geophones (output signal proportional to velocity) and accelerometers (proportional to acceleration).
seisviewer log	A well log wherein a pulsed, narrow acoustic (sonar) beam scans the borehole wall in a tight helix as the tool moves up the borehole. A display of the amplitude of the reflected wave on a cathode ray tube (television screen) is photographed yielding a picture of the borehole wall to reveal fractures, vugs, etc.
self-potential curve	An electric log curve that records changes in natural potential along an uncased borehole.
semiarid	Said of a type of climate in which there is slightly more precipitation (25-50 cm) than in an arid climate, and in which sparse grasses are the characteristic vegetation. In Thornthwaite's classification, the moisture index is between -20 and -40.
service main	The drift running parallel to the waste and tuff mains southwest through the longitudinal axis of the underground repository dedicated to equipment and personnel access.
settlement	The lowering of the overlying strata in a mine, owing to the extraction of the mined material.
settlement plug	A plug of cast concrete or similar material placed within a shaft, anchored to the surrounding bedrock, to provide physical support to overlying backfill in the shaft.

Sevier Orogeny	A name proposed by R. L. Armstrong for the well-known deformations that occurred along the eastern edge of the Great Basin in Utah during times intermediate between the Nevadan orogeny further west and the Laramide orogeny further east, culminating early in the late Cretaceous.
SH-wave (shear wave)	Shear waves with motion parallel to the free surface.
shaft collar	See "collar."
shaft liner	A structural lining usually made of steel, concrete, or timber that provides safe rock support and aids in preventing ground water from entering the shaft.
shaft pillar	An undisturbed buffer zone surrounding a shaft of sufficient area, so that any possible subsidence in nearby mined areas will not disturb the integrity of the shaft facility.
shaft station	A horizontally excavated opening of a shaft at a desired depth.
shear	(1) A stress state that produces a strain causing contiguous parts of a body to slide relative to each other in a parallel direction. (2) Surfaces and zones of failure by shear or surfaces along which differential movement has taken place.
shear modulus	The ability of atoms in a solid to slide past one another. The higher the value of the shear modulus the more rigid the material. Also referred to as the modulus of rigidity.
shear resistance	See "shear strength."
shear strength	The internal resistance of a body to shear stress, typically including a frictional part and a part independent of friction called cohesion.
shear stress	That component of stress that acts tangential to the plane through any given point on a body; any of the tangential components of the stress tensor.
shear wave (s-wave)	A type of seismic body wave propagated by a shearing motion of material, so that there is oscillation perpendicular to the direction of propagation. It does not travel through liquids or the outer core of the earth. Its speed is 3.0 to 4.0 km/s in the crust and 4.4 to 4.6 km/s in the upper mantle. The "s" stands for secondary, so named because it arrives later than the p-wave (primary body wave).

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sheave	A large, pulley-type wheel at the top of the headframe that carries the hoist rope.
sheet flow (laminar flow)	An overland flow or downslope movement of water taking the form of a thin, continuous film over relatively smooth soil or rock surfaces and not concentrated into channels larger than rills.
shelby tube	A thin-shelled tube used to take deep-soil samples. The tube is pushed into the undisturbed borehole and driven into the ground.
shield plug	A cylinder of concrete, steel, or other dense material used to plug emplacement boreholes after waste package emplacement. Its main function is to attenuate radiation by providing shielding from the radioactive waste.
shielding	The material interposed between a source of radiation and personnel to protect against radiation exposure; commonly used shielding materials are concrete, water, and lead.
shielding collar	A component of the shielding closure that provides radiation shielding by extending from the closure to the transporter cask during emplacement or retrieval.
shipping cask	A specially designed and certified massive metal container that provides shielding and containment in accordance with Federal and/or international radiological safety rules and regulations for safe transportation of radioactive materials through the public domain.
shotcrete	Cement-based compounds sprayed on mine surfaces to prevent erosion by air and moisture and on rock surfaces to stabilize against minor rock falls. Also used to prevent dehydration and decrepitation.
side-looking airborne radar (SLAR)	An airborne radar system in which a long, narrow, stabilized antenna, aligned parallel to the motion of an aircraft or satellite, projects radiation at right angles to the flight path. Returned signals are processed to give an image of returned microwave energy, which can be correlated to topography and geologic features.
sieve analysis	Determination of the percentage distribution of particle size by passing a measured sample of soil or sediment through standard sieves of various sizes.

sieve deposit	The formation of a coarse-grained mass on an alluvial fan whose material is sufficiently coarse and permeable to permit complete infiltration of water before it reaches the toe of the fan.
significant source of ground water	As defined in 40 CFR Part 191, an aquifer that (1) is saturated with water having less than 10,000 milligrams per liter of total dissolved solids, (2) is within 770 meters (2,500 feet) of the land surface, (3) has a transmissivity greater than $3 \times 10^{-5} \text{ m}^2/\text{s}$ (200 gallons per foot per day), provided that any second formation or part of a formation included within the source of ground-water has a hydraulic conductivity greater than $1 \times 10^{-6} \text{ m/s}$ (2 gallons per square foot per day), and (4) is capable of continuously yielding at least 1,600 liters per hour (10,000 gallons per day) to a pumped or flowing well for a period of at least a year; or an aquifer that provides the primary source of water for a community water system.
sink	(1) A depression containing a central playa or saline lake with no outlet, as where a desert stream comes to an end or disappears by evaporation. (2) To drill or put down a shaft or borehole. (3) A water lodgment or trap at a pumping station. (4) Generally synonymous with outflows or withdrawal of ground water.
sinking deck	A scaffold for staging that is designed for use during shaft sinking, particularly during lining operations.
site	A potentially acceptable site or a candidate site, as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same.
skin effect	The phenomena in which alterations in permeability in the vicinity of a drill hole are caused by drilling and completion operations.
skip	A basket, bucket, or open car used to raise materials that is mounted vertically or on an incline on wheels, rails, or shafts and hoisted by a cable.
slabbing	A stress-induced failure mechanism of the rock around an excavation.
Slake-durability	An index test that tests a rock's resistance to mechanical weathering by rotating samples in a sieve mesh drum for 10 minutes and comparing the sample's final weight to its initial weight.

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slash	A mining technique in which a large-diameter drilled hole is enlarged by using the drill-and-blast method.
sleeve	As related to the waste package, a metallic or non-metallic liner that may be located in the emplacement hole to aid in the emplacement and possible retrieval of the waste.
slough	Fragmentary rock material that has crumbled and fallen away from the sides of a borehole or mine working. It may obstruct a borehole or be washed out during circulation of the drilling mud.
slug flow	Movement of an isolated body of water, such as free water moving downward in the zone of aeration. The term is based on slang for a small amount of liquid, such as a slug of whiskey.
slug injection test	A method for determination of the in situ hydraulic conductivity of an aquifer by instantaneous addition of water to a piezometer.
snowcourses	A line or a series of connecting lines of regularly spaced observation stations (usually 10 or more) at which snow samples are taken for measuring depth, density, and water equivalent for forecasting subsequent runoff.
snowpillows	A device used to record the changing weight of the snow cover at a point. It consists of a fluid-filled bladder or metal container lying on the ground, the internal pressure of which measures the weight of overlying snow.
soil aspect	The direction toward which a slope faces with respect to the compass or to the rays of the sun.
soil horizons	A layer of soil that is distinguishable from adjacent layers by characteristic physical properties such as structure, color, or texture, or by chemical composition, including content of organic matter or degree of acidity, or alkalinity. Soil horizons are generally designated by a capital letter, with or without a numerical annotation (e.g., A horizon).
soil profile	A vertical section of soil from the surface to the bedrock that can usually be divided into three zones, or horizons, which develop as weathering takes place. The thickness of the soil profile depends on the age of the soil and the climate. The transitions from one zone to another are normally indistinct.

soil water	Water in the belt of soil. The upper subdivision of the zone of aeration, limited above by the land surface and below by the intermediate belt. This zone contains plant roots and water available for plant growth.
solar constant	The rate at which solar radiant energy is received outside the atmosphere on a surface normal to the incident radiation at the earth's mean distance from the sun.
solar radiation	The electromagnetic radiation emitted by the sun.
sole fault	A low-angle thrust fault forming the base of a thrust nappe. The basal main fault of an imbrication.
solid solution	A single crystalline phase that may be varied in composition within finite limits without the appearance of an additional phase.
sols	A colloidal dispersion of a solid in a liquid.
solution channel	Tubular or planar channel formed by solution in carbonate rock terranes, usually along joints and bedding planes. It is the main water carrier in carbonate rocks.
sonic log	A geophysical log made by an instrument, lowered and raised in a borehole or well, that continuously records, as a function of depth, the velocity of sound waves as they travel over short distances in the adjacent rocks. The log reflects porosity and lithologic changes.
sonic velocity log	A geophysical log made by an instrument, lowered and raised in the borehole or well, that continuously records, as a function of depth, the velocity (or inter-time) of sound waves as they travel over short distances in the adjacent rocks.
sorption	A term including both adsorption and absorption. The binding, on a microscopic scale, of one substance to another, such as by adsorption or ion exchange. In this document, the word is especially used for the sorption of dissolved radionuclides onto aquifer solids or waste-package materials by means of close-range chemical or physical forces.
sorptive minerals	The minerals (e.g., zeolites) that have the ability to take up large amounts of some guest molecules or ionic species. These molecules or ions can be in aqueous or gaseous form.

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special nuclear material	(1) Plutonium, uranium-233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the NRC, pursuant to the provisions of section 51 of the NWPA, determines to be special nuclear material, but does not include source material, or (2) any material artificially enriched by any of the foregoing but does not include source material.
specific activity	The measure of radioactivity as a function of mass. The unit of specific activity is curie per gram.
specific capacity (of a well)	The rate of discharge of a water well per unit of drawdown.
specific discharge (q/a)	Discharge (hydraulic) per unit area. It is often used to define the magnitude of a flood.
specific electrical conductance	The electrical conductivity of water at 25°C, measured in micro-ohms per centimeter.
specific gravity	The ratio of the density of a substance to the density of water when both densities are obtained by weighing in air.
specific storage	The volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head.
specific yield	The ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity to the volume of that mass.
spectral amplitude	A seismometer whose response is linearly proportional to the acceleration of the earth materials with which it is in contact.
spectroscopy	The production and observation of a spectrum and all methods of recording and measuring, including the use of the spectroscope.
spent nuclear fuel	Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.
spinner magnetometer	A laboratory instrument that continuously rotates the specimen whose remanent magnetism it is measuring, to produce an alternating voltage in a nearby coil by electromagnetic conduction.
splay (fault)	One of a series of minor faults at the extremities of a major fault; often associated with rifts.

split-barrel sampling (penetration test)	A method for making soil borings with a split-tube (split-spoon) sampler in order to obtain representative samples of soil for identification and a record of the soil's resistance to penetration by the tube.
spud	The beginning of actual drilling operations on a well or borehole; the first abrasion of the soil by the drill, or the first entrance of the drill into the ground; the preliminary boring of a well through earth material down to rock or other solid substrata.
stability, repository	The condition resulting from the nature and rates of natural processes affecting the site during the recent geologic past and the expectation that they will be relatively slow and will not significantly change during the next 10,000 yr or jeopardize the isolation of the waste. As defined in 10 CFR Part 60, the nature and rates of natural processes (e.g., erosion and faulting) have been and are projected to be such that their effects will not jeopardize the isolation of the waste.
stability (series)	A grouping of minerals according to their persistence in nature, (i.e., to their resistance to alteration or destruction by weathering, abrasion, or post-depositional solution (e.g., olivine (least stable), augite, hornblende, biotite (most stable))). The most stable minerals are those that tend to be at equilibrium at the earth's surface.
stable isotope	A nuclide that does not undergo radioactive decay.
stage (in hydrology)	The height of a water surface above an established datum plane.
standard mean ocean water (SMOW)	The mean isotopic composition of sea water; a reference standard for isotopes of oxygen and hydrogen.
standard neutron activation	A method of identifying stable isotopes of elements in a sample by irradiating the sample with neutrons to render the elements radioactive, after which the elements are identified by their characteristic radiations.
standoff	A variable distance between a drift wall or floor and the radioactive waste in a horizontal or vertical emplacement borehole. The standoff distance aids in controlling temperatures and radiation levels in the drift.
static water table	The average level of ground water that does not vary over time.

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statistical distribution function	The distribution function, $F(x)$, of a variate x is the total frequency of members with variate values less than or equal to x . As a general rule, the total frequency is taken to be unity, in which case the distribution function is the proportion of members bearing values less than or equal to x . Similarly, for p variates $x_1, x_2 \dots x_p$ the distribution function $F(x_1, x_2, \dots x_p)$ is the frequency of values less than or equal to x , for the first variate, x_1 , x_2 for the second and so on.
statistical dynamical models	These meteorological models include thermodynamic or energy balance models. The equations are often formulated in terms of averages for days, months, years, or still longer intervals.
statistical moments	See "moments."
steel sets	Steel support beams used for ground control in underground mines.
stemming	The material (sand, clay, gravel) that fills a shot-hole after the explosive charge has been inserted, to prevent the explosion from "blowing out" the top of the hole. Also, the process of installing packers or stemming material, in order to isolate an interval of a borehole, usually with a conduit of some type installed between the interval and the surface.
stereonet contouring	See "contoured stereonet."
stereonet plot	A two-dimensional projection of a hemispherical surface. Therefore, three-dimensional measurements are viewed in two dimensions, lines are plotted as points and planes are plotted as great circles. These plots are useful for determining angular relationships between lines and planes in space.
Stiff diagram	A diagram plotting cations and anions in water and used as a method to show water-composition differences and similarities in total ionic content between water samples.
stoichiometry	(1) The application of the laws of definite proportions and of the conservation of matter and energy to chemical activity. (2) The quantitative relationship between constituents in a chemical reaction.
storage	Retention of high-level radioactive waste, spent nuclear fuel, or transuranic waste with the intent to recover such waste or fuel for subsequent use, processing, or disposal.

storage coefficient	See "storativity."
storativity	The volume of water released from storage in a vertical column of 1 square foot when the water table or other potentiometric surface declines 1 foot. In an unconfined aquifer, it is equal to the specific yield. Also called storage coefficient.
straddle packer	A set of two or more packers deployed on a string of drill pipe or tubing, to isolate one or more intervals of a borehole. Often provided with some means of opening and shutting hydraulic communication between the pipe and the interval, and between the pipe and the packers. Used for hydrologic testing and for hydraulic fracturing.
strandline	(1) The ephemeral line or level at which a body of standing water (e.g., the sea) meets the land; the shoreline, especially a former shoreline now elevated above the present water level. (2) A beach, especially one raised above the present sea level.
stratiform deposits	Said of a special type of strata-bound deposit in which the desired rock or ore are strictly coextensive with one or more sedimentary, metamorphic, or igneous layers (e.g., beds of salt or iron oxide, or layers rich in chromite or platinum in a layered igneous complex).
stream capture (piracy)	The natural diversion of the headwaters of one stream into the channel of another stream having greater erosional activity.
stress cancellation	In situ stress is often measured by relieving the stress in a volume of rock, measuring the resultant strain or other physical response, then reloading the rock volume under controlled conditions to reverse the response. When the original state of the rock volume is achieved, the applied stress is regarded to be equal to the in situ stress. In this method, stress is applied until the unloading response is cancelled.
stress drop	(1) Sudden shear displacement accompanied by a sudden reduction in the shear stress on the fault plane. It reflects release of stored strain energy, much of which is radiated as seismic waves. (2) Loss of stress in a loading test.
stress province (field)	The state of stress, either homogeneous or varying from point to point and through time, in a given domain.

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stress raisers	Changes in contour or discontinuities in structure that cause local increases in stress.
stress tensor	A description of the state of stress at a point, which involves nine components, referring to three orthogonal coordinate axes. Three components are normal stresses, acting perpendicular to the coordinate planes; the remaining six components are shear stresses acting parallel to the coordinate planes.
stress trajectory	A line used to represent a stress field in a diagram, which is parallel to the principal direction of stress.
striation	One of a series of parallel, usually straight scratches or smooth furrows developed on a rock surface by tectonic forces, as a result of the abrasion of one projecting rock against another during fault movement.
strike rail goniometer	A tool that allows a geologist to measure the strike of a geologic feature in an underground exposure without using a magnetic compass.
stringer	A narrow vein or irregular filament in a rock mass of different material.
structural grain	The broad, linear arrangement of geologic structures (such as folds and bedding) of a country or region. For example, the arrangement of roughly parallel ridges and valleys often displayed in regions of tilted strata.
study plan	A plan that will describe the coordination of the work in more detail than is given in the discussions at the study level in Section 8.3.1 (site program).
subalpine	Of, pertaining to, or inhabiting cool upland slopes, beneath the timber line. Characterized by the dominance of evergreen trees.
subduction boundary	An elongate region along which a crustal block descends beneath another crustal block.
substantially complete containment	(1) By virtue of the intrinsic properties and design of the waste package components subjected to the range of conditions anticipated in the underground facility, 80 percent or more of the waste packages will retain all their radioactivity for a containment period of 1,000 yr after permanent closure of the repository. (2) At any time during the containment period, at least 99 percent of the radioactivity resulting from the original waste emplaced in the underground facility will be retained within the set

substantially complete containment (continued)	of waste packages. (3) Any releases from the waste packages that occur during the containment period should be gradual such that releases from the engineered barrier system in any year during this period should not exceed one part in 100,000 of the total inventory of radionuclide activity present in the geologic repository system in that year.
subsurface facilities	In this document, the underground facility and the shafts, ramps, boreholes, and shops.
suite (igneous)	(1) A set of apparently comagmatic igneous rocks. (2) A collection of rock specimens from a single area, generally representing related igneous rocks.
supergene phenomena (secondary enrichment)	The supergene process of mineral deposition; near-surface oxidation produces acidic solutions that leach metals, carry them downward, and reprecipitate them thus enriching sulfide minerals already present.
surface facilities	All repository operations and support facilities located on the surface of the site.
surface rupture	Deformation on the surface due to a momentary loss of cohesion or loss of resistance to differential stress and a release of stored elastic energy.
surface-wave	A seismic wave that travels along the surface of the earth, or parallel to the earth's surface. Surface waves include Rayleigh waves, love waves, and coupled waves.
swelling index number	A numerical expression to indicate the relative swelling properties of a sample when heated under standardized conditions.
synergism	Cooperative action of discrete agencies such that the total effect is greater than the sum of the two or more effects taken independently.
synoptic-scale	Pertaining to simultaneously existing meteorologic conditions that together give a description of the weather; also, said of a weather map or chart that shows such conditions.
system	The geologic setting at the site, the waste package, and the repository all acting together to contain and isolate the waste. See "mined geologic disposal system."

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system element	A subsystem or component of the total mined geologic disposal system to which performance can be allocated for meeting the regulatory and functional requirements.
system guideline	The system guidelines of the DOE's Siting Guidelines (10 CFR Part 960) establishes postclosure and pre-closure requirements for a repository system. These requirements are based on NRC and EPA regulations.
system performance	The complete behavior of a system in response to the conditions, processes, and events that may affect it.
system requirements (SR)	The Federal, State, local, DOE and OCRWM programmatic requirements that must be met by the prospective mined geologic disposal system (MGDS) at Yucca Mountain during all phases of MGDS development and after MGDS permanent closure.
tagging	Labelling radioactive atoms so that their movements can be traced by use of the Geiger tube.
tandem accelerator spectrometer (TAMS)	An electrostatic accelerator in which negative mass hydrogen ions generated in a special ion source are accelerated as they pass from ground potential up to a high-voltage terminal. Both electrons are then stripped from the negative ion by passage through a very thin foil or gas cell, and the proton is again accelerated as it passes to ground potential.
target horizon	The geologic unit in which it is planned to locate the repository.
tectosilicates	A class or structural type of silicate characterized by the sharing of all four oxygens of the SiO_4 tetrahedra with neighboring tetrahedra and with an Si:O ratio of 1:2. Quartz, SiO_2 is an example.
teleseismology	The aspect of seismology dealing with records made at a distance from the source of the impulse.
televiewer logs (tv)	See "seisviewer log."
tendon rods	A steel bar or wire that is tension-anchored to formed concrete, and allowed to regain its initial length to induce compressive stress in the concrete before use.
tensiometer	An instrument consisting of a porous cup attached to an airtight, water-filled tube. The porous cup is inserted into the soil at the desired depth, where it comes into contact with the soil water and reaches hydraulic equilibrium. The equilibration process involves the passage of water through the porous cup

tensiometer (continued)	from the tube into the soil. The vacuum created at the top of the airtight tube is a measure of the pressure head in the soil.
tensor	Physical quantities that are three-dimensional entities acting over surfaces or through volumes and requiring either six or nine quantities for their description.
thermal	A term applied to material properties that govern the flow of heat and resultant temperature of the material, or a term for the analysis of that response (e.g., thermal properties, thermal analysis).
thermal conductivity	(1) The time rate of transfer of heat by conduction, through unit thickness, across unit area for unit difference of temperature. (2) A measure of the ability of a material to conduct heat. Typical values of thermal conductivity for rocks range from 3 to 15 millicalories/cm-sec-degree C.
thermal decay	Chemical breakdown of a compound or substance at elevated temperature. Simple substances or constituent elements are produced.
thermal demagnetization	A technique of partial demagnetization by heating the specimen to a temperature T, then cooling to room temperature in a nonmagnetic space; this destroys a partial thermoremanent magnetization for that temperature interval, but leaves unaffected a partial thermoremanent magnetization for temperature intervals above T.
thermal diffusivity	Thermal conductivity of a substance divided by the product of its density and heat capacity. In rock, the common range of values is from 0.005 to 0.025 cm ² /s.
thermal loading	The application of heat to a system. Usually measured in terms of watt density. The thermal loading for a repository is the watts per acre produced by the radioactive waste in the active disposal area.
thermal/mechanical (units of rock)	A term applied exclusively to the delineation of stratigraphic units based on a combined consideration of their thermal, mechanical, and thermomechanical properties.
thermistor	An electrical resistor making use of a semiconductor whose resistance varies sharply in a known manner with temperature.

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thermocouple	(1) A device consisting of two dissimilar metals joined at two points, the potential difference between the two junctions being a measure of their difference in temperature. (2) An EMF-generating device that responds to temperature changes, formed by joining two dissimilar metals. Most often made by joining two dissimilar metal wires, and used to sense temperature.
thermocouple psychrometers	A psychrometer that uses thermocouples to measure temperature depression. See "psychrometer" and "thermocouple."
thermodynamic	(1) For geology and rock mechanics, the interacting properties of a geologic system as they are affected by heat and react physically to the stress. (2) For chemistry, thermodynamics refers to the energy evolved and consumed in chemical reactions and the relationship of this energy to equilibrium. The "thermodynamic data base" refers to a compilation of specific thermal properties (e.g., enthalpy, entropy, and free energy) of different chemical species that can be quantified.
thermogravimetric analysis (TGA)	A method of analysis that measures the loss or gain of weight by a substance as the temperature of the substance is raised or lowered at a constant rate.
thermoluminescence	The property possessed by many substances of emitting light when heated. It results from release of energy stored as electron displacements in the crystal lattice.
thermoluminescent dosimeter (TLD)	A type of dosimeter (or radiation measurement device) containing a "chip" of thermoluminescent material that emits light when subjected to heat. The amount of light emitted is directly proportional to the radiation dose absorbed by the chip, enabling the quantification of this dose.
thermomechanical	An adjective applied to the material properties that govern the physical response of a material to applied thermal stress, or to the analysis of that response (e.g., coefficient of thermal expansion thermomechanical analysis).
thin section	A fragment of rock or mineral mechanically ground to a thickness of approximately 0.03 mm and mounted between glasses as a microscope slide. This reduction renders most rocks and minerals transparent or translucent, thus making it possible to study their optical properties.

thixotropic	The property of certain colloidal substances, to weaken or change from a gel to a fluid when shaken but to increase in strength upon standing.
three-component geophones	An instrument that contains at least three detectors, and produces three signals that are proportional to the velocity of the earth in three orthogonal directions, where it is in contact with the instrument.
thrust	A fault with a dip of 40° or less over much of its extent in which the hanging wall moves up relative to the footwall. Horizontal compression rather than vertical displacement is its characteristic feature.
time domain reflectometry (transient electromagnetic method)	An electromagnetic method in which the waveform of the transmitted signal is a pulse, step function, ramp, or other form and in which measurements are made after changing. This method uses a train of primary pulses with measurements being made during the off-time between pulses.
tipping bucket rain gage	A type of recording rain gage. The precipitation collected by the receiver empties into one side of a chamber, which is partitioned transversely at its center and is balanced bistably upon a horizontal axis; when a predetermined amount of water has been collected, the chamber tips, spilling out the water and placing the other half of the chamber under the receiver; each tip of the bucket is recorded on a chronograph, and the record obtained indicates the amount and rate of rainfall.
to the extent practicable	The degree to which an intended course of action is capable of being effected in a manner that is reasonable and feasible within a framework of constraints.
tomographic analysis	Analysis by reconstruction of an object from a set of its projections.
total magnetic intensity (TMI) log	A geophysical wireline tool that measures the magnitude of the vector resultant of the horizontal and vertical components of the earth's magnetic field as a function of depth in a borehole. Usually incorporating a proton precession magnetometer See "proton spinner magnetometer."
tracer (radioactive)	One of several radioactive materials of short half-life that is introduced to a ground-water system in order to aid studies of ground-water movement.
transfer cask	A shielded enclosure for movement of highly radioactive material.

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transform fault	Horizontal shear fault that terminates abruptly at both ends, but which nevertheless may show great displacement.
transformation (crystallography)	The change from one crystal polymorph to another by one of several processes.
transient-line source technique	Similar to the "time domain reflectometry" (q.v.), but in addition may be used to determine thermal properties by application of a heating pulse.
transition-state theory	A theory that molecules, before undergoing reaction, must form an activated complex in equilibrium with the reactants, and that the rate of any reaction is given by the rate of decomposition of the complex to form the reaction products.
transition temperature	Either the temperature at which a substance changes from one state of aggregation to another (a first order transition), or the temperature of culmination of a gradual change (a second order transition).
transmissivity	The volumetric rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Mathematically it is the product of permeability and the thickness of the zone of the aquifer being measured.
transpiration	The process by which water vapor escapes from a living plant and enters the atmosphere.
transporter cask	The cask mounted on the waste transporter that provides shielding while the waste container is being transported from the waste-handling buildings to the emplacement borehole.
transuranic (TRU) waste	Waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, per gram of waste, with half-lives greater than twenty years, except for (1) high-level radioactive wastes, (2) wastes that the DOE has determined, with the concurrence of the EPA Administrator, do not need the degree of isolation required by 40 CFR Part 191, or (3) wastes that the NRC has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61.
trenching	The digging of shallow trenches to expose the underlying stratigraphy, structure, etc., for inspection and sampling.

Tresca yield criterion	This criterion states that when a material is subjected to increasing stress, it will yield in a ductile fashion when the maximum shear stress attains a value equal to one half the yield strength of the material.
triaxial compression test	A test in which a specimen of rock is subjected to a confining pressure and then loaded axially to failure.
trilateration	A method of surveying in which the lengths of the three sides of a series of touching or overlapping triangles are measured (electronically) and the angles are computed from the measured lengths.
triple junction	A point or small region where three lithospheric plates meet.
tubbing	Cast-iron liner plates for shafts, fabricated to specification, that bolt together to give support to rock.
tuff	A compacted pyroclastic deposit of volcanic ash and dust that may contain rock and mineral fragments incorporated during eruption or transport.
tuff main	A drift plan to run southwest through the longitudinal axis of the proposed repository that provides access from the surface to the underground facilities for the removal of tuff and exhaust of air during development.
two-phase flow	Flow through porous media in which both liquid and gas coexist in pore channels.
two-well convergence test	An aquifer test in which one well is pumped while water levels are monitored in both the pumping well and a nearby well. In a variation of the test, a chemical tracer may be placed in the unpumped well and allowed to migrate into the pumping well. Temporal variations in the concentration of the tracer in the pump's effluent stream are measured properties of the aquifer.
two-well recirculating test	See "cross hole recirculation test."
ultrasonic testing	A nondestructive testing method that employs high-frequency mechanical vibration energy to detect and locate structural discontinuities or differences and to measure thickness of a variety of materials.

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unanticipated processes and events	Those processes and events affecting the geologic setting that are judged not to be reasonably likely to occur during the period the intended performance objective must be achieved, but which are nevertheless sufficiently credible to warrant consideration.
unconfined aquifer	An aquifer containing ground water that has a water table or upper surface at atmospheric pressure.
unconfined compression test	A test in which a rock sample is loaded axially to failure without application of confining pressure.
unconfined compressive strength	The load per unit area at which an unconfined prismatic or cylindrical specimen of soil or rock will fail in an unconfined compression test.
underground facility	The underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals.
undersaturated	Contains less solute than the solution is capable of dissolving under the given conditions.
undisturbed performance	The predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events.
uniaxial compression test	See "unconfined compression test."
unit-cell	The smallest volume of parallelepiped within the three-dimensional repetitive pattern of a crystal that contains a complete sample of the atomic or molecular groups that compose this pattern. Crystal structure can be described in terms of the translatory repetition of this unit in space in accordance with one of the space lattices.
unrestricted area	Any area, access to which is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials, and any area used for residential quarters.
unsaturated flow	The flow of water under such conditions that the voids of the porous media are only partially filled with water, the remainder of the pore space being taken up by air.
unsaturated hydraulic conductivity	Hydraulic conductivity of an unsaturated material.

unsaturated zone	The zone between the land surface and the water table. Generally, water in this zone is under less than atmospheric pressure and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric.
unstressed aperture	The physical aperture or opening width of a fracture under a condition of zero normal or shear stress applied across the fracture. The condition of zero stress may be approximated by ascertaining that the actual stress transmitted across the fracture is very small with respect to the half closure stress or shear strength of the fracture.
upper plate	The hanging wall of a fault.
uranium fuel cycle	The operations of milling uranium ore, chemical conversion, and isotopic enrichment of uranium, fabrication of uranium fuel and reprocessing of spent uranium fuel.
uranium-series disequilibrium dating (uranium-series age method)	Calculation of an age in years for Quaternary materials based on the general finding that the decay products uranium-234, thorium-230, and protactinium-231 in natural materials are commonly in disequilibrium with their parent isotopes, uranium-238 and uranium-235, either deficient or in excess. The age is determined from the measured activity ratios of these isotopes.
uranium-thorium method	Calculation of an age in years for geologic material, often zircon, based on the known radioactive decay rate of uranium-238 to lead-206, uranium-235 to lead-207 and thorium-232 to lead-208 whose ratios give three independent ages for the same sample.
uranium-trend method	An open-system dating method based on uranium-series decay and the migration of daughter products of uranium-238 through a soil or sediment column. A successful technique in dating Quaternary deposits.
usable area	The surface location, as indicated on a map, of that portion of the primary area within which the underground facility can be located. Delineation of the usable area within the primary area will consider overburden thickness; the characteristics of the target emplacement horizon including mechanical and thermal properties of the tuff, thickness, and dip; and mining feasibility. See "primary area."

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vadose zone	The unsaturated region of soil or the zone of aeration between the ground surface and the water table.
validation (of a computer code)	The documented confirmation of the adequacy, (i.e., suitability for its intended purpose) of the computer code under review--demonstration that what the software does is appropriate to the problem. Validation includes assurance that any physical model, as embodied in software, is a correct representation of the intended physical system or process.
van der Waals attraction	The relatively weak attractive forces that act on neutral atoms and molecules and that arise because of the electric polarization induced in each of the particles by the presence of other atoms.
variance-reduction techniques	Analytic or numerical techniques applied to reduce the variance of estimates of the statistical moments of a distribution.
verification of computer codes	The documented confirmation that the computer code performs exactly the mathematical and logical operations described in the user's manual and other documents.
vertical seismic profiling (VSP)	A seismic survey method in which a mandrel-type wall-locking tool, or a hydrophone streamer, is lowered into a borehole on a wireline cable. The seismic source is usually located on the surface but can also be deployed in the same or an adjacent borehole.
vertical volumetric flux	The amount of water moving through the subsurface in a vertical direction.
Vibroseis	Trade name for a seismic method in which a vibrator is used as an energy source to generate a wave train of controlled frequencies.
vitric	Said of igneous material that is characteristically glassy, (i.e., contains more than 75 percent glass).
volumetric moisture content	Total unit volume of a soil or rock divided into the volume of contained water.
waste container	See "container."
waste containment time	See "containment period."
waste emplacement borehole	A borehole used specifically for emplacement of waste. See "emplacement borehole."

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waste emplacement envelope	See "emplacement envelope."
waste form	The radioactive waste materials and any encapsulating or stabilizing matrix.
waste main	A drift running parallel to the tuff and service mains through the longitudinal axis of the proposed underground facility and dedicated to transporting waste.
waste management	The planning, execution, and surveillance of essential functions related to the control of radioactive (and nonradioactive) waste, including treatment, solidification, packaging, transportation, initial or long-term storage, surveillance, disposal, and isolation.
waste matrix	The material that surrounds and contains the waste and to some extent protects it from being released into the surrounding rock and ground water. Only material within the canister (or drum or box) that contains the waste is considered part of the waste matrix.
waste package	The waste form and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container.
waste package envelope	See "emplacement envelope."
waste standoff	See "standoff."
waste storage envelope	See "emplacement envelope."
waste transporter	The vehicle used to move radioactive waste from the waste-handling building to the waste-emplacement borehole in the underground facility.
waste type	Refers to spent fuel (such as fuel rod assemblies from boiling water reactor or pressurized water reactor systems) or high-level waste (commercial or defense).
water balance (hydrologic budget)	An accounting of the inflow to, outflow from, and storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake, or reservoir; the relationship between evaporation, precipitation, runoff, and the change in water storage, expressed by the hydrologic equation.

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water-holding capacity	The smallest value to which the water content of a soil can be reduced by gravity drainage.
water of hydration	Water that is chemically combined in a crystalline substance, but that may be driven off by heat.
water potential	The total energy with which a rock matrix holds a unit weight of pore fluid.
water saturation method	A method used for determining porosity of a rock sample.
water table	That surface in a body of ground water at which the water pressure is atmospheric.
water yield	The runoff from a drainage basin; precipitation minus evapotranspiration.
well completion	The final sealing off of a drilled well (after drilling apparatus is removed from the borehole) with valving, safety, and flow-control devices.
wet-bulb depression	The difference in degrees between the dry-bulb temperature and the wet-bulb temperature.
wet-bulb temperature	Temperature at which water evaporating into air can bring the air to saturation adiabatically at that temperature; a measure of the evaporating capacity of air.
wet-chemical analysis	Any of the methods for chemical determinations using water or other liquids as part of the process.
Whittemore pin measurements	The Whittemore gauge in a dial micrometer with resolution of about 2.5 microns and a nominal gauge length of 25 cm. Specially prepared pins are anchored about 25 cm apart on the exterior surface of the measured specimen or rock mass, and the Whittemore gauge is used to manually measure any relative movement.
whole rock sample	A sample in which a portion of the rock, rather than individual minerals is used for analysis. For certain types of analysis (e.g., in the rubidium-strontium age method) it is preferred.
wick	To carry (as moisture) by capillary action.
wind rose	A diagram to illustrate the frequency with which wind blows from the various points of the compass.
windshield survey	Recording activities of interest in a chosen area by means of observation from a motor vehicle.

working level	Any combination of the short-lived radon daughters in one liter of air that will result in ultimate emission of 1.3×10^5 MeV (million electron volts) of potential alpha energy, and exposure to these radon daughters over a period of time is expressed in terms of "working level months." Inhalation of air containing a radon daughter concentration of 1 working level for 173 hours results in an exposure of 1 working level month.
wrench fault	A lateral fault in which the fault surface is more or less vertical.
x-ray diffraction (XRD)	A qualitative analytical technique that detects and interprets the diffraction of a beam of x-rays, usually by the three-dimensional periodic array of atoms in a crystal that has periodic repeat distances (lattice dimensions) of the same order of magnitude as the wavelength of the x-rays. This technique is most widely used for qualitative identification of crystalline substances.
x-ray fluorescence (XRF)	A type of x-ray emission spectroscopy in which the characteristic x-ray spectrum of a substance is provided by using x-rays of short wavelength to induce the substance to emit x-rays of a longer wavelength. This technique is most widely used for the quantitative (chemical) identification of crystalline substances.
xeric	Said of a habitat characterized by a low or inadequate supply of moisture.
xerophyte	A plant with very low water requirements.
Young's modulus	A linear relationship of stress and strain in an elastic material under tension or compression loading.
zeolites	A group of hydrous aluminosilicate minerals containing sodium, calcium, barium, strontium, and potassium, and characterized by their ease of exchange of these ions.
Zircaloy	An alloy whose major constituent is zirconium, used as cladding material for nuclear fuel rods.

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ACRONYMS AND ABBREVIATIONS

A&E	Administration and engineering
A/E	architect/engineer
ABC	acoustic borehole compensated
ACD	advanced conceptual design
ACGIH	American Conference of Governmental Industrial Hygienists
AEC	Atomic Energy Commission (now the DOE)
AFY	acre-feet per year
AGCM	atmospheric general circulation model
AGU	American Geophysical Union
ALARA	as low as is reasonably achievable
ANSI	American National Standards Institute
AO	annotated outline
APD	areal power density
API	American Petroleum Industry
APS	autocorrelated photon spectroscopy
ASTM	American Society of Testing Materials
AW	artificially prepared ground water
AWC	available water holding capacity
AWWA	American Water Well Association
BCL	Battelle Columbus Laboratory
BDG	borehole deformation gauge
BET	Brunauer-Emmett-Tesler (surface area measurements)
BF _n	Bullfrog nonwelded unit
BHC	borehole compensated
BHT	bottom hole temperature
BLM	Bureau of Land Management, U.S. Department of the Interior
B.P.	before present
BSM	borehole stress meters
BWIP	Basalt Waste Isolation Project
BWR	boiling water reactor
CAA	construction authorization application
CAM	constant air monitor
CCDF	complementary cumulative distribution function
CCL	casing collar locator (log)
CDF	cumulative distribution function
CDR	conceptual design report
CEC	cation exchange capacity
CFR	Code of Federal Regulations
CHLW	commercial high-level waste
CH _{nv}	Calico Hills nonwelded vitric unit
CH _{nz}	Calico Hills nonwelded zeolitic unit
CH-TRU	contact-handled transuranic waste
CIT	computed impedance tomography
CL	concentration limits
CLAMS	Common Los Alamos Mathematical Software
CLI	Core Laboratories Inc.
CLIMAP	Climate: Long-range Investigation Mapping and Prediction
COCORP	Consortium For Continental Reflection Profiling
CPD	Contracts and Property Division (WMPO)
CRRL	calculated release rate limit

CRT	cathode ray tube
CSF	core storage facility
CTM	container transport mechanism
CTRW	commercial transuranic waste
CY	calendar year
DAS	data acquisition system
DB	dry bulb
dBA	decibel (A-weighting network)
DBC	density borehole compensated (log)
DBE	design basis earthquake
DBR	demonstration breakout room
DCF	dose conversion factor
DHLW	defense high-level waste
DIFL	dual induction focused log
DNAG	Decade of North American Geology
DOA	U.S. Department of Agriculture
DOC	U.S. Department of Commerce
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE/HQ	U.S. Department of Energy, Headquarters
DOE/NV	U.S. Department of Energy, Nevada Operations Office
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
DPBM	development prototype boring machine
DRE	dense rock equivalent
DRI	Desert Research Institute
DRI	double-ring infiltrometer
DSC	differential scanning calorimetry
DST	drill stem test
DTA	differential thermal analysis
E-log	electric log
EA	environmental assessment
EBM	energy balance model
EBS	engineered barrier system
ECP	Environmental Compliance Plan
EG&G	Edgerton, Germeshausen & Grier, Inc.
EIS	environmental impact statement
EMF	electromagnetic field
EMMP	Environmental Monitoring and Mitigation Plan
ENP	epithermal neutron porosity (log)
EPA	U.S. Environmental Protection Agency
EPPM	expected partial performance measure
EPR	electrochemical potentiokinetic reaction
ES	exploratory shaft
ES	electrical survey
ESF	exploratory shaft facility
ESG	Environmental Systems Group
ESTP	Exploratory Shaft Test Plan
ETP	Engineering Test Plan
F&S	Fenix and Scisson, Inc.
FC	favorable condition
FDD	formation density dual proximity (log)
FDL	formation density log
FOM	Figure of Merit

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FPC	final procurement and construction
FPCD	final procurement and construction design
FY	fiscal year
GCM	general circulation model
GCM	global climate model
GCMS	gas chromatograph mass spectrometer
GDS	geologic disposal system
GFDL	Geophysical Fluid Dynamics Laboratory
GR	Generic Requirements
GRD	Generic Requirements document
GROA	general repository operations area
GSA	Geological Society of America
gtm	gross ton miles
GTP	Generic Technical Position
GWTT	ground-water travel time
HDO	deuterium tagged water
HFU	heat flow unit
HLF	higher-level findings
HLW	high-level waste
HTO	tritium tagged water
IAPD	initial areal power density
ICP	inductively coupled plasma (spectrometer)
IES	induction electrical survey (log)
IGSCC	intergranular stress corrosion cracking
INAA	instrumental neutron activation analysis
IRS	issue resolution strategy
IS	induction survey (log)
ISRM	International Society for Rock Mechanics
ITS	important to safety
LA	license application
LAD	license application design
LANL	Los Alamos National Laboratory
LBL	Lawrence Berkeley Laboratory
LET	linear energy transfer
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste
LPRS	large plot rainfall simulation
LR	leach rate
LWR	light water reactor
M	magnitude (Richter scale)
Ma	million years ago
MAP	mean annual precipitation
MAT	mean annual temperature
MGDS	Mined Geologic Disposal System
MGDSR	Mined Geologic Disposal System Requirements
M _L	local magnitude
MM	modified Mercalli (scale of earthquake intensity)
MMI	modified Mercalli intensity
MMP	meteorological monitoring plan
MP	Management Plan
MPBX	multiple-point borehole extensometer
MPC	maximum permissible concentration

MPZ	modified permeability zone
MSCFD	million standard cubic feet per day
MSL	mean sea level
MT	magnetotelluric (sounding method)
MT	magnetotelluric (geophysical survey method)
MT	metric tons
MTHM	metric tons of heavy metal
MTU	metric tons of uranium
MWD	megawatt-days
NAA	neutron activation analysis
NAAQS	Nevada Ambient Air Quality Standard
NAFB	Nellis Air Force Base
NAFR	Nellis Air Force Range
NAS	National Academy of Sciences
NBC	neutron borehole compensated (log)
NBS	National Bureau of Standards
NBS	natural barrier system
NCAR	National Center for Atmospheric Research
NEA	Nuclear Energy Agency
NEIC	National Earthquake Information Center
NEPA	National Environmental Policy Act
NGI	Norwegian Geotechnical Institute
NLI	elemental leaching
NNL	neutron-neutron log
NNWSI	Nevada Nuclear Waste Storage Investigations
NOAA	National Oceanic and Atmospheric Administration
NRC	U.S. Nuclear Regulatory Commission
NRDA	Nevada Research and Development Area
NRDS	Nuclear Rocket Development Station
NSTF	near-surface test facility
NTS	Nevada Test Site
NUREG	NRC regulation (or position preface)
NVO	Nevada Operations (DOE)
NWPA	Nuclear Waste Policy Act of 1982
NWPO	Nevada Nuclear Waste Project Office (State agency)
OCRWM	Office of Civilian Radioactive Waste Management (DOE)
OGR	Office of Geologic Repositories (DOE)
ONWI	Office of Nuclear Waste Isolation
ORNL	Oak Ridge National Laboratory, Oak Ridge, Tennessee
PAC	potentially adverse condition
PI	principal investigator
PIP	Prototype Investigation Plan
PIXE	particle induced x-ray emission
PMC	percent of modern carbon
PMF	probable maximum flood
PNL	Pacific Northwest Laboratories
POC	Project Overview Committee
PPW	Prow Pass welded unit
PQM	Project Quality Manager
PRAM	preclosure risk assessment methodology
PT	Paintbrush Tuff
PWBS	Project Work Breakdown structure
PWR	pressurized water reactor

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QA	Quality Assurance
QAD	Quality Assurance Division
QAL	Quaternary Alluvium
QALA	Quality Assurance Level Assignment
QALAS	Quality Assurance Level Assignment Sheet
QAPP	Quality Assurance Program Plan
QC	Quality Control
R&D	research and development
RCD	reference conceptual design
R _d	sorption ratio
REECo	Reynolds Electrical & Engineering Co., Inc.
REV	representative elementary volume
RH-TRU	remote-handled transuranics
RIB	reference information base
RMM	regional mesoscale model
RMP	Radiological Monitoring Plan
RMS	root mean square
RQD	rock quality designation
SAIC	Science Applications International Corporation
SAR	safety analysis report
SCC	stress corrosion cracking
SCP	Site Characterization Plan
SDR	Subsystem Design Requirements
SDRD	Subsystem Design Requirements Document
SEM	scanning electron microscope
SEPDB	Site and Engineering Properties Data Base
SF	spent fuel
SGBSN	Southern Great Basin Seismic Network
SIP	scientific investigation planning document
SL	sea level
SLAR	side-looking airborne radar
SMOW	standard mean ocean water
SNGBZ	Sierra Nevada-Great Basin Boundary Zone
SNL	Sandia National Laboratories
SNSZ	Southern Nevada Seismogenic Zone
SOC	SCP Overview Committee
SOP	standard operating procedures
SP	self potential (log)
SPRS	small-plot rainfall simulation
SR	system requirements
SRL	Savannah River Laboratory
SRPO	Salt Repository Project Office
SS&C	structures, systems, and components
SST	sea surface temperature
SZ	saturated zone
TAMS	tandem accelerator spectrometer
TBD	to be determined
TBM	tunnel boring machine
TC	Tiva Canyon Member
TGA	thermogravimetric analysis
TGSCC	transgranular stress corrosion cracking
TLD	thermoluminescent dosimeter
TM	thematic mapping

TMI	total magnetic intensity (log)
TPO	Technical Project Officer
TPT	Topopah Spring Member of the Paintbrush Tuff
TRU	transuranic
TRW	Tram welded unit
TSM	Topopah Spring Member
TSW	Topopah Spring welded unit
TU	tritium units
TUFFDB	Tuff Data Base (the computerized data base containing site-related information collected by the NNWSI Project)
UNE	underground nuclear explosion
UNLV	University of Nevada, Las Vegas
UNR	University of Nevada, Reno
USBM	U.S. Bureau of Mines
USDWS	underground sources of drinking water
USGS	United States Geological Survey
UV	ultraviolet
UZ	unsaturated zone
VSP	vertical seismic profiling
WB	wet bulb
WBS	Work Breakdown Structure
WMPO	Waste Management Project Office
WMPO/NV	Waste Management Project Office/Nevada Operations
XRD	x-ray diffraction
XRF	x-ray fluorescence
YM	Yucca Mountain
YMMGDS	Yucca Mountain mined geologic disposal system